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ABSTRACT

Markov switching models with time-varying transition probabilities address the limitations of the earlier methods in the early warning system literature on currency crises. Most of the Markov switching models in the literature are largely based on univariate models of exchange rate fluctuations. In this thesis, the components of the index of speculative pressure are modeled using the Markov Switching VAR with time-varying transition probabilities of Martinez Peria (2002). Two approaches, both of which are derived from this model, are taken to determine the probability of a currency crisis: the probability of a turbulent regime and the expected value of the index of speculative pressure. This study shows that the Markov Switching VAR model with time-varying transition probabilities is a good method to use in building an early warning system of a currency crisis. Results show significant improvement on predicting the Asian Financial Crisis by signaling its occurrence at an earlier period with a higher probability when the probability of a turbulent regime approach is employed. It is also more sensitive in detecting turbulent periods that are not necessarily currency crises and therefore renders itself useful in short-term forecasting of speculative pressure episodes. The leading indicators of the Asian Financial Crisis identified in this study are real effective exchange rate, export growth, GDP growth, real domestic credit, M2 ratio, deposits to M2 ratio and non-FDI flows.

Table of Contents

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I. Introduction

1.1 Background

Financial crises had come and gone and have come time and again. It is of interest to anyone who had experienced at least one in his lifetime and more importantly so with economists. This is not an understatement given the disastrous consequence that comes with these tumultuous events and the ramifications to economic growth and political stability afterwards. Currency crises occur as an outcome of unsustainable government policies and also as a consequence of speculative attack that is motivated by either self-fulfilling expectations or through contagion from crises occurring someplace else.

A currency crisis can bring down a country not just economically but also politically. The Argentinian crisis is an example of the collapse of a fixed exchange rate regime. The devaluation of the Argentinian peso in 2002 precipitated the replacement of the presidency several times within days. Another example of the collapse of the fixed exchange rate includes the attack on the European Monetary System (EMS) in 1992-93 which undermined the monetary union of the member currencies and made realignments unmanageable. The Mexican peso crisis in 1994-95 is an example of a currency crisis that resulted in contagion; known as the Tequila crisis it subjected neighboring countries, and even including the Philippines, to speculative pressures. The impact of the devaluation of the Thailand baht in July 1997 is another example of a currency crisis that led to the collapse of crawling peg regimes in East Asia resulting to the Asian Financial Crisis of 1997-98. Other notable examples of speculative attacks in the last two decades were the attacks on the Russian ruble in 1998 and the Turkish currency and banking crisis in 2001.

Economic theory attempts to understand the underlying causes of a currency crisis or periods of speculative attack that render a currency vulnerable to devaluation. A currency crisis can be characterized by a large and persistent depreciation of the currency. However, a speculative attack can occur even prior to devaluation. This is manifested in a persistent decline in the foreign exchange (FX) reserve as the government attempts to defend a given exchange rate.

Krugman (1979), in a seminal work, demonstrated how unsustainable macroeconomic policies being pursued by a government lead to vulnerability and eventual collapse of a fixed exchange rate regime. For example, a persistent fiscal deficit or a gaping current account deficit strains a government's ability to sustain a peg by financing the fiscal deficit or by filling the gap of current account deficit through the FX reserve. Speculators pressure the currency to devalue by purchasing the FX reserve because they know that devaluation will eventually occur. Capital outflow also adds pressure to the currency as short-term investors avoid foreign exchange losses for holding the local currency. In the end, the FX reserve is depleted and the currency devalues.

While the fundamentals-based currency crisis articulated by Krugman (1979) is theoretically elegant it is inadequate in explaining the EMS crisis in 1992-93. Obstfeld (1994) proposed that self-fulfilling expectations can explain this crisis. In self-fulfilling expectations a crisis can occur even without any visible macroeconomic weakness and even though the currency peg appears sustainable. The experience of the EMS countries demonstrated this. They did not exhibit the weakness in macroeconomic fundamentals assumed by the Krugman model and yet they experienced devaluations. In the theory of self-fulfilling crisis there is a feedback effect between the expectation of speculators regarding devaluation of a currency and the response of government policy to such expectation. Such response serves as confirmation of the speculators' expectation. This feedback between speculators and the government proceeds into a downward spiral resulting in a self-inflicted currency crisis.

The fundamentals and self-fulfilling approaches are referred to as the first and second generation theories of currency crises. These theories however were not enough to explain the episodes of speculative pressure and eventual turbulence that happened to countries affected by the Tequila crisis in 1994-95 and the Asian Financial Crisis in 1997-98. The Brazilian real and Argentinian peso experienced currency crises following the speculative attack and devaluation of the Mexican peso in 1994-95. In addition, the Philippines experienced speculative pressure in early 1995. Proximity in terms of trade partnership may able to explain the experiences of Brazil and Argentina. But not so with the Philippines other than that it had the same macroeconomic vulnerability as Mexico during that period. Sachs, Tornell & Velasco (1996) suggest that this demonstrated the existence of multiple equilibria. In this type of crisis according to Masson (1998), a country's currency can be affected by a crisis from another country that could not be explained by economic fundamentals. The market's sentiment about the currency or the market's perspective regarding new information about a particular country's economy can change dramatically because of a crisis in another country. When this happens the common action of investors is to dump assets in this currency and this action can lead to a crisis.

While theories were developed to explain the economics of currency crises the empirical literature focused on estimating models that would best characterize the factors that led to these crises. From an econometric modeling point-of-view there are four major methods used to evaluate the theories underlying currency crises: cross-country regressions, limited dependent variables (LDV), signaling approach and Markov switching. The cross-country regression and the limited dependent variable models use the index of speculative pressure (ISP) and ISP crisis dummy as their dependent variables, respectively. The ISP typically consists of three components: the changes in nominal exchange rate, FX reserve and interest rate differentials. The signaling approach uses macroeconomic indicators which are evaluated on how well they can predict a crisis within a given period in the future. The Markov switching models mainly use the change in the nominal exchange rate with the exception of Martinez Peria (2002) who modeled the ISP components in her study of the EMS crisis in 1992-93.

The cross-country regression model of Sachs, Tornell & Velasco (1996) attempted to explain the crisis from the fundamentals approach and found evidence of both macroeconomic and self-fulfilling factors that led to the Tequila crisis. However, Berg & Patillo (1999) found the model of Sachs, Tornell & Velasco (1996) to be unstable. The probit model of Frankel & Rose (1996) showed success in predicting currency crashes and in accounting for factors that influence these events. However, LDV models use subjective classification of a crisis period where potential errors of assignment can occur. This problem can be dealt with using the Markov switching model of Hamilton (1989). Markov switching models are an innovative tool for dating currency crises as well as determining the factors that lead an economy from one state to another, say, ordinary period to a turbulent one. Engel & Hakkio (1996) started the use of Markov switching models in the study of currency crises. Eventually this led to the use of Markov switching in early warning system (EWS) models.

The EWS initiated by Kaminsky, Lizondo & Reinhart (1998) focused on identifying signals that would indicate a potential currency crisis within a given timeframe in the future. The signaling approach is nonparametric because it involves a procedure, not an estimation of a model based on an underlying theoretical distribution, of identifying whether a macroeconomic variable serves as a good leading indicator of a crisis within a 24-month window where the threshold for each indicator is adjusted to maximize the signal-to-noise ratio. While the exercise of identifying crises was satisfactory this approach has been criticized for the subjective thresholds and the potential misclassification of crises when future turbulent periods are included in the data. New data can reset the thresholds thereby potentially reclassifying crises. The Markov switching approaches in Cerra & Saxena (2002), Martinez Peria (2002), Abiad (2003), Mariano, Abiad, Gultekin, Shabbir & Tan (2003) and Brunetti, Scotti, Mariano & Tan (2008) deal with this limitation by endogenously classifying the periods of turbulence.

1.2 Research Problem

One of the main limitations of an LDV model is the use of a dummy variable to identify currency crisis periods which is subject to misclassification and information loss. Similarly, the signaling approach depends on arbitrary thresholds set for the macroeconomic indicators. These dependencies can result in crises disappearing when new data comes in containing new crisis information but this problem is avoided by endogenously identifying the crisis regime in the model. This was the motivation behind the use of Markov switching in the EWS literature. Abiad (2003), Mariano, Abiad, Gultekin, Shabbir & Tan (2003) and Brunetti, Scotti, Mariano & Tan (2008) used Markov switching regression (MSR) models to identify the factors that influence the state of the economy to either a turbulent or an ordinary regime. While their papers model the change in nominal exchange rate where the underlying regime is driven by macroeconomic factors this study will simultaneously model the three indicators associated with the ISP: the change in nominal exchange rate, the change in foreign reserve and the change in the difference between local and foreign interest rates. These three indicators will be modeled using Markov switching vector autoregression (MSVAR) as suggested by Mariano, Abiad, Gultekin, Shabbir & Tan (2003). Mariano, Abiad, Gultekin, Shabbir & Tan (2003) expect this approach to improve on the short-term forecasting performance of the univariate RS approach. The use of MSVAR with time-varying transition probabilities (TVTP) in an empirical currency crisis model was first implemented by Martinez Peria (2002) where the objective was on dating periods of currency crisis in the EMS countries. In this study, the focus is on modeling the ISP indicators to build an EWS model.

The ISP is an index commonly used to measure the extent of speculative attack on a currency. When a currency becomes vulnerable, monetary authorities in a fixed exchange or in a crawling peg regime employ three measures. The first is to defend the currency by selling its FX reserve thereby depleting it. The second is to raise the domestic interest rate. And third, the currency depreciates when the government ceases to defend it. Eichengreen, Rose & Wyplosz (1994, 1995, 1996), among other economists, made use of a linear combination of these three variables to build an ISP.

This study develops an EWS by identifying factors that can serve as leading indicators of vulnerability of an economy from speculative attacks. By using MSVAR with TVTP, the objective is to identify indicators that could signal ahead a turbulent regime. By endogenously modeling the ordinary periods and periods of speculative pressure using Markov switching this study avoids the problems associated with other econometric models. The TVTP facilitates the identification of significant factors that influence the probability of an economy going into a turbulent period. The MSVAR with TVTP will be specifically applied to Southeast Asian currencies.

1.3 Significance and Contribution

This study contributes to the literature on EWS of currency crises using Markov switching models by employing the MSVAR with TVTP for the components of the ISP in identifying leading indicators of the Asian Financial Crisis. It is also the first time that MSVAR with TVTP was used to analyze Asian Financial Crisis countries to identify macroeconomic indicators of turbulence in the currency markets and to determine its potential as method for early warning systems. Furthermore, the study shows that using MSVAR with TVTP enhances prediction of turbulent periods and improves on short-term forecasting of speculative attacks when compared to univariate Markov switching models.

II. Literature Review

There are several literature reviews on the theory and empirical studies of currency crises. The purely theoretical review of Blackburn & Sola (1993) examined the incorporation of stylized facts prior to the collapse of a fixed exchange rate regime based on the fundamentals theory of Krugman (1979) and Flood & Garber (1984) and the self-fulfilling crisis theory of Obstfeld (1986), including extensions and relaxations of assumptions of the primary papers of these first and second generation theories, respectively. Another literature review tested the theories empirically in Garber & Svensson (1995). The literature review of Eichengreen, Rose & Wyplosz (1996) classified the categories into three: the fundamentals, multiple equilibria or self-fulfilling, and contagion. The most recent comprehensive review was made by Abiad (2003). He outlined the theories, the empirical studies and methodologies employed to explain and evaluate the forecast of currency crises. To avoid duplication of these reviews, this study instead outlines the main theories and methods while at the same time focuses on methods recently developed on early warning systems based on Markov switching models.

2.1 Theoretical Models

2.1.1 Fundamentals

The first theory on currency crises was formally developed by Krugman (1979) where he demonstrated how the weakness in macroeconomic fundamentals of a country can induce speculators to bet against the fixed exchange rate regime. As monetary authorities defend the exchange rate by drawing down their FX reserves the fixed regime eventually collapses when the reserves are exhausted. This collapse leads the currency to freely float.

Krugman (1979) showed that when the government is committed to maintaining the fixed exchange rate regime it gives up control of the level of FX reserve. The level of FX reserve rather responds to changes in economic conditions. When macroeconomic weakness, e.g. a fiscal deficit, occurs the government can finance it through issuing domestic credit or through its FX reserve. However, both will have the consequence of drawing down reserves. Prior to exhaustion of the FX reserve, attack begins from speculators with foresight who expect the government will soon enough abandon the fixed exchange rate regime. Speculators desiring to avoid capital losses on the domestic currency will demand for more FX leading to complete depletion of the reserves resulting in the collapse of the currency regime. The time of the collapse of the regime according to Krugman (1979) can be known. Flood & Garber (1984) extended the Krugman model by accounting for the collapse of a fixed exchange rate regime, not based on a huge cataclysmic event due to weakness in fundamentals but rather on arbitrary speculative behavior. This speculative behavior creates growing instability in a weak currency on a fixed exchange rate leading to its eventual collapse. Unlike in the Krugman model, the timing of the collapse in Flood & Garber's (1984) is assumed to be random.

2.1.2 Self-fulfilling Crisis

While Krugman (1979) showed how weakness in fundamentals eventually unhinges a fixed exchange rate regime Obstfeld (1986) demonstrated that even without such weakness a crisis may ensue based on self-fulfilling expectations of a devaluation. The seemingly sustainable fixed exchange rate collapses due to expectations of the market that it will occur with speculators putting pressure on the currency to devalue. The monetary authorities respond to the weakness of the currency by defending it. However, the feedback between speculators' actions and the monetary authorities' responses proceeds to a downward spiral resulting in a self-fulfilling crisis. In another study, Dellas and Stockman (1993) have shown that the expectations of capital controls and devaluations can precipitate a currency crisis even when the fundamentals of the economy are intact.

Eichengreen & Wyplosz (1993) and Jeanne (1997) provided evidence of self-fulfilling expectations on the French franc as it went on to devalue during the EMS crisis that unraveled in August 1993. While Krugman (1979) puts emphasis on FX reserve adequacy, Obstfeld (1994) noted that during the EMS crisis some countries employed other tools like high interest rates in response to devaluation expectations. The responses had a huge negative impact on a country's fiscal position resulting in the realized devaluation of its currency. Governments also responded to shocks in competitiveness and employment by realigning their currencies. This action changed expectations and turned a pegged currency into a fragile one.

The theory of self-fulfilling expectations is not without its critics. Krugman (1996) showed that when fundamentals deteriorate deterministically over time then multiple equilibria, and therefore self-fulfilling expectations, do not occur. However, Jeanne & Masson (2000) provided conditions on the fundamentals whereby self-fulfilling expectations do occur and when they do not as in Krugman's (1996) model.

Empirical studies on finding evidence of self-fulfilling expectations during the EMS crisis were done by Eichengreen & Wyplosz (1993), on the Tequila crisis by Obstfeld and Rogoff (1995) and on the Asian Financial Crisis by Radelet & Sachs (1998).

2.1.3 Contagion

The experience in the EMS and the Tequila crises also showed that other currencies can be subject to speculative attacks even though a crisis is occurring someplace else. Gerlach & Smets (1995) provided the first systematic theoretical treatment of the concept of contagion in currency crises. Their model of contagion is an extension to multiple countries of the model by Flood & Garber (1984) on a single-country speculative attack. Gerlach & Smets (1995) showed that contagion occurs because the collapse of a currency may have effects on the prices and income of another country through competitiveness. The collapse of a currency causes another country's real exchange rate to appreciate and thereby depressing prices and income; the demand for money drops as a result and so FX reserves fall. This reduction in reserves leads to speculative attacks on another country's currency accelerating its implosion.

Gerlach & Smets (1995) observed that the floating of the Finnish markka seemed to have influenced the turbulence in the Swedish krona, while the forced floating of the Italian lira and British pound could have been related to the speculative pressure on the French franc, and the floating of the Swedish krona affected the parity of the Norwegian krone. Aside from evidence of self-fulfilling expectations found by Eichengreen & Wyplosz (1993) during the EMS crisis Gerlach & Smets (1995) showed that contagion also occurred.

Fratzscher (1999) demonstrated that the severity of a crisis in a country is not only determined by its fundamentals and exogenous agents' belief but also by the degree of how crises in other countries are transmitted across economies. He defined contagion as the transmission of a crisis that is not caused by the affected country's fundamentals (only *ex post*) but by its proximity from the country where the crisis originated. Here Fratzscher (1999) identified two types of proximity: real integration contagion and financial integration contagion. The real integration contagion occurs when a crisis and sharp devaluation of a country's currency results in the loss of competitiveness of its competitor countries whose currencies also devalue. The financial integration contagion occurs when a crisis or sharp devaluation makes investors withdraw from other economies to raise cash for redemptions or to follow other investors who fear that these economies will also experience currency attacks and devaluations.

Another type of contagion is related to a banking crisis and was theoretically investigated by Goldfajn & Valdes (1997). They found evidence that a fragile banking system that is subject to shortening liabilities that is matched to long term assets as an outcome of a surge in capital flow into the economy can be vulnerable to a run by foreign investors. This run ramps up demand for foreign reserves putting pressure on the currency. If there is expected devaluation in the currency this surge in demand is exacerbated. And investors that experience liquidity problems in a banking crisis in this country respond by liquidating their position in other countries as well, thus resulting in contagion.

Sachs, Tornell & Velasco (1996) explained that the Mexican peso crisis-initiated turbulence in the currencies of Argentina, Brazil and the Philippines was evidence of contagion. These countries that experienced vulnerability are the ones with weak fundamentals thereby initiating speculative pressures. Using 1959 to 1993 data of 20 industrialized countries Eichengreen, Rose & Wyplosz (1996) have shown that accounting for fundamentals and policies, there exists evidence of pure contagion in currency crises. Furthermore, Frankel & Schmukler (1996) found evidence of herding behavior in the Mexican peso crisis.

On the Asian Financial Crisis, Baig & Goldfajn (1999) found evidence of contagion through economic and political news in Asian countries. Fratzscher (1999) showed that real integration and financial integration are the culprits of the contagion of the Mexican peso crisis and the Asian Financial Crisis. Chang & Velasco (1998) blamed the short-term liabilities of banks exceeding the foreign reserves during the Asian Financial Crisis. Other evidence of contagion is in the studies of Goldfajn & Valdes (1997), Fratzscher (1998) and Glick and Rose (1999).

In terms of the role of financial linkages Calvo and Mendoza (1999) argued that herding behavior causes contagion. They explained that globalization reduces the incentive to get information first hand so that investors follow common investment strategies. Frankel and Schmuckler (1998) found evidence of this in the Tequila crisis. Fratzscher (1998) found evidence of contagion from the observed high correlations of equity returns of those countries affected by the Tequila crisis and the Asian Financial Crisis. Kaminsky & Reinhart (2000) investigated the sources of contagion through empirical evidence from the Tequila crisis, the Asian Financial Crisis and the Russian rubble crisis and found that trade links, financial sector links and cross-market hedging as potential causes of contagion; while Cerra & Saxena (2002) linked the Thai baht devaluation to the Indonesian crisis during the Asian Financial Crisis to demonstrate contagion.

2.2 Econometric Methods

The investigation of the theories that explain the occurrence of currency crises and periods of speculative attacks can be summarized into four groups. Three are parametric models and one is a nonparametric model. The parametric models consist of cross-country regressions, LDV and Markov switching, while the nonparametric model is the signaling approach.

Before elaborating on these methods any further it is necessary to discuss first how economists date periods of speculative attacks and currency crises. The ISP is a useful measure of speculative attack on a currency and was used by researchers to identify turbulent episodes.

Most of the research papers employ the ISP which was first introduced by Eichengreen, Rose & Wyplosz (1994). The ISP was a modification of Girton & Roper's (1977) index of exchange-market pressure. This index is based on their monetary model of money demand and supply. The ISP is defined as a linear combination of the change in exchange rate (ΔER), the change in FX reserve (ΔFR), and the change in interest differential (ΔID). This interest differential is between a country's interest rate and the corresponding interest rate of the U.S. or of Germany. Martinez Peria (2002) referred to Germany as the anchor country in Europe as other currencies realigned themselves to the deutsche mark during the EMS period. The following is an ISP with three components where the standard deviation of each is equalized to ΔER's in the following sense:

$$ISP_t = \Delta ER_t + \frac{\sigma_{\Delta ER}}{\sigma_{\Delta FR}} \Delta FR_t - \frac{\sigma_{\Delta ER}}{\sigma_{\Delta ID}} \Delta ID_t \quad (1)$$

where

$$\Delta ER_t = -\left(\frac{ER_t - ER_{t-1}}{ER_{t-1}} \right) \times 100\% ,$$ ER_t is in currency per U.S. dollar,

$$\Delta FR_t = \frac{FR_t - FR_{t-1}}{FR_{t-1}} \times 100\% ,$$

$\Delta ID_t = ID_t - ID_{t-1}$, $ID_t = IR_{country,t} - IR_{U.S.,t}$ and IR is interest rate in %.

The literature has different variations of the ISP. Table 1 presents these differences.

Table 1. Index of Speculative Pressure

Author(s)	Components	Standard Deviation Equalizer	Threshold Indicating Period of Speculative Attack
Eichengreen, Rose & Wyplosz (1994)	ΔER, ΔFR, ΔID	$\sigma_{\Delta ER}$	$\geq 1.5\sigma_{ISP}$ from the mean
Eichengreen, Rose & Wyplosz (1995)	ΔER, ΔID and ΔFR/M1 with respect to Germany's	$\sigma_{\Delta ER}$	$\geq 2\sigma_{ISP}$ from the mean
Eichengreen, Rose & Wyplosz (1996)	ΔER, ΔID and ΔFR/M1 with respect to Germany's	$\sigma_{\Delta ER}$	$\geq 1.5\sigma_{ISP}$ from the mean
Frankel & Rose (1996)	ΔER, ΔID and ΔFR/M1 with respect to Germany's	$\sigma_{\Delta ER}$	$\geq 2\sigma_{ISP}$ from the mean
Sachs, Tornell & Velasco (1996)	ΔER, ΔFR	Relative precision using inverse of the variance of each series over the past 10 years.	No threshold.
Kaminsky & Reinhart (1999)	ΔER, ΔFR	$\sigma_{\Delta ER}$	$\geq 3\sigma_{ISP}$ from the mean
Tornell (1999)	ΔER, ΔFR	Relative precision using inverse of the variance of each series over the past 10 years.	No threshold.

Note: The signs of ΔER, ΔFR and ΔID in this table are opposite to those in Equation (1).

2.2.1 Cross-Country Regressions

Sachs, Tornell & Velasco (1996) employed a cross-country regression to study the nature of the Mexico peso crisis using an ISP of exchange rate and reserve changes as a function of macroeconomic indicators among 20 emerging economies. Similarly, Tornell (1999) used the same ISP as Sachs, Tornell & Velasco (1996) for 23 emerging economies in his investigation of the Mexican peso crisis and the Asian Financial Crisis. However, Berg & Patillo (1999) showed that Sachs, Tornell & Velasco's (1996) model has unstable parameters.

2.2.2 Limited Dependent Variable

Eichengreen, Rose & Wyplosz (1996) used probit regression to study the currency crises in the 1960s until the EMS crisis. They defined the ISP consisting of changes in exchange rate, reserves and the interest differential for 20 industrial countries where a crisis occurs when the index exceeds its mean by one and a half of its standard deviation. Frankel & Rose (1996) also used probit regression to study over a hundred developing countries for crises that occurred from the 1970s to prior to the EMS crisis. A crash is measured as a 25% depreciation of a currency and a corresponding depreciation of at least 10% with respect to the previous year's change occurring in a 3-year window.

In the Asian Development Bank (2005) edited book on EWS, a panel LDV model was estimated where the dependent variable is determined by the month-on-month change in nominal exchange rate exceeding the downside threshold of two standard deviations from the mean. In this panel LDV model, Koo, Oh, Joo, Lee & Tan (2005) analyzed how well this model predicted the Asian Financial Crisis in Indonesia, Korea, Malaysia, Philippines, Singapore and Thailand.

2.2.3 Signaling Approach

Kaminsky, Lizondo & Reinhart (1998) proposed a signaling or leading indicator approach in forecasting currency crises. In their exercise on the crises between 1970 and 1995 among 15 developing and 5 developed countries they identified potential factors that exceed a given threshold. They then tested whether a factor is able to predict a currency crisis within a 24-month window. The thresholds were adjusted to balance the signal-to-noise ratio of correctly and incorrectly calling a crisis. Kaminsky & Reinhart (1999) evaluated the signaling approach on the Asian Financial Crisis and found evidence of commonalities in leading indicators of banking and currency crisis from the 1970 to 1995 that predicted well the Asian Financial Crisis in 1997-98.

2.2.4 Markov Switching

The LDV models and the signaling approach of Kaminsky, Lizondo & Reinhart (1998) are not without their problems. First, the threshold to mark a period as turbulent or speculative is arbitrary. Second, Abiad (2003) and Mariano, Abiad, Gultekin, Shabbir & Tan (2003) reasoned that the threshold may adjust higher depending on the severity of a future crisis making formerly classified periods of crisis disappear. This means that the crisis in the future can influence identification of crisis periods in the past. Third, there is a possible misclassification of a crisis in LDV models. Abiad (2003) noted that arbitrarily set thresholds in the signaling approach introduces serial correlation in the dependent variable and Harding & Pagan (2008) showed analytically that it exists.

These inherent limitations of LDV models and of the signaling approach give reason to model periods of turbulence using Markov switching. By endogenously identifying the ordinary and turbulent periods these problems are avoided. Another advantage of a Markov switching model according to Abiad (2003) and Mariano, Abiad, Gultekin, Shabbir & Tan (2003) is that, unlike in a binary or a threshold indicator, it utilizes all information contained in the exchange rate dynamics. In addition, Jeanne & Masson (2000) provided a theoretical justification for the use of Markov switching in modeling currency crises where the jump in states corresponds to the policy maker’s decision rule induced by shifts in the speculator’s expectations. Furthermore, Lee & Chen (2006) have shown that modeling FX rate movements using Markov switching is consistent with common exchange rate policies of most central banks.

The Markov switching model of Hamilton (1989, 1990) gave rise to the exploration of the dynamics of exchange rate movements and one area is the study of currency crises. Engel & Hakkio (1996) modeled the EMS currencies using MSR with TVTP where they considered two regimes, the stable and the volatile, as a mixture distribution of two normals. Volatile periods occur during realignments of currencies in the EMS band where the transition probability depends on the location of the currency within the EMS band. They have shown that the probability of realignment depends on what regime the period belongs to.

In their study of the EMS crisis, Gomez-Puig & Montalvo (1997) classified the volatility of the exchange rate into stormy or stable states. The stormy regime indicates low credibility and is associated with a change in state through realignment, while a stable regime means credibility where a change in state is not associated with realignment. Their MSR with FTP model seemed to capture the sudden change in expectations that gave rise to a self-fulfilling attack. Cerra & Saxena (2002) on the other hand employed TVTP of the MSR model to show evidence of contagion in the Asian Financial Crisis where an ISP of Thailand and Korea driving the TVTP improved the estimation of the conditional probability of a crisis in Indonesia. Similarly, Abiad (2003) and Mariano, Abiad, Gultekin, Shabbir & Tan (2003) used an MSR with TVTP to develop an EWS using Markov switching of the change in nominal exchange rate with three categories of early warning indicators. Abiad's (2003) indicators involved macroeconomic, capital flow and financial fragility variables. Brunetti, Scotti, Mariano & Tan (2008) further sought to improve on the model of Mariano, Abiad, Gultekin, Shabbir & Tan (2003) by factoring in a GARCH model in the conditional variance to account for large time-varying variances during periods of turbulence. Brunetti, Scotti, Mariano & Tan (2008) also covered a wider class of crisis indicators which include the external sector, financial sector, real sector and the banking sector. These indicators have supporting empirical evidence from the study of Kaminsky & Reinhart (1999) on the Asian Financial Crisis.

The use of MSVAR model for a currency crisis was first employed by Fratzscher (1999). Using an MSVAR with FTP he investigated evidence of fundamentals, self-fulfilling and contagion basis of currency crises using MSVAR with FTP. While Martinez Peria (2002) used an MSVAR with TVTP to identify speculative episodes during the EMS currencies from 1979-1993 where the ISP and the transition probabilities are functions of the fundamentals and expectations.

2.3 Summary of Indicator Variables

Researchers of currency crises treat macroeconomic and other indicators in two different ways. The first one is to use the indicators to explain the cause of the crises and the second one is to use the indicators to forecast the crises. In the first group, the most notable papers consist of Eichengreen, Rose & Wyplosz (1994, 1995, 1996), Frankel &

Rose (1996), Sachs, Tornell & Velasco (1996) and Tornell (1999). In the second group, we have Kaminsky, Lizondo & Reinhart (1998), Kaminsky & Reinhart (1999, 2000), Abiad (2003), Mariano, Abiad, Gultekin, Shabbir & Tan (2003), Asian Development Bank (2005) which edited the papers of Zhuang (2005) and Koo, Oh, Joo, Lee & Tan (2005), and Brunetti, Scotti, Mariano & Tan (2008). Table 2 presents a summary of the models and the different macroeconomic and leading indicators of currency crises.

Table 2. Econometric Models, Dependent and Indicator Variables

Author(s)	Model	Dependent Variable	Significant Indicators
Eichengreen, Rose & Wyplosz (1994)	None. Kolmogorov-Smirnov testing of an indicator's difference in distributions between crisis and non-crisis periods.	ISP for identifying periods of speculative attack.	
Eichengreen, Rose & Wyplosz (1995)	Multinomial Logit	ISP dummy exceeding threshold	past government election loss, future controls, CA
Eichengreen, Rose & Wyplosz (1996)	Probit Model	ISP dummy exceeding threshold	crisis elsewhere dummy, inflation, unemployment rate, capital accounts to GDP ratio, capital controls, incumbent government election victory
Sachs, Tornell & Velasco (1996)	Cross-country Regression	ISP	real exchange rate, M2 to FX reserve ratio, bank lending to private sector to GDP ratio
Frankel & Rose (1996)	Cross-country Probit Regression	ISP	real ER, CA deficit, fiscal deficit, debt composition, external variables, ratio of FDI to debt, reserves to import ratio, domestic credit growth, economic growth rate, foreign interest rate
Kaminsky, Lizondo & Reinhart (1998)	Signals Approach	No dependent variable. Each indicator in the last column is tested whether exceeding a threshold signals a crisis in the next 24 months.	exports, real effective ER, M2 to FX reserve ratio, output, equity prices
Kaminsky & Reinhart (1999)	Signals Approach	ISP to identify turbulent periods. No dependent variable. Each indicator to the right is tested whether exceeding a threshold signals a crisis in the next 24 months.	M2 multiplier, growth of domestic credit to GDP ratio, real interest rate, lending to deposit ratio, excess M1 balances, M2 to FX reserve ratio, bank deposit growth, export growth, terms of trade, real ER, growth in FX reserve, output growth, stock price returns, ratio of fiscal deficit to GDP
Cerra & Saxena (2002)	MSR with TVTP	ISP	lagged ISP of other countries
Martinez Peria (2002)	MSVAR with TVTP	ISP components ΔER, ΔFR and ΔID	fiscal deficit
Abiad (2003)	MSR with TVTP	Month-on-month % change in nominal ER	real effective ER, CA to GDP ratio, export growth, M2 to FX reserve ratio, growth of M2 to FX reserve ratio, FX reserve growth, real GDP growth, growth in industrial production, domestic credit growth, central bank credit to the banking sector, M2 to deposit ratio, growth of M2 to deposit ratio, stock market performance, share of non-FDI flows to total capital flows, real interest rate, LIBOR

Table 2. Econometric Models, Dependent and Indicator Variables (cont'd.)

Author(s)	Model	Dependent Variable	Significant Indicators
Mariano, Abiad, Gultekin, Shabbir & Tan (2003)	MSR with TVTP	Month-on-month % change in nominal ER	real effective ER, M2 to FX reserve ratio, real domestic credit
Zhuang (2005)	Signals Approach	No dependent variable. Each indicator in the last column is tested whether exceeding a threshold signals a crisis in the next 24 months.	real effective ER, ratio of short-term external debt to FX reserve, ratio of deposits in BIS banks to FX reserve, M2 to FX reserve ratio, year-on-year change in short-term capital flows to GDP ratio, CA to GDI ratio, year-on-year change in real commercial bank deposits
Koo, Oh, Joo, Lee & Tan (2005)	Cross-country Panel LDV	Two standard deviations from the mean of the change in nominal ER	real effective ER, export growth, ratio of CA to GDP, ratio of short-term external debt to GDP, growth in FX reserve
Brunetti, Scotti, Mariano & Tan (2008)	MSR-GARCH with TVTP	Month-on-month change in log of nominal ER	real effective ER, M2 to FX reserve ratio, banking index returns, banking index return volatility, general stock market index return

III. Markov Switching VAR Model with Time-Varying Transition Probabilities

The following MSVAR model with TVTP is an extension of the MSVAR with FTP by Krolzig (1997). While MSVAR models of Krolzig (1997) and Bellone (2005) covered extensively the different structures of the variance-covariance matrix of the error vector in this study the approach of Martinez Peria (2002) is adapted so that the MSVAR is Cholesky transformed where the variance-covariance matrix is effectively diagonal. This was done to simplify the estimation of the likelihood function with the focus on the TVTP equation.

3.1 Time-Varying Transition Probabilities

Two states are considered here. The turbulent state represents periods of speculative pressure. This state covers both speculative attack periods that result in reduction of FX reserves and periods of crisis. As Brunetti, Scotti, Mariano & Tan (2008) have observed, the turbulent period need not be a crisis period. When the monetary authorities are able to handle the speculative attack, the turbulence need not turn into a currency crisis. Brunetti, Scotti, Mariano & Tan (2008), including Abiad (2003) and Mariano, Abiad, Gultekin, Shabbir & Tan (2003), employed a probit form of the transition probabilities. In this study, a logistic functional form of the TVTP is specified and shown below.

$$S_t = \begin{cases} 1, & turbulent \\ 2, & ordinary \end{cases} \tag{2}$$

$$p_t^{11} = P\left(S_t = 1 \middle| S_{t-1} = 1, x_{t-1}; \xi^1\right) = \frac{\exp\left(x_{t-1}'\xi\left(S_{t-1} = 1\right)\right)}{1 + \exp\left(x_{t-1}'\xi\left(S_{t-1} = 1\right)\right)} \tag{3}$$

$$p_t^{12} = 1 - p_t^{11} \tag{4}$$

$$p_t^{22} = P\left(S_t = 2 \middle| S_{t-1} = 2, x_{t-1}; \xi^2\right) = \frac{\exp\left(x_{t-1}'\xi\left(S_{t-1} = 2\right)\right)}{1 + \exp\left(x_{t-1}'\xi\left(S_{t-1} = 2\right)\right)} \tag{5}$$

$$p_t^{21} = 1 - p_t^{22} \tag{6}$$

The equations of the transition probabilities above indicate that the transition probabilities are one-period forecasts, *ex post*.

3.2 Markov Switching Vector Autoregression

The underlying regime in Equation (2) drives the mean equation that is specified by an MSVAR model

$$y_t = \alpha_0(S_t) + \alpha(S_t)y_{t-1} + \sigma(S_t)\eta_t \text{, where } \eta_t \sim N(0, I). \tag{7}$$

The y_t is a vector of endogenous variables consisting of the change in nominal exchange rate $y_{1,t} = \Delta ER_t$, the change in foreign reserve $y_{2,t} = \Delta FR_t$ and the change in interest differentials $y_{3,t} = \Delta ID_t$. The covariance matrix, which is an identity matrix I, of η_t can be replaced with Σ_t which is a diagonal matrix consisting of univariate GARCH models. This is an extension to MSVAR from MSR-GARCH with TVTP of Brunetti, Scotti, Mariano & Tan (2008). The scalar specification of the standard deviation $\sigma(S_t)$ comes from the equalization of the standard deviation of the ISP components similar to Eichengreen, Rose & Wyplosz (1994, 1995, 1996), Frankel & Rose (1996) and Kaminsky & Reinhart (1999). This equalization technically results in equal $\sigma_{1,t}$, $\sigma_{2,t}$ and $\sigma_{3,t}$ in a given regime of the y_t-vector components.

By applying a Cholesky transformation to y_t the MSVAR model ends up with the following,

$$y_t = \beta^0(S_t) + \beta^F(S_t)y_{t-1} + \beta^L(S_t)y_t + \sigma(S_t)\varepsilon_t . \tag{8}$$

where

$$\beta^0 = \begin{bmatrix} \beta_1^0 \\ \beta_2^0 \\ \beta_3^0 \end{bmatrix},\ \beta^F = \begin{bmatrix} \beta_{11}^F & \beta_{12}^F & \beta_{13}^F \\ \beta_{21}^F & \beta_{22}^F & \beta_{23}^F \\ \beta_{31}^F & \beta_{32}^F & \beta_{33}^F \end{bmatrix} = \begin{bmatrix} \beta_1^F \\ \beta_2^F \\ \beta_3^F \end{bmatrix} \text{ and } \beta^L = \begin{bmatrix} 0 & 0 & 0 \\ \beta_{24} & 0 & 0 \\ \beta_{34} & \beta_{35} & 0 \end{bmatrix} = \begin{bmatrix} 0 \\ \beta_2^L \\ \beta_3^L \end{bmatrix},$$

$$\beta_1 = \{\beta_1^0, \beta_1^F, 0\},$$

$$\beta_2 = \{\beta_2^0, \beta_2^F, \beta_2^L\},$$

$$\beta_3 = \{\beta_3^0, \beta_3^F, \beta_3^L\}.$$

As Martinez Peria (2002) noted, since there is a one-to-one relationship between the triangular and non-triangular versions of the VAR, and because the transition probability models are the same for both normalizations, the estimates are unaffected. To show this relationship, Equation (8) is re-expressed back to Equation (7).

$$(I - \beta^L)y_t = \beta^0 + \beta^F y_{t-1} + \sigma\varepsilon_t \tag{9}$$

$$y_t = (I - \beta^L)^{-1}\beta^0 + (I - \beta^L)^{-1}\beta^F y_{t-1} + (I - \beta^L)^{-1}\sigma\varepsilon_t \tag{10}$$

where

$$(I - \beta^L)^{-1}\beta^0 = \alpha_0 ,$$

$$(I - \beta^L)^{-1}\beta^F = \alpha ,$$

$$(I - \beta^L)^{-1}\sigma\varepsilon_t = \sigma\eta_t .$$

In particular,

$$(I - \beta^L)^{-1}\sigma\varepsilon_t = \begin{bmatrix} 1 & 0 & 0 \\ \beta_{24} & 1 & 0 \\ \beta_{34} + \beta_{24}\beta_{35} & \beta_{35} & 1 \end{bmatrix} \sigma \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \\ \varepsilon_{3,t} \end{bmatrix} \tag{11}$$

$$= \sigma \begin{bmatrix} \varepsilon_{1,t} \\ \beta_{24}\varepsilon_{1,t} + \varepsilon_{2,t} \\ (\beta_{34} + \beta_{24}\beta_{35})\varepsilon_{1,t} + \beta_{35}\varepsilon_{2,t} + \varepsilon_{3,t} \end{bmatrix} = \sigma \begin{bmatrix} \eta_{1,t} \\ \eta_{2,t} \\ \eta_{3,t} \end{bmatrix}.$$

The conditional density of each element of y_t is given below.

$$f\left(y_{1,t}\middle|S_t, y_{t-1};\beta_1(S_t),\sigma_1(S_t)\right)$$
$$= \frac{1}{\sqrt{2\pi}\sigma_1(S_t)}\exp\left[-\frac{1}{2}\left(\frac{y_{1,t}-\left[\beta_1^0(S_t)+\beta_1^F(S_t)y_{t-1}\right]}{\sigma_1(S_t)}\right)^2\right] \tag{12}$$

$$f\left(y_{2,t}\middle|S_t, y_{t-1}, y_{1,t};\beta_2(S_t),\sigma_2(S_t)\right)$$
$$= \frac{1}{\sqrt{2\pi}\sigma_2(S_t)}\exp\left[-\frac{1}{2}\left(\frac{y_{2,t}-\left[\beta_2^0(S_t)+\beta_2^F(S_t)y_{t-1}+\beta_2^L(S_t)y_t\right]}{\sigma_2(S_t)}\right)^2\right] \tag{13}$$

$$f\left(y_{3,t}\middle|S_t, y_{t-1}, y_{1,t}, y_{2,t};\beta_3(S_t),\sigma_3(S_t)\right)$$
$$= \frac{1}{\sqrt{2\pi}\sigma_3(S_t)}\exp\left[-\frac{1}{2}\left(\frac{y_{3,t}-\left[\beta_3^0(S_t)+\beta_3^F(S_t)y_{t-1}+\beta_3^L(S_t)y_t\right]}{\sigma_3(S_t)}\right)^2\right] \tag{14}$$

The conditional density of the MSVAR is

$$\begin{aligned} f\left(y_t\middle|S_t, y_{t-1}, z_t;\beta(S_t),\sigma(S_t)\right) = {} & f\left(y_{1,t}\middle|S_t, y_{t-1};\beta_1(S_t),\sigma_1(S_t)\right) \\ & \times f\left(y_{2,t}\middle|S_t, y_{t-1}, y_{1,t};\beta_2(S_t),\sigma_2(S_t)\right) \\ & \times f\left(y_{3,t}\middle|S_t, y_{t-1}, y_{1,t}, y_{2,t};\beta_3(S_t),\sigma_3(S_t)\right) \end{aligned} \tag{15}$$

where

$\beta = \{\beta_1, \beta_2, \beta_3\}$,

$\sigma = \{\sigma_1, \sigma_2, \sigma_3\}$, and

$z_t = \{y_{1,t}, y_{2,t}\}$.

The complete-data likelihood is

$$\begin{aligned} & f\left(y_T^*, S_T^*\middle|z_T^*, x_T^*;\beta,\sigma,\xi\right) \\ & = f\left(y_1, S_1\middle|z_T^*, x_T^*;\beta,\sigma,\xi\right)\prod_{t=2}^{T} f\left(y_t, S_t\middle|y_{t-1}^*, S_{t-1}^*, z_T^*, x_T^*;\beta,\sigma,\xi\right) \\ & = f\left(y_1\middle|S_1, z_1;\beta,\sigma\right)P(S_1)\prod_{t=2}^{T} f\left(y_t\middle|S_t, y_{t-1}, z_t;\beta,\sigma\right)P\left(S_t\middle|S_{t-1}, x_{t-1};\xi\right) \end{aligned} \tag{16}$$

where y_T^*, S_T^*, z_T^* and x_T^* refer to all observations from $t=1$ to $t=T$ of y_t, S_t, z_t and x_t, respectively, and the incomplete-data loglikelihood is

$$\begin{aligned}
&\log f\left(y_T^*, S_T^* \middle| z_T^*, x_T^*; \beta, \sigma, \xi\right) \\
&\quad = I(S_1 = 1)\left[\log f\left(y_1 \middle| S_1 = 1; \beta(S_1 = 1), \sigma(S_1 = 1)\right) + \log \rho\right] \\
&\qquad + I(S_1 = 2)\left[\log f\left(y_1 \middle| S_1 = 2; \beta(S_1 = 2), \sigma(S_1 = 2)\right) + \log(1-\rho)\right] \\
&\qquad + \sum_{t=2}^{T} \Big\{ I(S_t = 1)\log f\left(y_t \middle| S_t = 1; \beta(S_t = 1), \sigma(S_t = 1)\right) \\
&\qquad\quad + I(S_t = 2)\log f\left(y_t \middle| S_t = 2; \beta(S_t = 2), \sigma(S_t = 2)\right) \\
&\qquad\quad + I(S_t = 1, S_{t-1} = 1)\log p_t^{11} + I(S_t = 2, S_{t-1} = 1)\log\left(1 - p_t^{11}\right) \\
&\qquad\quad + I(S_t = 1, S_{t-1} = 2)\log\left(1 - p_t^{22}\right) + I(S_t = 2, S_{t-1} = 2)\log p_t^{22} \Big\}.
\end{aligned} \tag{17}$$

Since, all variables in this model estimation are stationary, ρ is not a parameter but is initialized and determined by ξ.

Using the EM algorithm for MSR with TVTP by Diebold, Lee & Weinbach (1994), which is based on Hamilton's (1990) EM algorithm for MSR with FTP, the incomplete-data loglikelihood is maximized to estimate the parameters.

3.3 Index of Speculative Pressure from MSVAR with TVTP

From Equation (1), the ISP in each regime is

$$ISP_t(S_t) = \Delta ER_t(S_t) + \frac{\sigma_{\Delta ER}(S_t)}{\sigma_{\Delta FR}(S_t)}\Delta FR_t(S_t) - \frac{\sigma_{\Delta ER}(S_t)}{\sigma_{\Delta ID}(S_t)}\Delta ID_t(S_t) \tag{18}$$

from which the expected ISP is derived and given by

$$ISP_t = P(S_t = 1|\Im_{t-1})ISP_t(S_t = 1) + P(S_t = 2|\Im_{t-1})ISP_t(S_t = 2) \tag{19}$$

where

$$P(S_t = 1|\Im_{t-1}) = p_t^{11} + p_t^{21} \tag{20}$$

and

$$P(S_t = 2|\Im_{t-1}) = p_t^{22} + p_t^{12}. \tag{21}$$

The p_t^{11}, p_t^{12}, p_t^{22} and p_t^{21} are the transition probabilities specified in Equations (3) to (6), respectively, and are all conditional on information up to $t-1$, that is, $\Im_{t-1}$.

There are two ways of defining a crisis probability. The first one is the probability of a turbulent regime $P(S_t = 1)$, that is,

$$P(Crisis_t|\Im_{t-1}) = P(S_t = 1|\Im_{t-1}) \tag{22}$$

and the second one is

$$P\left(Crisis_t \mid \Im_{t-1}\right) = P\left(ISP_t < \tau \mid \Im_{t-1}\right) \tag{23}$$

where τ is a threshold below which the ISP indicates that a currency crisis has occurred. The crisis forecasts of these two approaches are compared.

IV. Results and Discussion

The MSVAR with TVTP in this study is adapted from Martinez Peria's (2002) model. The difference with this study and her paper was on the application. First, the objective of Martinez Peria (2002) in estimating the MSVAR model was for dating periods of speculative pressure in the EMS countries while in this study the purpose is to identify leading indicators of speculative pressure for the four Asian Financial Crisis countries: Indonesia, Malaysia, Philippines and Thailand. Second, Martinez Peria (2002) pooled the data for all the European countries in her analysis of the EMS crisis. She obtained this pooled data by stacking the data for each country and estimating one MSVAR with TVTP for all countries at once while including country dummies to control for country fixed effects. The country dummies turned out to be jointly significant but individually insignificant. In this study, the MSVAR with TVTP model is estimated for each country separately. This approach is along the lines of Abiad (2003), Mariano, Abiad, Gultekin, Shabbir & Tan (2003) and Brunetti, Scotti, Mariano & Tan (2008) who noted the idiosyncrasies of each country facing periods of speculative pressure. Different country characteristics imply different currency vulnerabilities. Abiad (2003) and the other studies, for example, found that countries have varying significant early warning indicators of the Asian Financial Crisis.

The three measures of speculative pressure are the month-on-month percentage change in the nominal exchange rate ΔER, and the foreign exchange reserve ΔFR and the month-on-month change in the interest rate differential ΔID between a country and the U.S. The monthly data from 1980 to 1999 data were sourced from Abiad's (2003) dataset including the early warning indicators.

4.1 Descriptive Statistics

Table 3 shows that the three measures of speculative pressure have large differences in magnitude. The change in FX reserve is the most volatile among the three except for Indonesia where it is the change in exchange rate. It is also evident that the least volatile is the change in interest rate differential. These are shown in Figures 1.1, 2.1, 3.1 and 4.1 for Indonesia, Malaysia, Philippines and Thailand, respectively. The large differences in magnitude obscure the impact of the changes in the ISP components. In econometric modeling the standard deviations of ΔER, ΔFR and ΔID are equalized in order to remove these differences in magnitude. This approach is given in Equation (1). This approach was taken by Eichengreen, Rose & Wyplosz (1994, 1995, 1996), Frankel & Rose (1996), Sachs, Tornell & Velasco (1996) and Kaminsky & Reinhart (1999). The base is the standard deviation of ΔID for Indonesia while it is ΔER for Malaysia, Philippines and Thailand. Figures 1.2, 2.2, 3.2 and 4.2 show the effect of equalizing the standard deviations. While ΔID seems muted in Figures 1.1, 2.1, 3.1 and 4.1 during periods of speculative pressure the equalization reveals in Figures 1.2, 2.2, 3.2 and 4.2 that this is not so.

The turbulent episodes are shown by the shaded portions of Figures 1 to 4. These are according to Abiad's (2003) classification of periods of speculative pressure based on a three standard deviation from the mean of the ISP. In these periods, the currencies experienced depreciations or devaluations. If small depreciations are observed during periods of speculative pressure there are correspondingly huge changes in the FX reserve reflecting drawdowns by the monetary authority to defend its currency. There are also large positive changes in interest rate differentials. Raising the domestic interest rate is another tool a government employs to stem the impact of speculation thereby raising the interest differentials. This is clearly the case for Indonesia in the early 1980s where there was a huge drop in FX reserves at the beginning of the period of speculative attack with no devaluation yet and no change in interest differential. The devaluation of the rupiah came afterwards. Malaysia experienced a similar occurrence in the early 1980s and 1990s where the ringgit only depreciated after reduction in FX reserve and increase in interest rates. In the mid-1980s and the early 1990s, Philippines' had decreases in FX reserves before the depreciation of the peso with further reduction in reserves during the mid-1980s. A similar pattern happened in Thailand in the 1980s where the FX reserves contracted first before the baht devalued.

During the Asian Financial Crisis all three components of the ISP responded to speculative attacks as governments attempted but failed to preserve the crawling pegs of the four countries. The drawdowns from the FX reserve and the monetary tightening to stabilize the devaluated currency all reflected the defensive moves in response to speculative pressure. The baht floated in July 1997 after the unsustainable losses in FX reserve by Thailand coupled with interest rate hikes. Indonesia allowed its rupiah to devalue in the early period of the crisis but still incurred huge losses in FX reserves on a month-on-month basis while at the same time it raised interest rate to ease pressures on its currency. Malaysia's FX reserves also contracted and its interest rates went up to defend the ringgit. Eventually the ringgit was devalued. While the Philippines allowed the peso to severely devalue after providing brief support through its FX reserve and through interest rate hikes.

Table 3. Descriptive Statistics

Country	Statistics	ΔER	ΔFR	ΔID
IND	Mean	-1.390	1.020	0.029
	Median	-0.319	0.757	0.000
	Maximum	29.439	30.903	12.000
	Minimum	-123.118	-33.771	-7.950
	Std. Dev.	10.344	6.880	1.728
	Skewness	-7.666	0.042	1.780
	Kurtosis	84.964	7.155	19.724
MAL	Mean	0.264	1.031	-0.009
	Median	0.004	0.849	0.000
	Maximum	17.357	36.559	1.500
	Minimum	-19.560	-18.366	-3.330
	Std. Dev.	2.590	5.979	0.446
	Skewness	0.133	1.023	-2.550
	Kurtosis	27.742	8.503	18.854
PHI	Mean	0.771	2.441	-0.011
	Median	0.107	0.511	-0.006
	Maximum	28.567	108.838	6.015
	Minimum	-8.133	-51.294	-3.934
	Std. Dev.	3.734	20.264	1.256
	Skewness	3.940	2.140	0.642
	Kurtosis	27.116	11.008	6.483
THA	Mean	0.306	1.389	-0.022
	Median	0.000	1.466	0.000
	Maximum	24.335	30.912	3.000
	Minimum	-21.853	-16.612	-3.250
	Std. Dev.	3.313	5.845	0.593
	Skewness	2.077	0.560	-0.728
	Kurtosis	29.871	6.954	13.742

Note: ER is in country currency per U.S. dollar. $\Delta ER = -(ER_t - ER_{t-1})/ER_{t-1}$ in %, so that a negative ΔER means depreciation. For example, IND rupiah jumped to IDR 10,375 per dollar in January 1998 from IDR 4,650 in December 1997, a change of 123.118%. This means that ΔER = -123.118%. $\Delta FR = (FR_t - FR_{t-1})/FR_{t-1}$ in %. $\Delta ID = (ID_t - ID_{t-1})/ID_{t-1}$ in %, where ID = Country interest rate minus U.S. interest rate.

Figure 1.1. Changes in Exchange Rate, FX Reserve and Interest Differential: Indonesia

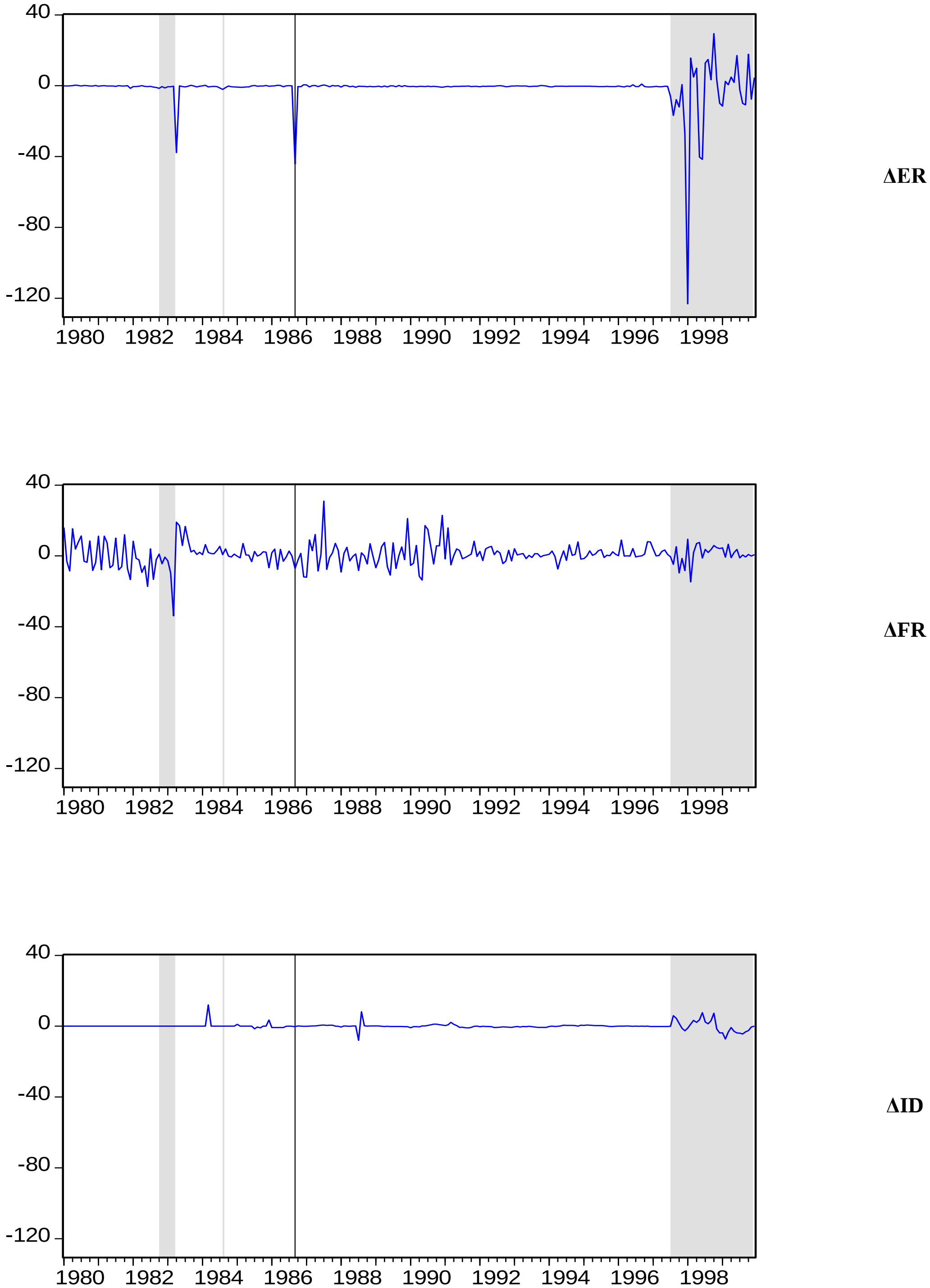
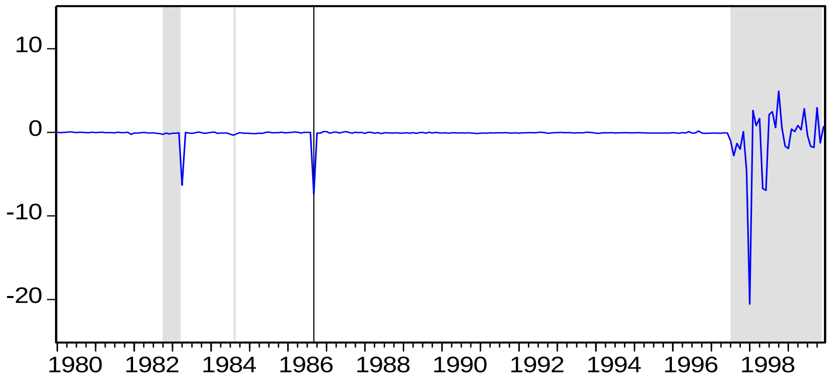
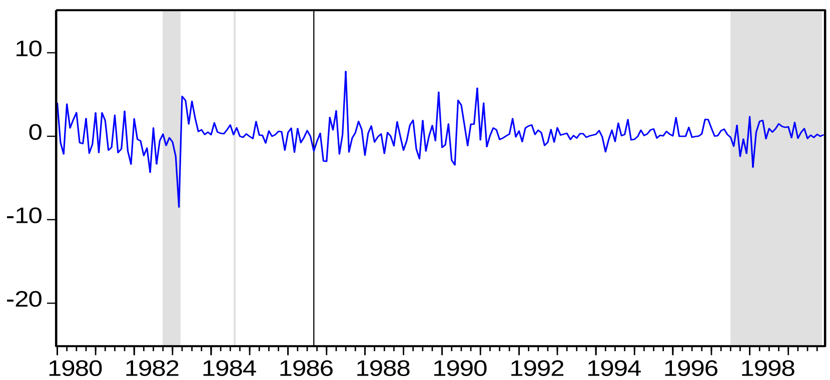


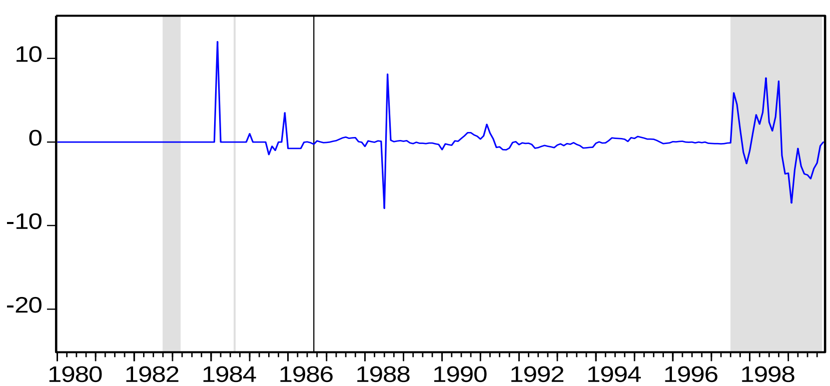
Figure 1.2. Standardized Changes in Exchange Rate, FX Reserve and Interest Differential: Indonesia



ΔER

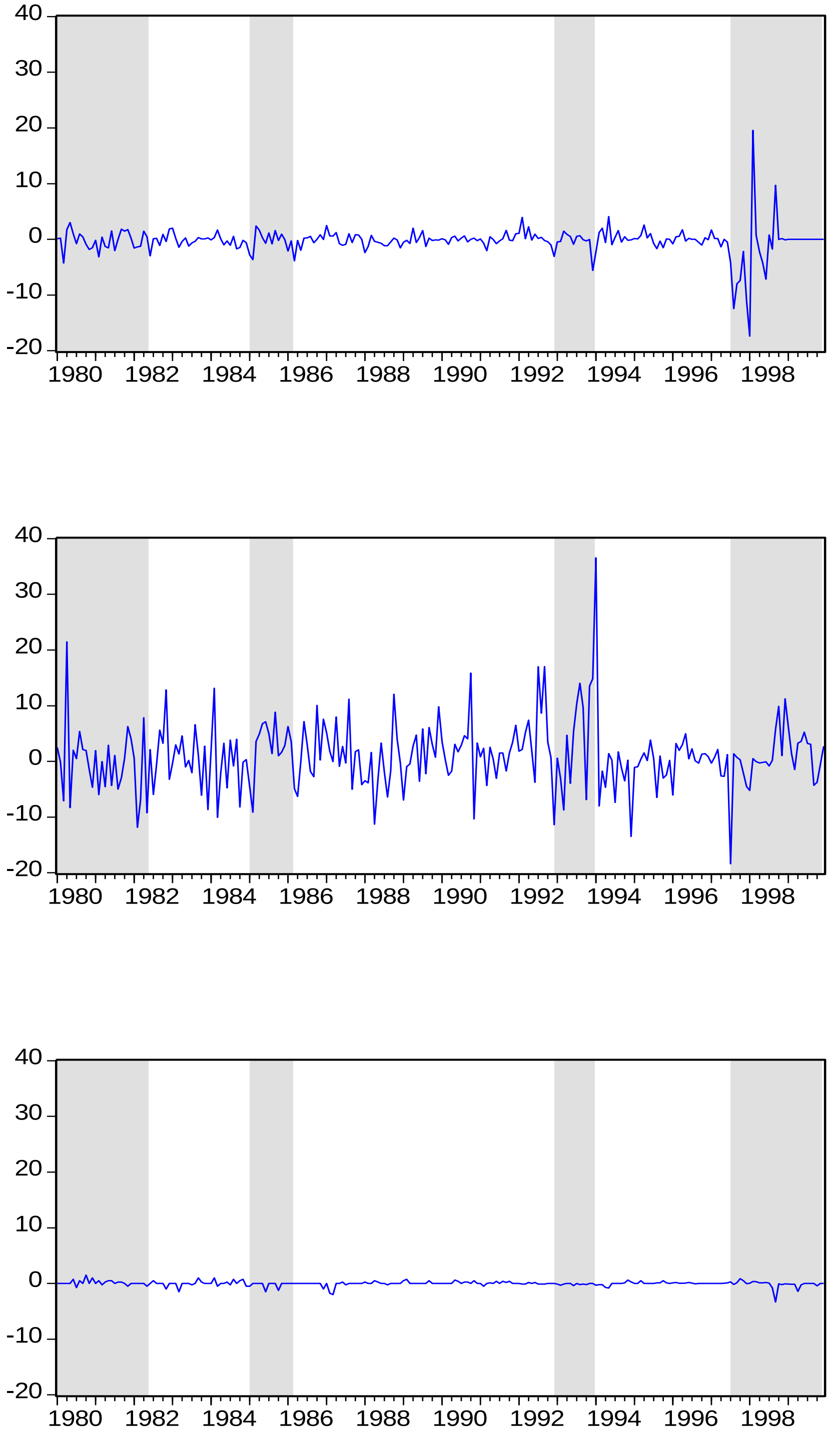


ΔFR



ΔID

Figure 2.1. Changes in Exchange Rate, FX Reserve and Interest Differential: Malaysia



ΔER

ΔFR

ΔID

Figure 2.2. Standardized Changes in Exchange Rate, FX Reserve and Interest Differential: Malaysia

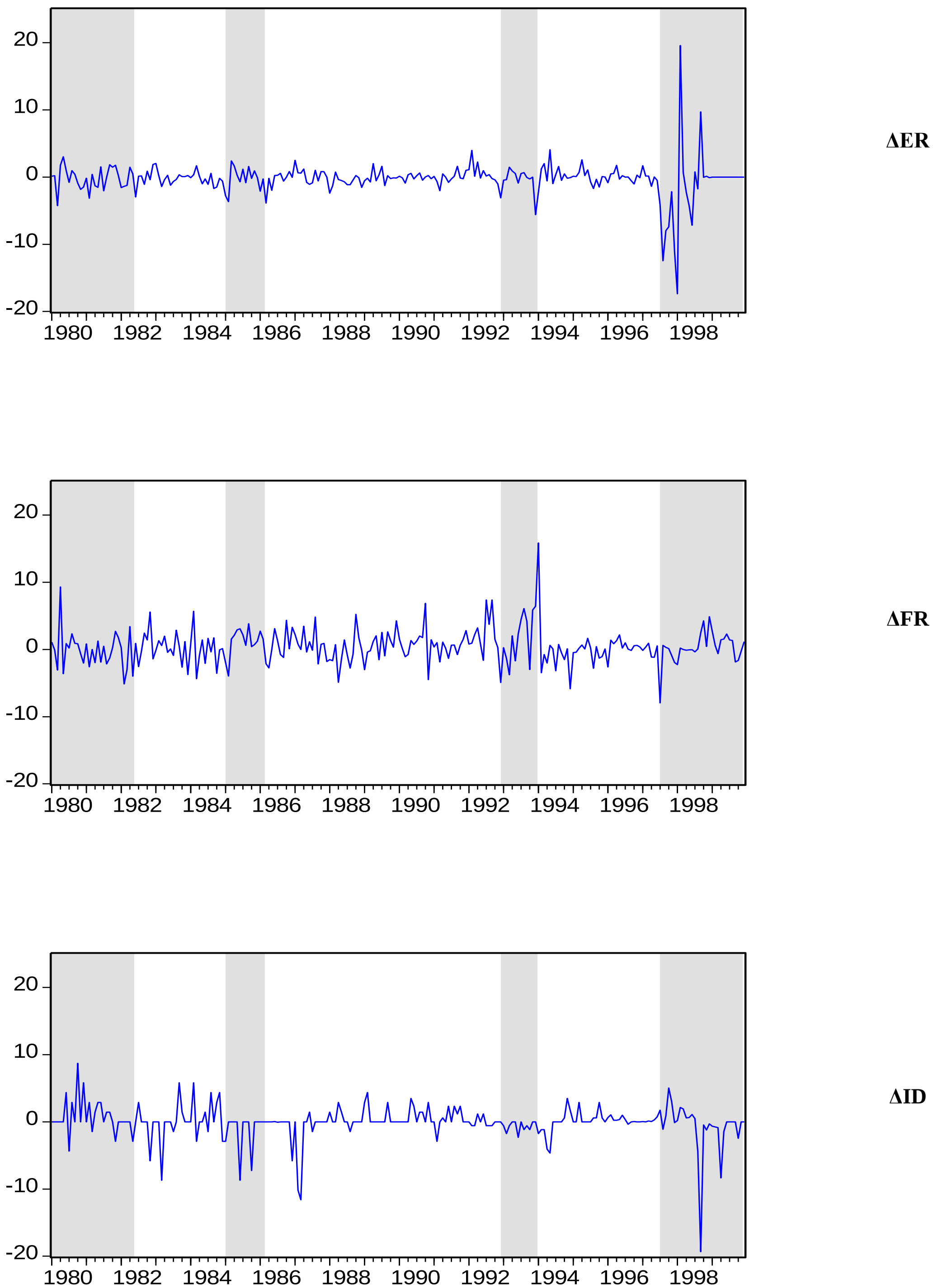


Figure 3.1. Changes in Exchange Rate, FX Reserve and Interest Differential: Philippines

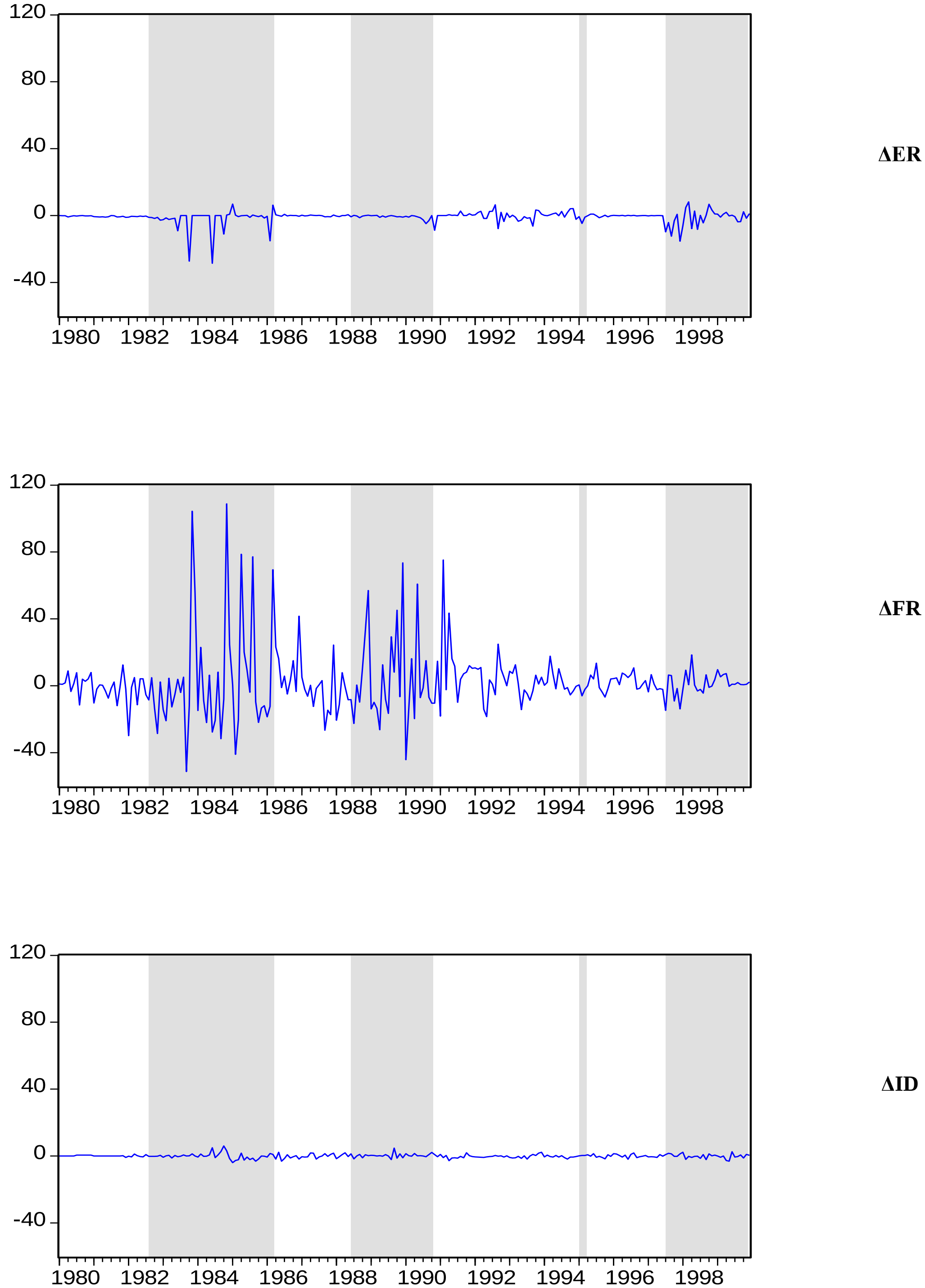


Figure 3.2. Standardized Changes in Exchange Rate, FX Reserve and Interest Differential: Philippines

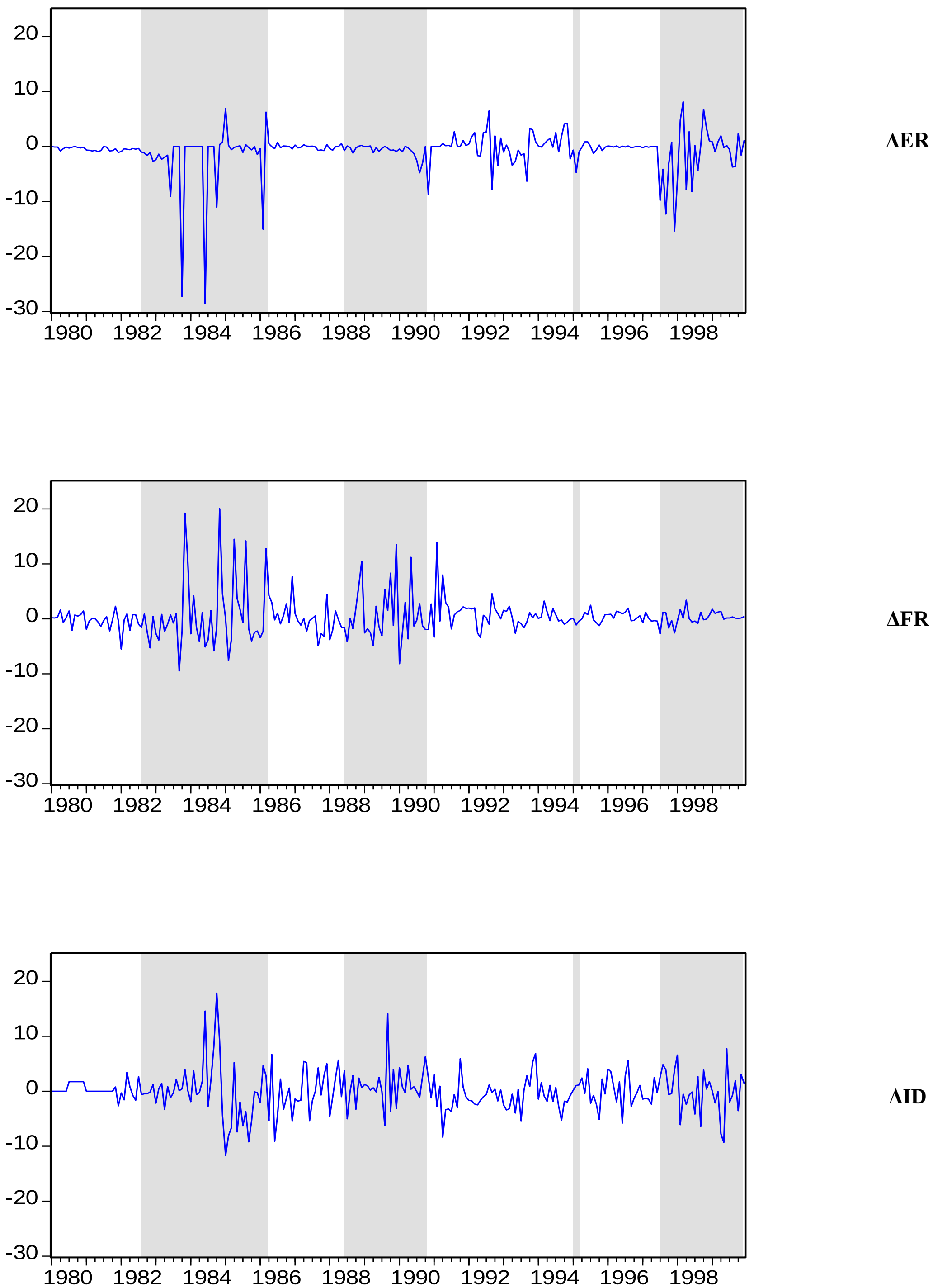
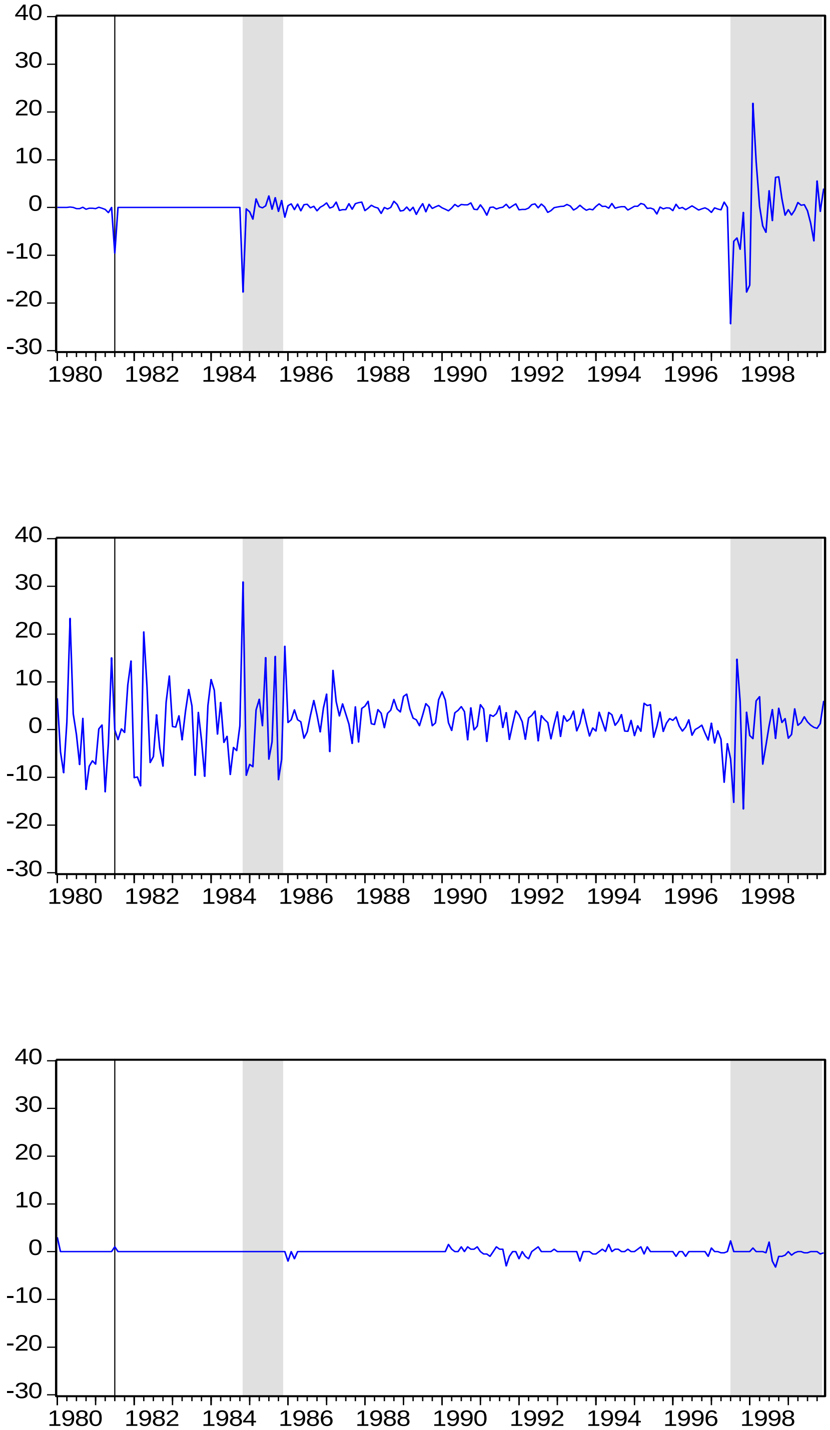


Figure 4.1. Changes in Exchange Rate, FX Reserve and Interest Differential: Thailand

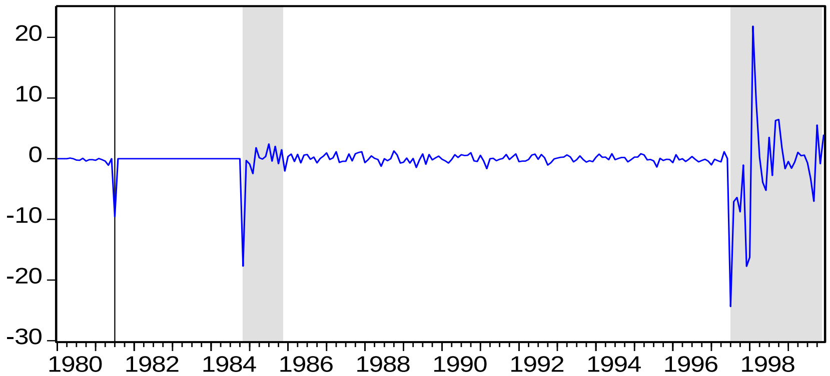


ΔER

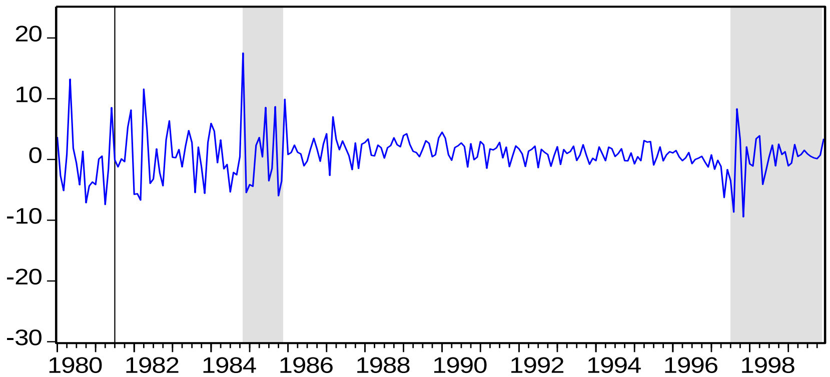
ΔFR

ΔID

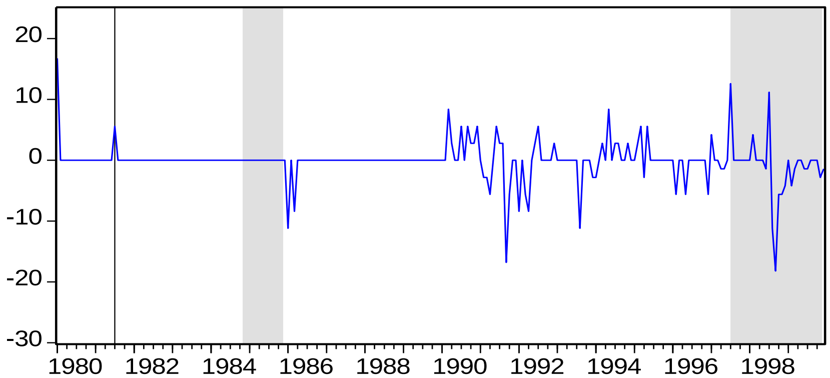
Figure 4.2. Standardized Changes in Exchange Rate, FX Reserve and Interest Differential: Thailand



ΔER



ΔFR



ΔID

4.2 Macroeconomic Indicators

The overvaluation of the currency is reflected in the real effective exchange rate (REER), the ratio of the current account balance with the GDP (NEGCA/GDP) and the export growth rate (NEGEXPORTG) which all go back to Sachs, Tornell & Velasco (1996) and Krugman (1996). The adequacy of the reserves is measured by the M2 ratio with the foreign exchange reserve (NEGM2RATIO) and its growth rate (NEGM2RATIOG). As Sachs, Tornell & Velasco (1996) had discussed, this reflects how well the monetary authorities are able to cover the demand for foreign exchange during periods of panic where investors dump the local currency. The overexpansion of domestic credit (RDC) led to the collapse of the Bretton Woods system in 1971 according to Blackburn & Sola (1993). The RDC was similarly explained by Sachs, Tornell & Velasco (1996) in their investigation of the EMS and Tequila crises. The slowdown in overall economic activity, represented by the change in the real gross domestic product growth (NEGGDP) interpolated from quarterly data, is another factor that reflects vulnerability of the currency. The ratio of cumulative non-FDI flows with GDP (NFDIFLW) is an indicator of movement of hot money that becomes a source of weakness for the currency when there is flight of capital as an outcome of the bursting of an asset price bubble. Another source of vulnerability would be the potential capital flow reversal as reflected in the LIBOR. The weakness of the banking system was identified by Kaminsky & Reinhart (1999) as another cause of a currency crisis. A measure of such weakness is the extent of bailout of ailing banks by the government through the ratio of central bank credit to banks' total bank liabilities (CBBAIL). Similarly, the confidence of the depositors as measured by the ratio of total bank deposits to M2 (NEGDEPM2) and its change (NEGDEPM2G) serve as indicator of the stability of the banking system.

In Table 4 the potential early warning indicators are presented. Some were reversed in sign so that the TVTP p_t^{11} logistic regression would have an expected positive regressor coefficient. This means that the indicator influences the probability of remaining in a turbulent regime. Pre-screening was done based on Abiad's (2003) simple linear regressions. Furthermore, each indicator is evaluated and selected depending on how well each is able to provide early signals of periods of speculative pressure where a signal is marked when p_t^1 goes above 50%. After which the best combination of variables are chosen in the final model for each country. Table 5a and 5b report the parameter estimates of the TVTP equation, however, the parameter estimates of the MSVAR model in two states were omitted since the primary interest here is to identify the indicators of the probability of a crisis occurring. Only the parameter estimates of the final MSVAR model are reported.

Table 4. Variable Description

Classification	Indicator	Value Interpretation
Real Overvaluation	REER	(+) overvalued; deviating above trend
Trade Balance	NEGCA/GDP NEGEXPORTG	(+) deficit (+) contraction in growth
FX Reserve Adequacy	NEGM2RATIO NEGM2RATIOG	higher (+) value, less adequate getting more inadequate
Credit Overexpansion	RDC	(+) overexpansion
Real Economy	NEGIP NEGGDP	(+) contraction in growth (+) contraction in growth
Short-term Capital Flow	NFDIFLW	(+) higher flows
Capital Flow Reversal	LIBOR	(+) higher potential flow reversal
Central Bank Bailout	CBBAIL	higher (+) value, more bailout
Bank Confidence	NEGDEPM2 NEGDEPM2G	less (-), less confident getting less confident

4.3 Indonesia

Among the early warning indicators examined, Table 5.1 presents the ones that provide a reasonable identification of periods of speculative pressure based on p_t^{11} and p_t^1. The variables that were initially on the list are REER, NEGEXPORTG, CBBAIL and NEGDEPM2G. Although only real effective exchange rate and export growth are significant the good fit of p_t^{11} and p_t^1 during periods of speculative pressure suggests that the central bank bailout and growth of the deposit to money supply ratio are potential indicators as well. The four indicators imply that the overvaluation of the currency after many years of fixed exchange rate of the rupiah with the dollar, with corresponding outcome of loss of competitiveness resulting in contracting exports, is a potential indicator of an impending currency crisis. Central bank credit to the banking system is another indicator of potential vulnerability when the system is under stress. This is consistent with the costly bank bailouts in Indonesia during the Asian Financial Crisis.

The confidence of the public in the banking system suggests another signal and a potential source of vulnerability of the rupiah and the economy as a whole.

Table 5.1. TVTP indicators: Indonesia and Malaysia

	IND				MAL				
$S_t = 1$: Turbulent									
ξ_0	4.1717 (0.6528)	3.6401 (0.5329)	4.4853 (0.4801)	3.8392 (0.6254)	2.7590 (3.2537)	4.6477 (9.1803)	1.9807 (0.4100)	2.6721 (0.4939)	3.3816 (1.8254)
ξ_1 : REER	0.9566 (0.3273)				1.7961 (2.2576)				
ξ_1 : NEGCA/GDP									
ξ_1 : NEGEXPORTG		0.7672 (0.4620)							
ξ_1 : NEGM2RATIO									
ξ_1 : NEGM2RATIOG									
ξ_1 : RDC						2.8067 (7.6623)			
ξ_1 : NEGGDP							0.4250 (0.4197)		
ξ_1 : LIBOR								0.3455 (0.6628)	
ξ_1 : NFDIFLW									
ξ_1 : CBBAIL			0.0415 (0.3801)						
ξ_1 : NEGDEPM2									0.6726 (3.2600)
ξ_1 : NEGDEPM2G				-0.1567 (0.4633)					
$S_t = 2$: Ordinary									
β^0	0.6795 (0.5341)	-0.2277 (0.4522)	0.1045 (0.4628)	-0.0800 (0.4742)	2.8916 (2.1504)	1.6131 (2.4199)	-1.3345 (0.5495)	-1.4183 (0.6476)	2.4156 (1.2993)
LogL	-1798.6	-1808.7	-1824.7	-1829.0	-2509.0	-2479.6	-2221.0	-2271.1	-2394.2
AIC	15.4086	15.4931	15.6274	15.6636	21.3780	21.1309	18.9577	19.3787	20.4131
SIC	15.9192	16.0037	16.1380	16.1742	21.8887	21.6416	19.4684	19.8893	20.9237
HQ	15.6144	15.6989	15.8332	15.8694	21.5838	21.3367	19.1635	19.5845	20.6189

Note: Standard error in parenthesis. Highlighted coefficient estimates are significant at the 10% level.

Table 6 presents the final MSVAR model for Indonesia. The common standard deviation of the error terms, $\sigma(S_t)$, during turbulent periods is higher than during ordinary periods. This is consistent with the results of Abiad (2003) and Mariano, Abiad, Gultekin, Shabbir & Tan (2003). The three indicators: real effective exchange rate, export growth and growth of the deposit to money supply ratio are all significant.

Although the fit of only either REER or NEGEXPORTG is better based on the loglikelihood compared to the three indicators REER, NEGEXPORTG and NEGDEPM2G taken together in the TVTP equation, the individual indicator in the former contain too many false signals in the transition probabilities p_t^{11} and p_t^{1} compared to the combination of the three in the latter. This supports the choice of the final model in Table 6 as the best one. The final model provides signal of the Asian Financial Crisis as early as November and December 1996 with 92% although the signal eventually diminished and only jumped up again to 77% in July 1997, the onset of the crisis.

Figures 5 and 6, based on estimated values of the transition probabilities in Equations (3), (6), (20) and (22), show that the model adequately accounted for the turbulence in the rupiah during the Asian Financial Crisis. However, there were signals of speculative pressure in Figure 6 during the 1980s which are not crisis episodes, but had large fluctuations in the FX reserves. This indicates that the MSVAR with TVTP is very sensitive to relatively volatile periods of even one of the ISP components. Figures 1.1 and 1.2 show that there were large changes in FX reserves in the early 1980s and in between the mid-1980s to early 1990s and these were reflected in the transition probabilities in Figures 5 and 6. This also means that a turbulent period need not be a crisis and still is detected by the MSVAR with TVTP model. This sensitiveness to changes in the regime of the ISP indicators enables one to use this model for short-term forecasting of speculative pressure episodes.

In Figures 7 and 8, the ISP derived from the MSVAR with TVTP model and specified in Equations (19), (20), (21) and (23) is presented. The ISP shows large fluctuations during turbulent periods for the Indonesian rupiah, especially during the Asian Financial Crisis. The crisis period identified by the ISP is based on ISP values lower than the threshold $\tau = \mu_{ISP} - 1.5\sigma_{ISP}$. The choice of 1.5 times the standard deviation is the same as in Eichengreen, Rose & Wyplosz (1994). The reason for this choice, instead of the typical factor of 2 or 3, is that this cut-off provides a good balance between identifying a crisis episode from a non-crisis one.

Comparing Figures 6 and 8, which correspond respectively to Equations (22) and (23), reveals that $P\left(S_t = 1 \middle| \Im_{t-1}\right)$ produces more false signals than $P\left(ISP_t < \tau \middle| \Im_{t-1}\right)$. However, $P\left(ISP_t < \tau \middle| \Im_{t-1}\right)$ cannot serve as a forecasting approach for the Indonesian rupiah because it largely detected a crisis episode after it already occurred, including the Asian Financial Crisis.

Table 5.2. TVTP indicators: Philippines and Thailand

	PHI					THA		
$S_t = 1$: Turbulent								
ξ_0	5.9278	**3.1199**	4.6331	3.2339	**5.4327**	2.0211	2.4069	2.0661
	(5.8530)	(0.8262)	(25.0731)	(4.6175)	(0.9002)	(2.9175)	(3.2388)	(2.7358)
ξ_1 :	1.0769					1.4592		
REER	(2.9104)					(2.3290)		
ξ_1 :								
NEGCA/GDP								
ξ_1 :		0.4247						
NEGEXPORTG		(0.7499)						
ξ_1 :			0.7391					
NEGM2RATIO			(40.4858)					
ξ_1 :				0.9822				
NEGM2RATIOG				(5.6662)				
ξ_1 :								
RDC								
ξ_1 :							2.8699	
NEGGDP							(8.1939)	
ξ_1 :								
LIBOR								
ξ_1 :								1.2281
NFDIFLW								(2.7595)
ξ_1 :								
CBBAIL								
ξ_1 :								
NEGDEPM2								
ξ_1 :					-0.1197			
NEGDEPM2G					(0.8034)			
$S_t = 2$: Ordinary								
ξ_0	0.9471	-1.0664	0.7599	2.9018	-0.4958	1.8362	1.4488	1.6271
	(0.8559)	(0.9854)	(2.1186)	(2.5263)	(0.8850)	(2.8679)	(3.0278)	(2.5709)
LogL	-3174.6	-3178.9	-3324.8	-3380.1	-3161.4	-3340.9	-3311.8	-3330.2
AIC	26.9718	27.0072	28.2334	28.6985	26.8607	28.3690	28.1240	28.2788
SIC	27.4824	27.5178	28.7440	29.2091	27.3713	28.8796	28.6346	28.7894
HQ	27.1776	27.2130	28.4392	28.9043	27.0664	28.5748	28.3298	28.4846

Note: Standard error in parenthesis. Highlighted coefficient estimates are significant at the 10% level.

Table 6. MSVAR Model: Indonesia

	ΔER	ΔFR	ΔID
$S_t = 1$: Turbulent			
β^0	-0.2690	0.1309	-0.0281
	(0.1276)	(0.0772)	(0.0901)
β_{i1}^F	0.0798	0.0369	-0.1353
	(0.0334)	(0.0519)	(0.0620)
β_{i2}^F	0.1072	-0.0698	-0.0309
	(0.0581)	(0.0371)	(0.0597)
β_{i3}^F	0.0856	-0.0560	0.3347
	(0.0607)	(0.0894)	(0.0212)
β_{j4}		-0.0340	-0.0594
		(0.0670)	(0.0604)
β_{k5}			0.1171
			(0.0931)
$S_t = 2$: Ordinary			
β^0	0.1549	0.4756	0.0069
	(0.1067)	(0.0645)	(0.1461)
β_{i1}^F	2.8777	1.2632	1.2627
	(0.9153)	(0.7289)	(2.2036)
β_{i2}^F	0.1716	-0.0448	0.0609
	(0.0895)	(0.0436)	(0.0937)
β_{i3}^F	-0.1067	0.3010	0.6617
	(0.1336)	(0.0899)	(0.1389)
β_{j4}		-0.0187	-0.7941
		(0.4839)	(1.4441)
β_{k5}			-0.0980
			(0.1640)
$S_t = 1$: Turbulent			
σ		1.7655	
		(0.0338)	
$S_t = 2$: Ordinary			
σ		0.1392	
		(0.0122)	

	TVTP
$S_t = 1$: Turbulent	
ξ_0	**4.6300**
	(0.6694)
ξ_1: REER	**0.9754**
	(0.5841)
ξ_2: NEGEXPORTG	**1.3444**
	(0.5835)
ξ_3: NEGDEPM2G	**0.8783**
	(0.4414)
$S_t = 2$: Ordinary	
ξ_0	0.0223
	(0.5326)
LogL	-1819.2
AIC	15.5982
SIC	16.1380
HQ	15.8158

Note: Standard error in parenthesis. Highlighted coefficient estimates are significant at the 10% level.. $i = \{1,2,3\}$, $j = \{2,3\}$, $k = \{3\}$.

Table 7. Transition Probabilities: Indonesia

Time	p11	p21	p1
1996M01	0.0022	0.0419	0.0441
1996M02	0.0440	0.4604	0.5044
1996M03	0.0236	0.0001	0.0237
1996M04	0.0046	0.0005	0.0052
1996M05	0.0002	0.0002	0.0004
1996M06	0.0002	0.0007	0.0009
1996M07	0.0002	0.0003	0.0005
1996M08	0.0003	0.0013	0.0016
1996M09	0.0016	0.0101	0.0116
1996M10	0.0115	0.0595	0.0710
1996M11	0.0710	0.8482	0.9192
1996M12	0.9154	0.0071	0.9225
1997M01	0.2287	0.0000	0.2287
1997M02	0.0109	0.0000	0.0109
1997M03	0.0015	0.0000	0.0015
1997M04	0.0013	0.0004	0.0017
1997M05	0.0017	0.0047	0.0064
1997M06	0.0064	0.0318	0.0382
1997M07	0.0382	0.7343	0.7725
1997M08	0.7725	0.2275	1.0000
1997M09	1.0000	0.0000	1.0000
1997M10	1.0000	0.0000	1.0000
1997M11	1.0000	0.0000	1.0000
1997M12	1.0000	0.0000	1.0000
1998M01	1.0000	0.0000	1.0000
1998M02	1.0000	0.0000	1.0000
1998M03	1.0000	0.0000	1.0000
1998M04	0.9937	0.0000	0.9937
1998M05	0.9937	0.0063	1.0000
1998M06	1.0000	0.0000	1.0000
1998M07	1.0000	0.0000	1.0000
1998M08	1.0000	0.0000	1.0000
1998M09	1.0000	0.0000	1.0000
1998M10	1.0000	0.0000	1.0000
1998M11	1.0000	0.0000	1.0000
1998M12	1.0000	0.0000	1.0000
1999M01	1.0000	0.0000	1.0000
1999M02	1.0000	0.0000	1.0000
1999M03	1.0000	0.0000	1.0000
1999M04	1.0000	0.0000	1.0000
1999M05	1.0000	0.0000	1.0000
1999M06	1.0000	0.0000	1.0000

Figure 5. Transition Probabilities: Indonesia

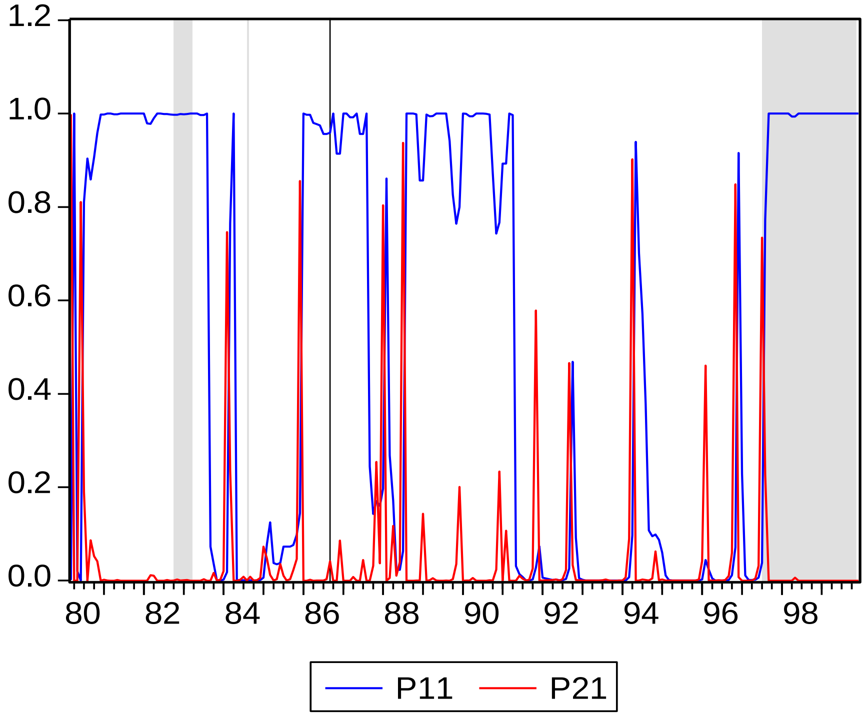


Figure 6. Probability of Crisis $P\left(S_t = 1 \middle| \Im_{t-1}\right)$: Indonesia

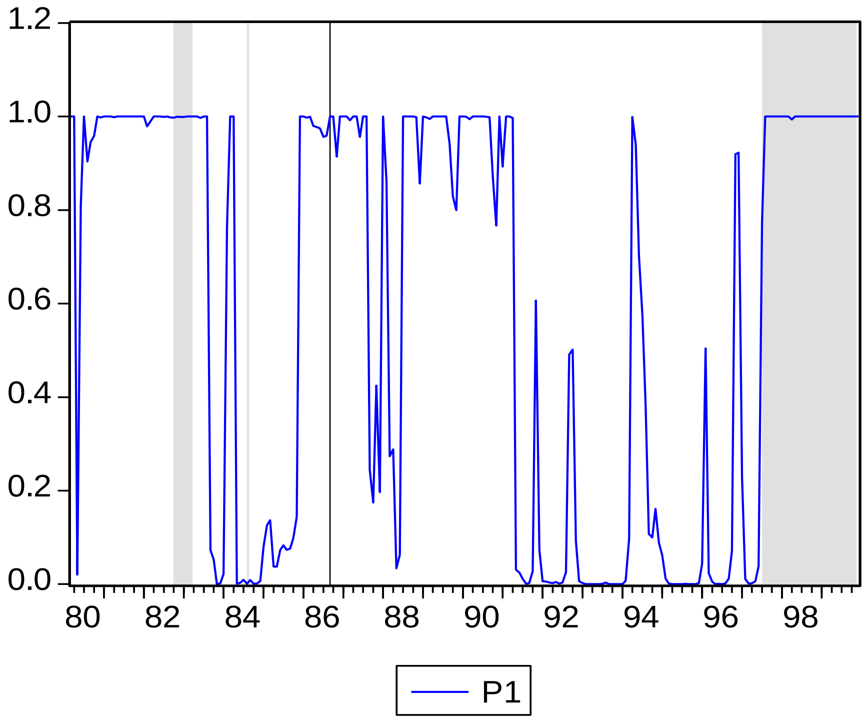


Figure 7. Index of Speculative Pressure: Indonesia

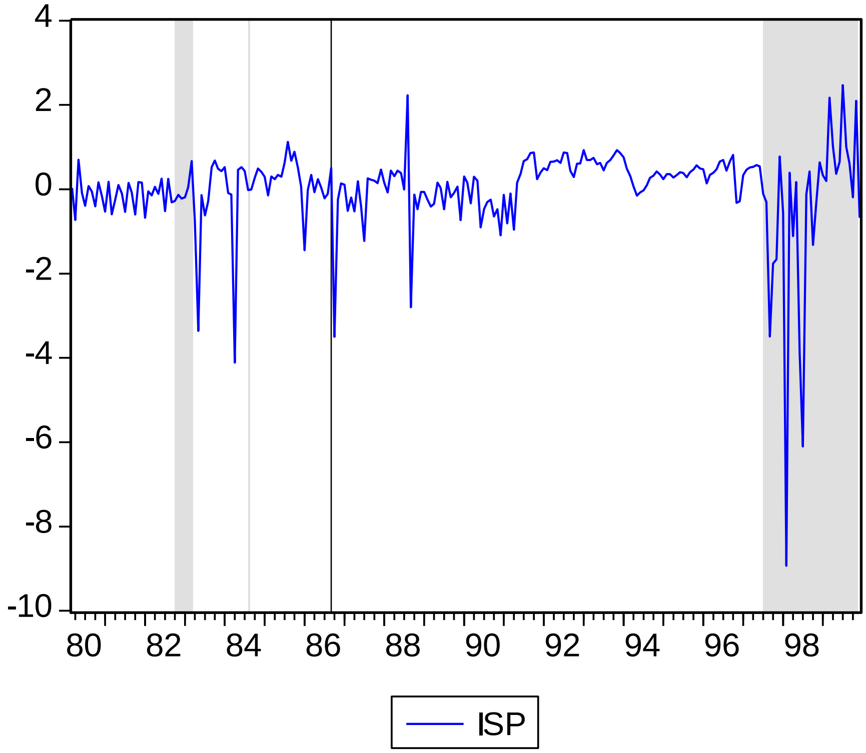
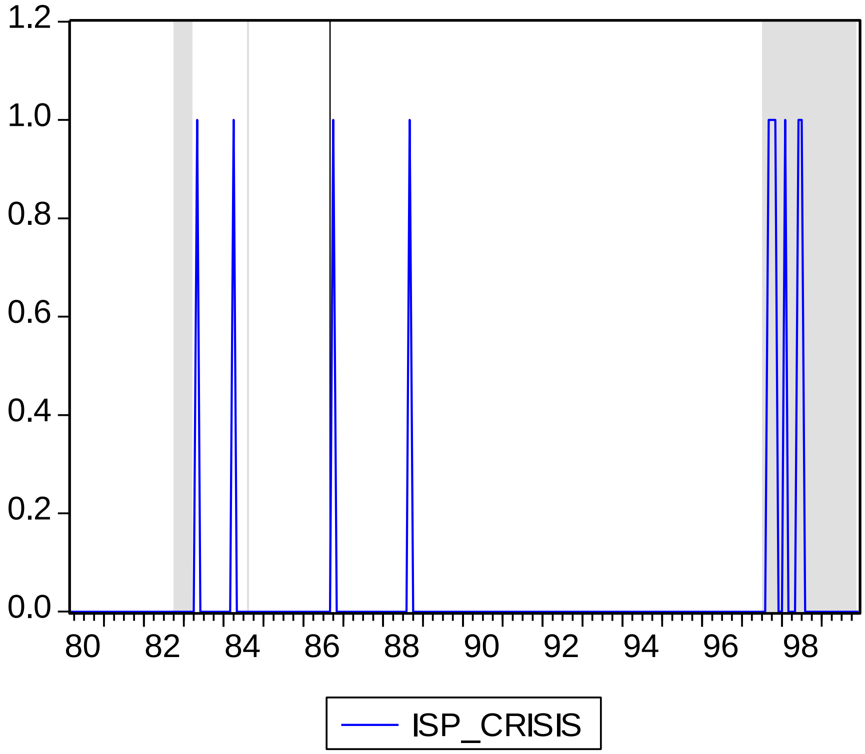


Figure 8. Probability of Crisis $P\left(ISP_t < \tau \middle| \Im_{t-1}\right)$**: Indonesia**



4.4 Malaysia

The early warning indicators that provided reasonable predictions of the periods of speculative pressure in Malaysia are given in Table 5.1. The variables in this list are REER, RDC, NEGGDP, LIBOR and NEGDEPM2. Overvaluation of the currency, excessive lending by financial institutions, contracting economy, capital flow reversal and confidence in banks are potential indicators of vulnerability that can lead to periods of turbulence in the ringgit. Although there are no individual significant indicators, the good fit of p_t^{11} and p_t^{1} during periods of speculative pressure suggests that these indicators remain useful.

Table 8 presents the final MSVAR model for Malaysia. The common standard deviation of the error terms, $\sigma(S_t)$, during turbulent periods is higher than during ordinary periods. The three indicators: real effective exchange rate, real domestic credit growth and GDP growth result in a good fit of p_t^{11} and p_t^{1} during periods of speculative pressure. Figures 9 and 10 show that the model has adequately signaled the turbulent periods of the ringgit including early signals for the Asian Financial Crisis and during the 1980s.

Although the fit of only either RDC, NEGGDP, LIBOR and NEGDEPM2 is better based on the loglikelihood compared to the three indicators REER, RDC and NEGGDP taken together in the TVTP equation, the individual indicator in the former contain too many false signals in the transition probabilities p_t^{11} and p_t^{1} compared to the combination of the three in the latter. This lends support to the final model in Table 8. The final model provides signal of the Asian Financial Crisis as early as April 1997 with more than 58% and has increasing probability until July 1997.

In Figures 11 and 12, the ISP derived from the MSVAR with TVTP model is presented. The ISP shows large fluctuations during turbulent periods for the Malaysian ringgit, especially during the Asian Financial Crisis. Similar to Indonesia, the crisis period identified by the ISP is based on ISP values lower than $\mu_{ISP} - 1.5\sigma_{ISP}$. Comparing Figures 10 and 12, which correspond respectively to Equations (22) and (23), reveals that $P(S_t = 1 | \Im_{t-1})$ produces better forecasting signals than $P(ISP_t < \tau | \Im_{t-1})$. While the

$P\left(S_t = 1 \middle| \Im_{t-1}\right)$ is able to detect crisis episodes ahead of time, the $P\left(ISP_t < \tau \middle| \Im_{t-1}\right)$ cannot and only signals a crisis when it has already occurred.

4.5 Philippines

The potential indicators of periods of speculative pressure in the Philippines are given in Table 5.2. These are REER, NEGEXPORTG, NEGM2RATIO, NEGM2RATIOG and NEGDEPM2G. Overvaluation of the currency, contraction in export, inadequacy of the FX reserve to fund conversions, slowdown in economic activity and confidence in the banking sector are potential indicators of the currency crisis. Although there are no significant individual indicators, the good fit of p_t^{11} and p_t^{1} during turbulent periods suggests that they remain useful.

Table 10 presents the final MSVAR model for the Philippines. The common standard deviation of the error terms, $\sigma(S_t)$, during turbulent periods is higher than during ordinary periods. The three indicators: real effective exchange rate, export growth and adequateness of FX reserve to fund conversions result in a good fit of p_t^{11} and p_t^{1} during periods of speculative pressure. Figures 13 and 14 show that the model has adequately signaled the turbulent periods of the peso including early signals for the Asian Financial Crisis including during the early 1980s and 1990s.

Although the fit of only either REER, NEGEXPORTG, NEGM2RATIO, NEGM2RATIOG and NEGDEPM2G is better based on the loglikelihood compared to the three indicators REER, NEGEXPORTG and NEGM2RATIOG taken together in the TVTP equation, the individual indicator in the former contain too many false signals in the transition probabilities p_t^{11} and p_t^{1} compared to the combination of the three in the latter. This makes the choice of the final model in Table 10 as the best one. The final model provides signal of the Asian Financial Crisis as early as February 1997 with more than 54% and has increasing probability until July 1997.

Similar to Malaysia and Indonesia, in Figures 15 and 16 the ISP derived from the MSVAR with TVTP model is plotted. The ISP shows large fluctuations during turbulent periods for the Philippine peso, especially at the time of political turmoil in the early to mid-1980s and during the Asian Financial Crisis. The crisis period identified by the ISP is also based on ISP values lower than $\mu_{ISP} - 1.5\sigma_{ISP}$. Comparing Figures 14 and 16, which correspond respectively to Equations (22) and (23), reveals that $P\left(S_t = 1 \middle| \Im_{t-1}\right)$ produces better forecasting signals than $P\left(ISP_t < \tau \middle| \Im_{t-1}\right)$. The $P\left(S_t = 1 \middle| \Im_{t-1}\right)$ is able to indicate way ahead a currency crisis unlike the $P\left(ISP_t < \tau \middle| \Im_{t-1}\right)$ which only provided a signal close towards the Asian Financial Crisis beginning July 1997. A similar observation is made that while the $P\left(S_t = 1 \middle| \Im_{t-1}\right)$ is able to detect crisis episodes ahead of time, the $P\left(ISP_t < \tau \middle| \Im_{t-1}\right)$ cannot and only signals a crisis when it has already occurred.

Table 8. MSVAR Model: Malaysia

	ΔER	ΔFR	ΔID
$S_t = 1$: Turbulent			
β^0	-0.3316	0.4010	-0.0345
	(0.1433)	(0.1349)	(0.1312)
β_{i1}^F	0.4303	-0.0691	-0.1473
	(0.0298)	(0.0421)	(0.0747)
β_{i2}^F	0.0757	0.0200	-0.0537
	(0.0429)	(0.0380)	(0.0722)
β_{i3}^F	-0.0731	-0.1370	0.1615
	(0.0670)	(0.0881)	(0.0326)
β_{j4}		0.1696	0.0609
		(0.0483)	(0.0839)
β_{k5}			-0.1221
			(0.0607)
$S_t = 2$: Ordinary			
β^0	-0.2069	0.3789	0.0551
	(0.2565)	(0.1538)	(0.2122)
β_{i1}^F	0.4047	-0.0271	-0.1135
	(0.1454)	(0.1742)	(0.2754)
β_{i2}^F	0.0212	0.0203	-0.0245
	(0.1717)	(0.0752)	(0.1410)
β_{i3}^F	-0.0227	-0.1386	0.1661
	(0.2526)	(0.1187)	(0.1442)
β_{j4}		0.2393	0.0772
		(0.1736)	(0.3401)
β_{k5}			-0.0930
			(0.1437)
$S_t = 1$: Turbulent			
σ		1.9653	
		(0.0519)	
$S_t = 2$: Ordinary			
σ		1.6590	
		(0.0883)	

	TVTP
$S_t = 1$: Turbulent	
ξ_0	3.0003
	(6.2062)
ξ_1: REER	1.7878
	(6.9077)
ξ_2: RDC	2.2144
	(6.8628)
ξ_3: NEGGDP	2.1535
	(7.4537)
$S_t = 2$: Ordinary	
ξ_0	2.5650
	(2.4480)
LogL	-2492.7
AIC	21.2580
SIC	21.7978
HQ	21.4756

Note: Standard error in parenthesis. Highlighted coefficient estimates are significant at the 10% level.. $i = \{1,2,3\}$, $j = \{2,3\}$, $k = \{3\}$.

Table 9. Transition Probabilities: Malaysia

Time	p11	P21	p1
1996M01	0.1100	0.0401	0.1501
1996M02	0.0572	0.0261	0.0833
1996M03	0.0385	0.0251	0.0636
1996M04	0.0218	0.0162	0.0381
1996M05	0.0334	0.0180	0.0514
1996M06	0.0489	0.0196	0.0685
1996M07	0.0668	0.0238	0.0907
1996M08	0.0873	0.0283	0.1156
1996M09	0.1124	0.0330	0.1455
1996M10	0.1437	0.0389	0.1826
1996M11	0.1810	0.0435	0.2245
1996M12	0.2231	0.0531	0.2761
1997M01	0.2754	0.0640	0.3394
1997M02	0.3394	0.0664	0.4058
1997M03	0.4058	0.0790	0.4848
1997M04	0.4848	0.0962	0.5810
1997M05	0.5810	0.1034	0.6844
1997M06	0.6844	0.1279	0.8123
1997M07	0.8123	0.1498	0.9622
1997M08	0.9622	0.0378	1.0000
1997M09	1.0000	0.0000	1.0000
1997M10	1.0000	0.0000	1.0000
1997M11	0.9928	0.0000	0.9928
1997M12	0.9928	0.0072	1.0000
1998M01	1.0000	0.0000	1.0000
1998M02	0.7467	0.0000	0.7467
1998M03	0.7450	0.0652	0.8103
1998M04	0.8101	0.0836	0.8937
1998M05	0.8936	0.0633	0.9569
1998M06	0.9568	0.0321	0.9890
1998M07	0.9884	0.0037	0.9921
1998M08	0.9920	0.0054	0.9974
1998M09	0.9974	0.0026	1.0000
1998M10	1.0000	0.0000	1.0000
1998M11	0.9999	0.0000	0.9999
1998M12	0.9999	0.0000	0.9999
1999M01	0.9997	0.0000	0.9997
1999M02	0.9959	0.0000	0.9959
1999M03	0.9922	0.0008	0.9929
1999M04	0.9851	0.0018	0.9869
1999M05	0.8376	0.0005	0.8381
1999M06	0.6428	0.0078	0.6506

Figure 9. Transition Probabilities: Malaysia

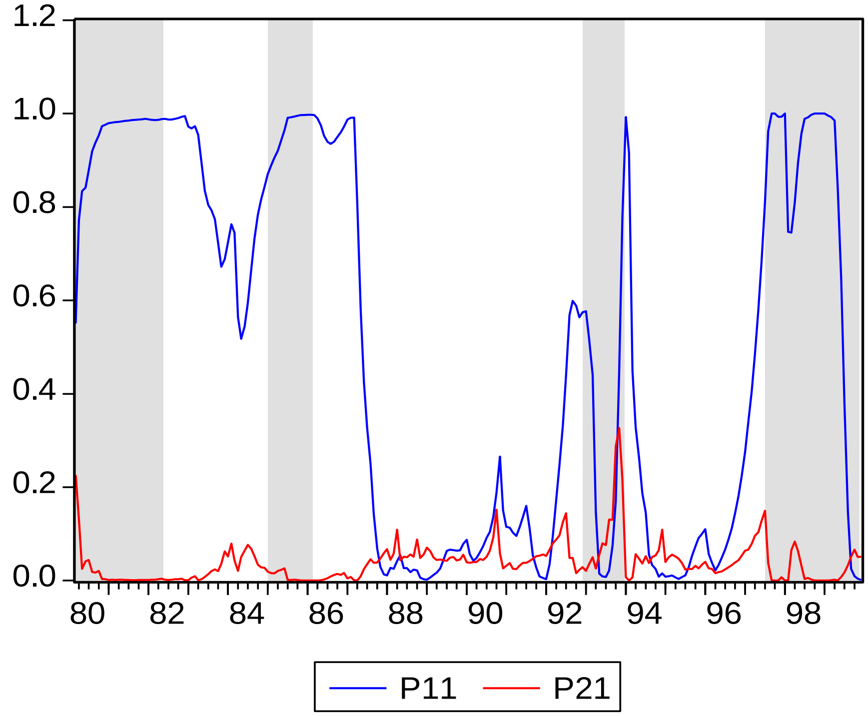


Figure 10. Probability of Crisis $P\left(S_t = 1 \middle| \Im_{t-1}\right)$**: Malaysia**

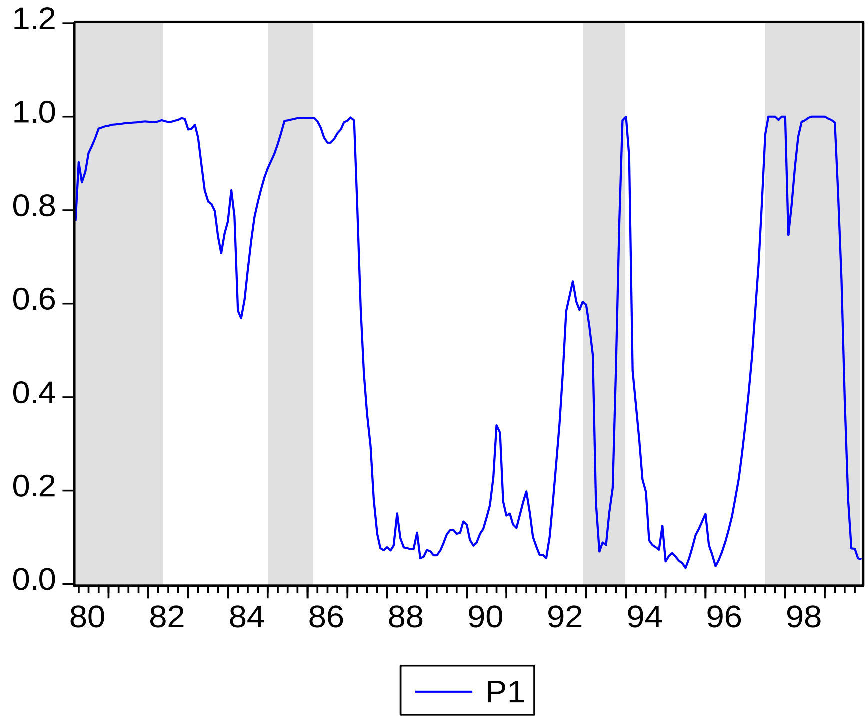


Figure 11. Index of Speculative Pressure: Malaysia

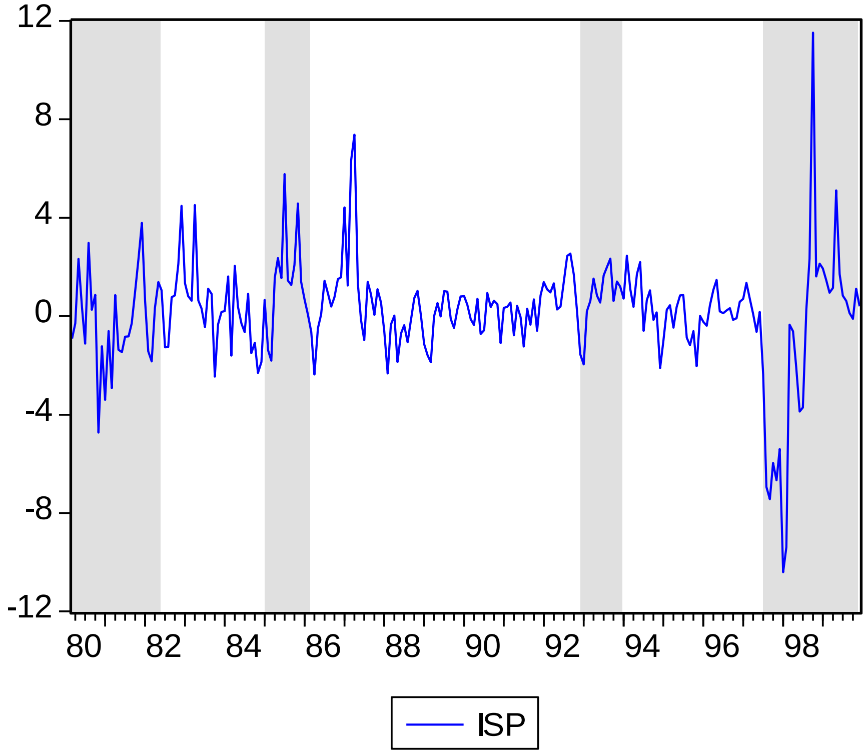


Figure 12. Probability of Crisis $P\left(ISP_t < \tau \middle| \Im_{t-1}\right)$: Malaysia

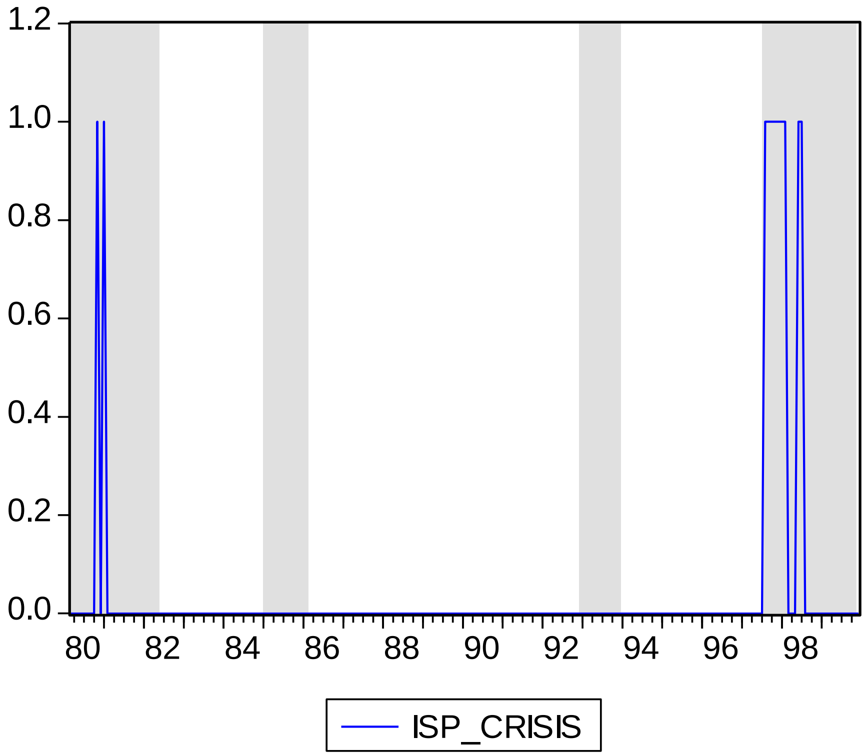


Table 10. MSVAR Model: Philippines

	ΔER	ΔFR	ΔID
$S_t = 1$: Turbulent			
β^0	-0.9657	0.4106	-0.3269
	(0.1572)	(0.1042)	(0.1260)
β_{i1}^F	-0.0715	-0.1918	-0.0941
	(0.0516)	(0.0121)	(0.0525)
β_{i2}^F	0.1883	0.0358	-0.0619
	(0.0299)	(0.0194)	(0.0208)
β_{i3}^F	-0.1150	0.1571	0.0259
	(0.0464)	(0.0183)	(0.0224)
β_{j4}		0.1777	-0.3047
		(0.1039)	(0.0300)
β_{k5}			0.0155
			(0.0229)
$S_t = 2$: Ordinary			
β^0	-0.7998	0.3709	-0.3296
	(0.2995)	(0.2703)	(0.1589)
β_{i1}^F	-0.0707	-0.1610	-0.0835
	(0.0845)	(0.1479)	(0.0906)
β_{i2}^F	0.1664	0.0585	-0.0658
	(0.2422)	(0.1226)	(0.1015)
β_{i3}^F	-0.1063	0.1248	0.0204
	(0.0973)	(0.0919)	(0.0456)
β_{j4}		0.1672	-0.2937
		(0.3266)	(0.1419)
β_{k5}			0.0036
			(0.0855)
$S_t = 1$: Turbulent			
σ		3.4254	
		(0.0532)	
$S_t = 2$: Ordinary			
σ		3.0235	
		(0.1586)	

	TVTP
$S_t = 1$: Turbulent	
ξ_0	3.0922
	(4.6215)
ξ_1: REER	1.4899
	(2.9533)
ξ_2: NEGEXPORTG	1.7276
	(3.2797)
ξ_3: NEGM2RATIOG	1.4955
	(4.4225)
$S_t = 2$: Ordinary	
ξ_0	2.4849
	(2.7762)
LogL	-3420.5
AIC	29.0545
SIC	29.5943
HQ	29.2720

Note: Standard error in parenthesis. Highlighted coefficient estimates are significant at the 10% level.. $i = \{1,2,3\}$, $j = \{2,3\}$, $k = \{3\}$.

Table 11. Transition Probabilities: Philippines

Time	p11	P21	p1
1996M01	0.1415	0.0662	0.2077
1996M02	0.1890	0.0538	0.2429
1996M03	0.1928	0.0458	0.2386
1996M04	0.1859	0.0557	0.2416
1996M05	0.2378	0.0650	0.3028
1996M06	0.2956	0.0675	0.3632
1996M07	0.3541	0.0491	0.4033
1996M08	0.4004	0.0479	0.4483
1996M09	0.4415	0.0263	0.4678
1996M10	0.4515	0.0288	0.4804
1996M11	0.4624	0.0329	0.4953
1996M12	0.4073	0.0394	0.4467
1997M01	0.4401	0.0516	0.4917
1997M02	0.4883	0.0584	0.5467
1997M03	0.5458	0.0652	0.6110
1997M04	0.6085	0.0731	0.6816
1997M05	0.6564	0.0886	0.7450
1997M06	0.7426	0.1000	0.8426
1997M07	0.8424	0.1207	0.9631
1997M08	0.9615	0.0188	0.9802
1997M09	0.9762	0.0138	0.9900
1997M10	0.7466	0.0013	0.7479
1997M11	0.6147	0.0738	0.6885
1997M12	0.6842	0.2855	0.9698
1998M01	0.7312	0.0046	0.7358
1998M02	0.1181	0.0368	0.1549
1998M03	0.0962	0.2444	0.3406
1998M04	0.2537	0.1705	0.4242
1998M05	0.3492	0.0587	0.4079
1998M06	0.2841	0.1234	0.4074
1998M07	0.2548	0.0461	0.3009
1998M08	0.1117	0.0801	0.1918
1998M09	0.0888	0.1017	0.1905
1998M10	0.0900	0.1662	0.2563
1998M11	0.1238	0.0602	0.1840
1998M12	0.1289	0.0646	0.1935
1999M01	0.1410	0.0773	0.2183
1999M02	0.1534	0.1308	0.2842
1999M03	0.2679	0.1765	0.4444
1999M04	0.4387	0.2223	0.6610
1999M05	0.6587	0.1138	0.7725
1999M06	0.7554	0.0351	0.7905

Figure 13. Transition Probabilities: Philippines

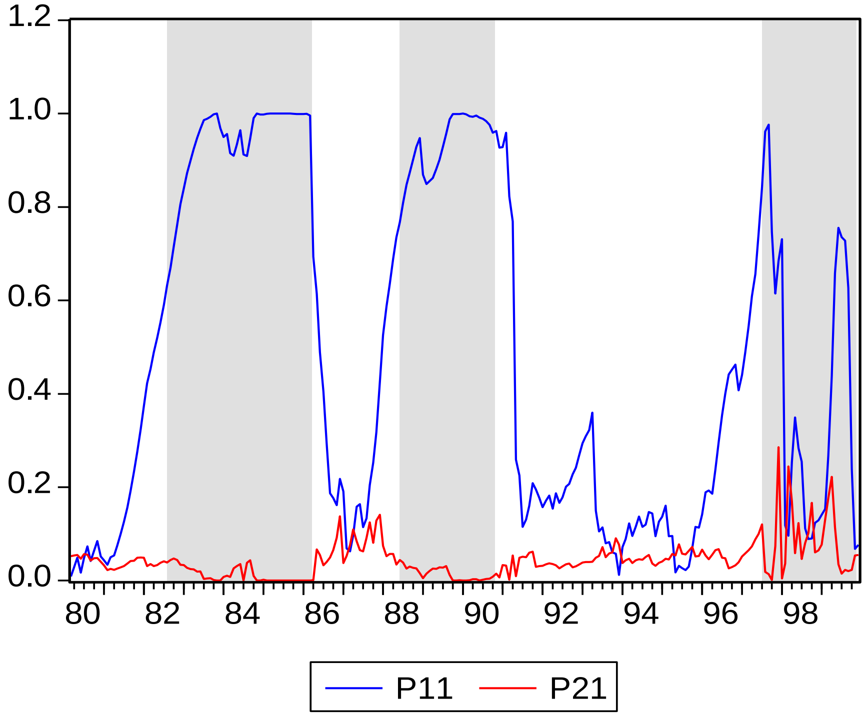


Figure 14. Probability of Crisis $P\left(S_t = 1 \middle| \Im_{t-1}\right)$: Philippines

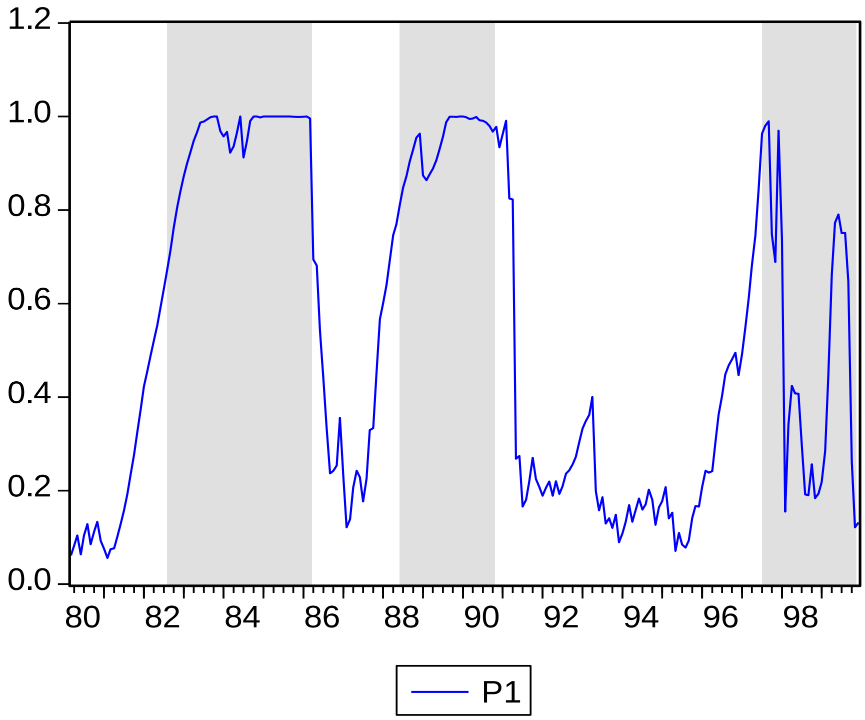


Figure 15. Index of Speculative Pressure: Philippines

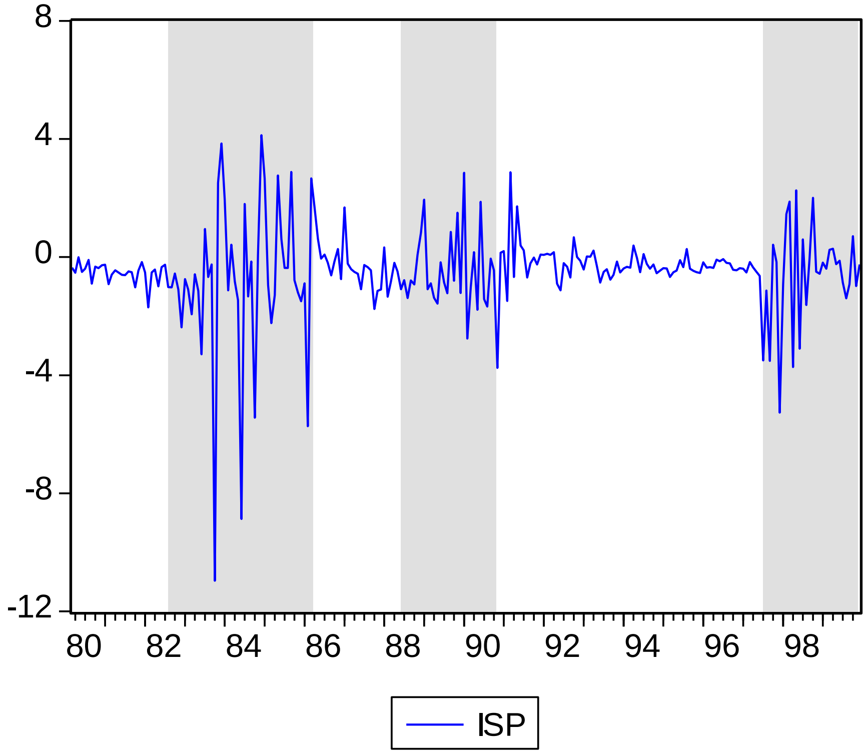
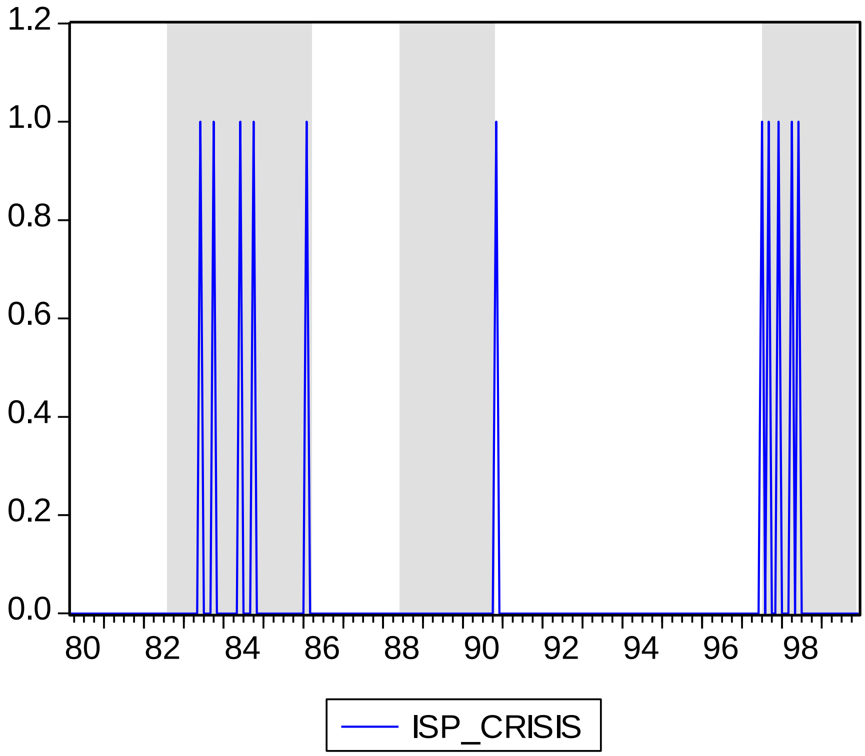


Figure 16. Probability of Crisis $P\left(ISP_t < \tau \middle| \Im_{t-1}\right)$**: Philippines**



4.6 Thailand

The potential indicators for Thailand consist of REER, NEGGDP and NFDIFLW. See Table 5.2. Overvaluation of the currency, slowdown in the overall economy and large non-FDI flows are indicators of vulnerability that can precipitate into a crisis. Although there are no individual significant indicators, the good fit of p_t^{11} and p_t^{1} during turbulent periods suggests that they remain useful.

Table 12 presents the final MSVAR model for the Thailand. The common standard deviation of the error terms, $\sigma(S_t)$, during turbulent periods is higher than during ordinary periods. The three indicators: real effective exchange rate, economic growth and inflow of hot money result in a good fit of p_t^{11} and p_t^{1} during periods of speculative pressure. Figures 17 and 18 show that the model has adequately signaled the turbulent periods of the baht during the 1980s, including early signals for the Asian Financial Crisis. However, there were signals of speculative pressure during the 1990s, especially in periods of large fluctuations of the interest rate differentials. This again indicates the sensitiveness of the MSVAR with TVTP to relatively volatile periods of even one of the ISP components.

Although the fit of only NEGGDP is better based on the loglikelihood compared to the three indicators REER, NEGGDP and NFDIFLW taken together in the TVTP equation, the individual indicator in the former contains more false signals in the transition probabilities p_t^{11} and p_t^{1} compared to the combination of the three in the latter. This supports the choice of the final model in Table 12 as the better one. The final model provides signal of the Asian Financial Crisis as early as January 1996 with more than 60% and has increasing probability until July 1997.

Similar to the three previous countries, in Figures 19 and 20 the ISP derived from the MSVAR with TVTP model is plotted. The ISP shows large fluctuations during turbulent periods for the Thailand baht, especially during the Asian Financial Crisis. The threshold for the ISP is again $\mu_{ISP} - 1.5\sigma_{ISP}$. Comparing Figures 18 and 20, which correspond respectively to Equations (22) and (23), reveals that although $P(S_t = 1 | \Im_{t-1})$ has false signals it produces better forecast than $P(ISP_t < \tau | \Im_{t-1})$ on the Asian Financial

Crisis. The $P\left(S_t = 1 \middle| \Im_{t-1}\right)$ is able to detect a currency crisis unlike the $P\left(ISP_t < \tau \middle| \Im_{t-1}\right)$ which provided a signal only at the time of the occurrence of a crisis.

Table 12. MSVAR Model: Thailand

	ΔER	ΔFR	ΔID
$S_t = 1$: Turbulent			
β^0	-0.3261	0.7829	-0.2188
	(0.1349)	(0.1111)	(0.1612)
β_{i1}^F	0.1553	0.2294	-0.0248
	(0.0134)	(0.0315)	(0.0584)
β_{i2}^F	0.0642	0.0401	-0.0166
	(0.0176)	(0.0233)	(0.0305)
β_{i3}^F	-0.0833	-0.0214	0.1452
	(0.0403)	(0.0867)	(0.0249)
β_{j4}		-0.0844	-0.1197
		(0.0169)	(0.0252)
β_{k5}			-0.0224
			(0.1047)
$S_t = 2$: Ordinary			
β^0	-0.0682	0.7977	-0.1079
	(0.6473)	(0.1898)	(0.3514)
β_{i1}^F	0.1128	0.2423	0.0154
	(0.1758)	(0.1645)	(0.3165)
β_{i2}^F	0.0350	0.0529	0.0238
	(0.2489)	(0.0441)	(0.1443)
β_{i3}^F	0.0036	0.0065	0.1521
	(0.3255)	(0.1768)	(0.0930)
β_{j4}		0.0638	-0.0719
		(0.2996)	(0.4095)
β_{k5}			0.0101
			(0.1601)
$S_t = 1$: Turbulent			
σ		3.2159	
		(0.0282)	
$S_t = 2$: Ordinary			
σ		2.7828	
		(0.1722)	

	TVTP
$S_t = 1$: Turbulent	
ξ_0	2.2199
	(4.3410)
ξ_1: REER	1.8748
	(4.3787)
ξ_2: NEGGDP	2.5973
	(9.8273)
ξ_3: NFDIFLW	1.3600
	(5.4078)
$S_t = 2$: Ordinary	
ξ_0	1.3450
	(2.2511)
LogL	-3327.8
AIC	28.2756
SIC	28.8154
HQ	28.4932

Note: Standard error in parenthesis. Highlighted coefficient estimates are significant at the 10% level.. $i = \{1,2,3\}$, $j = \{2,3\}$, $k = \{3\}$.

Table 13. Transition Probabilities: Thailand

Time	p11	p21	p1
1996M01	0.4869	0.1210	0.6079
1996M02	0.6049	0.1171	0.7220
1996M03	0.7138	0.0442	0.7580
1996M04	0.7531	0.0491	0.8022
1996M05	0.7956	0.0496	0.8452
1996M06	0.8255	0.0209	0.8464
1996M07	0.8275	0.0233	0.8508
1996M08	0.8269	0.0249	0.8518
1996M09	0.8406	0.0292	0.8698
1996M10	0.8653	0.0310	0.8963
1996M11	0.8957	0.0322	0.9278
1996M12	0.9277	0.0314	0.9591
1997M01	0.9591	0.0134	0.9725
1997M02	0.9725	0.0072	0.9797
1997M03	0.9797	0.0062	0.9859
1997M04	0.9859	0.0061	0.9920
1997M05	0.9920	0.0054	0.9973
1997M06	0.9973	0.0014	0.9987
1997M07	0.9987	0.0013	1.0000
1997M08	1.0000	0.0000	1.0000
1997M09	1.0000	0.0000	1.0000
1997M10	1.0000	0.0000	1.0000
1997M11	0.9999	0.0000	0.9999
1997M12	0.9999	0.0001	1.0000
1998M01	1.0000	0.0000	1.0000
1998M02	0.9999	0.0000	0.9999
1998M03	0.9999	0.0000	0.9999
1998M04	0.9999	0.0000	0.9999
1998M05	0.9999	0.0000	1.0000
1998M06	1.0000	0.0000	1.0000
1998M07	1.0000	0.0000	1.0000
1998M08	1.0000	0.0000	1.0000
1998M09	1.0000	0.0000	1.0000
1998M10	1.0000	0.0000	1.0000
1998M11	1.0000	0.0000	1.0000
1998M12	1.0000	0.0000	1.0000
1999M01	0.9999	0.0000	0.9999
1999M02	0.9995	0.0000	0.9995
1999M03	0.9980	0.0001	0.9981
1999M04	0.9942	0.0003	0.9945
1999M05	0.9927	0.0011	0.9938
1999M06	0.9925	0.0016	0.9941

Figure 17. Transition Probabilities: Thailand

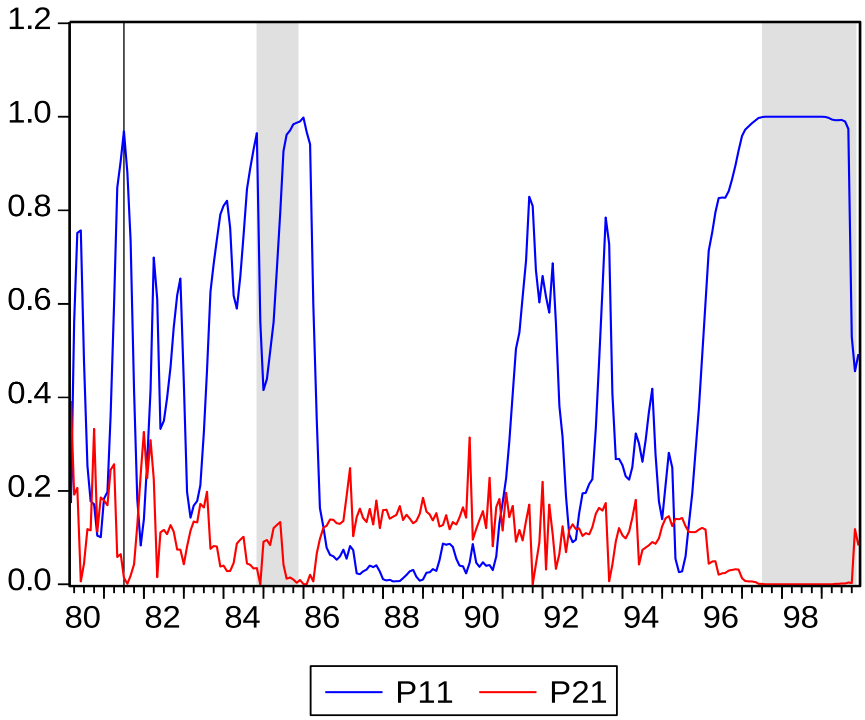


Figure 18. Probability of Crisis $P\left(S_t = 1 \middle| \Im_{t-1}\right)$**: Thailand**

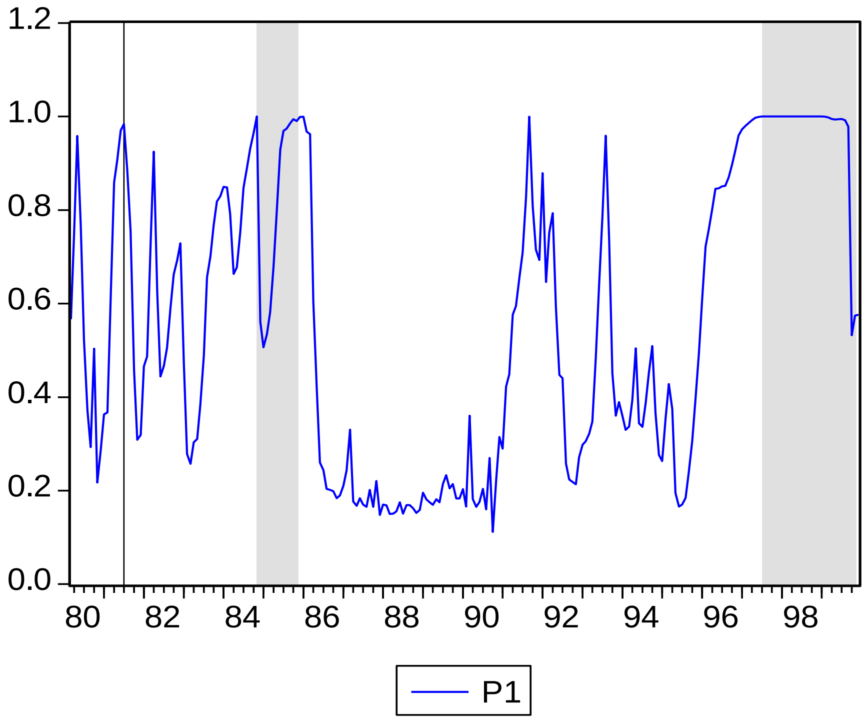


Figure 19. Index of Speculative Pressure: Thailand

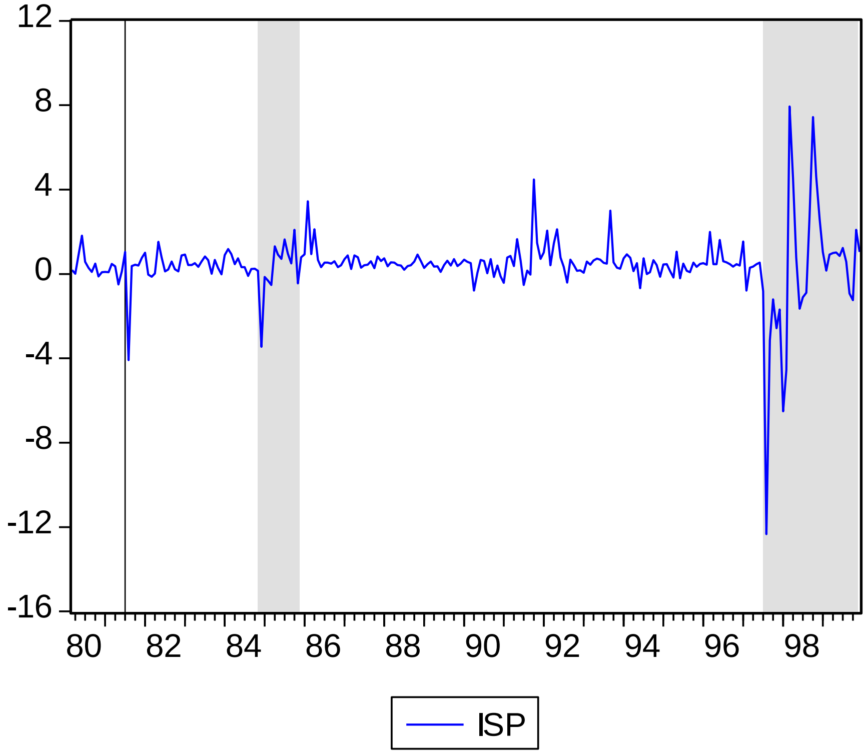
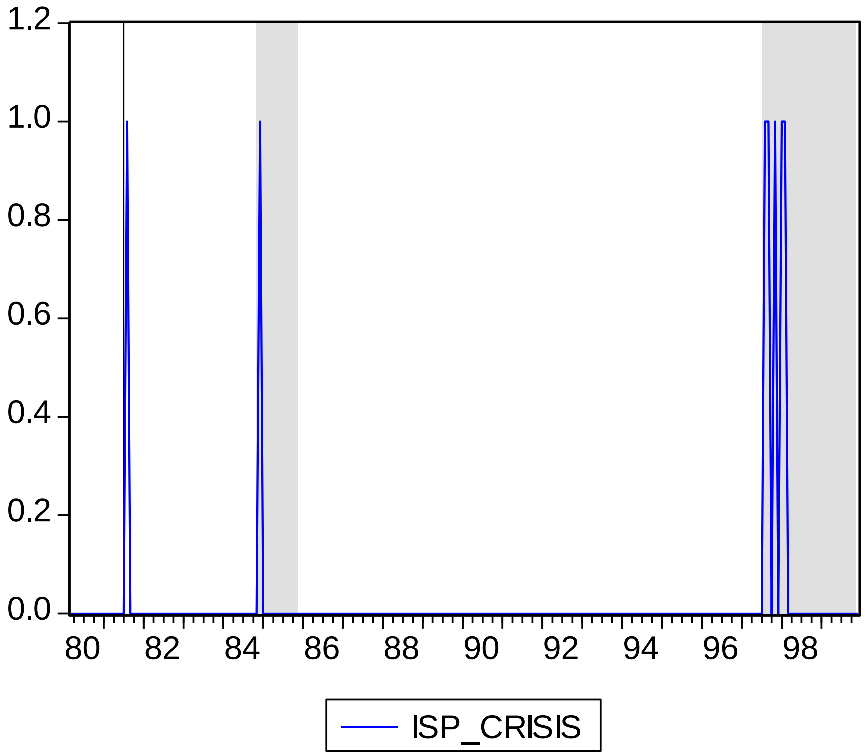


Figure 20. Probability of Crisis $P\left(ISP_t < \tau \middle| \Im_{t-1}\right)$**: Thailand**



4.7 Comparisons of Markov Switching Models with TVTP

The results for the four countries present evidence that the MSVAR model is more sensitive to information and thus gives stronger early warning signals of a currency crisis. Table 14 shows comparisons of signals of the Asian Financial Crisis among MS models. The results reveal that the MSVAR with TVTP model provides stronger signals at an earlier time, in general, compared to the other MSR with TVTP models.

Table 14. Asian Financial Crisis Signals (>50% or max) Prior to July 1997

Country	MSVAR with TVTP	Abiad (2003) MSR with TVTP	Mariano, Abiad, Gultekin, Shabbir & Tan (2003) MSR with TVTP	Brunetti, Scotti, Mariano & Tan (2008) MSR with TVTP
Indonesia	Nov 1996, 92%	Jun 1997, 45%	Dec 1996, 23%	--
Malaysia	Apr 1997, >50%	Jan 1997, >50%	Jun 1997, 38%	Jun 1997, 25%
Philippines	Feb 1997, >50%	May 1996, >50%	Feb 1997, 13%	Jun 1997, 12%
Thailand	Jan 1996, >50%	Dec 1996, >50%	Jun 1997, 32%	Jun 1997, 82%

V. Conclusion

A common indicator that is critical in modeling periods of speculative pressure using the MSVAR model with TVTP is the REER. It results in a good fit of the TVTP with the currency crisis episodes. The overvaluation of the four ASEAN currencies is one important factor that subjected them to speculative attack prior to the Asian Financial Crisis in 1997-98. There are, however, other currency specific factors that also drive the TVTP. The speculative pressure on rupiah has export growth and financial stability of banks as significant indicators. While the speculative pressure on the ringgit involves overexpansion of domestic credit and a slowing economy. The peso has contraction in exports and inadequacy of FX reserves. And for the baht, inflow of hot money and a slowdown in the economy serve as early warnings of vulnerability.

The use of the MSVAR with TVTP model confirmed a stylized fact that the turbulent regime has a higher volatility than an ordinary regime in all four currencies. This study also demonstrated that the MSVAR with TVTP is highly sensitive to changes in the underlying components of the ISP and thus detects periods of speculative pressure that are not necessarily crisis episodes as in the case of Indonesia and Thailand. Furthermore, the MSVAR with TVTP improved on the univariate MSR with TVTP models on predicting the Asian Financial Crisis by giving earlier and stronger signals of a currency crisis. Finally, the comparison of the two approaches of extracting information from an MSVAR with TVTP on predicting a currency crisis favors the use of the probability of a crisis based on the transition probabilities instead of a crisis identified by the expected ISP when it exceeds its threshold.

There are several areas of future research that can be explored from this MS approach to EWS. First of which is an extension of the MSR-GARCH with TVTP model of Brunetti, Scotti, Mariano & Tan (2008) to an MSVAR-GARCH with TVTP to account for heteroskedasticity between regimes. Another extension would be to model an MSVAR with TVTP of the ISP of Asian Financial Crisis countries to measure the effect of contagion.

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