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Application of Fuzzy Optimization and Time Series for Early Warning System in Predicting Currency Crisis

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ABSTRACT

Application of early warning system (EWS) in predicting crisis has drawn a lot of research interests in earlier literature. Recent studies have shown that the development of new EWS models from different field such as artificial intelligence or expert system achieved better prediction than the old statistical model. This paper analyzes the predictability of new methods for EWS which is the combination of time series and fuzzy optimization models. The method used analytic hierarchy process (AHP) to get weights of indicators and ARIMA to forecast the individual indicator and finally by using fuzzy optimization theory to compute the general risk-based relative membership grade. Furthermore, to evaluate the prediction accuracy of our model, we do a comparison of its performance with logistic regression analysis (Logit). According to the results, this model was able to signal currency crisis for four countries only out of ten countries and we concluded that the forecasting power of this model was found to be rather poor. The results emphasized the view that developing a stable model that can predict currency crisis accurately is a challenging task.

Keywords: Fuzzy optimization, time series, early warning system, currency crisis, analytic hierarchy process.

1. INTRODUCTION

Currency crisis is a recurrent phenomenon and sometimes contagious. The first episode of the currency crisis was back in 1992 where United Kingdom had their exchange-rate mechanism (ERM) crisis which also known as Black Wednesday. The next episode was the large-scale crisis that happened in Mexico once peso folded at the tip of 1994. The previous episodes solely gave impact on a region; while the later crisis episodes gave impact to the complete world economy. The episodes of crisis continued in 1997 where it had begun with the violent devaluation of the Thai Baht which then caused the Asian Financial Crisis. Same case applied to Russia in 1998, Brazil in early 1999 and finally in the 2001, the outbreak of the Argentinean financial crisis. Before the crisis, most of these countries had stable economies, for example the economies of East Asia had been one in all the foremost roaring rising market countries in terms of growth and gains in living standards. However, the success story was not last long when the crisis attacked and it's then contagious to the neighboring countries.

The past crises left lessons for both economists and academic researchers that we need a tool to deal with the probability of any occurrence crises in the future like an early warning system. An early warning is a system that indicates an alarm whenever a measurement exceeds the threshold. The applications of EWS in preventing economics, financial or currency crises are quite behind to be compared with others such as natural disasters, the spread of diseases and even in business. The first EWS in currency crisis was proposed by Kaminsky *et al.* (1998) using a signal approach. In their study, they took 15 macroeconomic variables as the indicators and come to conclusion that two of the most important variables that have proven useful in predicting currency crisis are international reserves and real effective exchange rate.

Berg and Patillo (1999) compare this signaling method to a panel probit model. Probit model was first used by Frankel and Rose (1996) in their study to approximate the probability of crisis. However, for the out-of-sample forecasting results in some recent study that had been done by Chowdhry (2000) were quite not up to scratch for most of the existing theoretical models particularly for the Asian crisis case. Therefore, a multinomial logit model was proposed by Bussiere and Fratzscher (2006), whereas others such as Abiad (2003) and Martinez-Peria (2002) proposed Markov-switching models; Fratzscher (2003) and Kim *et al.* (2004) proposed artificial neural network; and Lei *et al*. (2006) proposed genetic algorithm.

The purpose of this paper is to test whether the new method from combination of time series models and fuzzy optimization can predict better currency crisis than previous model that had been used before such as logit model. This paper is systematized as follows: Section 2 presents our new evaluation framework. Every single method that will be used in developing our early warning system is explained here. The results of the analysis based on 10 countries data are reported in Section 3. Also, we will have our comparison with the logit method in the same section and finally, conclusion about this paper in Section 4.

2. MATERIALS AND METHODS

In designing EWS for any crisis, we must know its requirements. To design EWS for currency crisis, firstly we need to define the crisis definition. Then, we need to know a set of possible explanatory variables which also known as indicators, and finally a statistical and others fitting methodology to generate warnings of crises. Before we introduce our overall framework, currency crisis needs to be defined. In the theoretical literature, currency crisis identified as an official devaluation or revaluation, or a flotation of the currency. In other words, currency crisis happens when there is a rapidly changing of the value of a currency because of speculative attack on the foreign exchange market. In this paper, currency crisis is defined by using Girton and Roper (1977) concept of exchange market pressure. This will be explained more detail in section 3.

For the last part which is a statistical and others fitting methodology, as mentioned earlier in this paper the two methods that will be used are fuzzy optimization and time series. The first step in developing our early warning system is choosing suitable indicators. Amongst all variables, real effective exchange rate (REER) which is a gauge of a country's export competitiveness in the world market seems to play a very significant role. Since REER might be useful to predict future currency crisis, it will be chosen as one of our variables. For the other variables like stock index, it is also important to notice its role. Even stock index is not a determinant whether its collapse affects currency crises, but there are some opinions about its regularities pattern movement may give effect to currency crises. The other three variables which are export, national output (GDP) and international reserves are chosen since these macroeconomic variables play quite a significant role as individual leading indicators based on Kaminsky *et*

al. (1998) findings. From their results of the study, they found these indicator issues at least one signal 24 months prior to a crisis.

2.1 Analytic Hierarchy Process (AHP)

There are lots of tools in solving decision-making problems. One of them is the analytic hierarchy process (AHP) which is a mathematical decision-making tool. It is broadly used and has fruitfully been applied to several practical decision-making problems. This tool allows any case of decision-making either qualitative or quantitative and it works by generating the results after reducing complex decisions to a series of one-on-one comparisons. The mathematical thinking behind the process is based on simple linear algebra. There are three parts of the process in AHP which: (i) identify and categorize decision's aims, decisive factors, limitation and options into a hierarchy, (ii) evaluate pairwise comparisons between factor, and finally (ii) synthesize by using the solution algorithm of the results of the comparisons over all the levels. The results give the comparative importance of alternative courses of action.

Pairwise comparisons are fundamental in the use of the AHP. The elements at a given level are compared on a pairwise basis. A scale of 1 to 9 is utilized as in Table 1 to generate a pairwise comparison matrix. For a matrix of order s, the number of elements being compared is $s*(s-1)/2$. The matrix eigenvalue approaches to pairwise comparisons provides a way for the determination of the priorities of the elements.

TABLE 1: The basic scale

Value (intensity of importance)	Definition (description of comparison)
1	Equal importance
3	Moderate importance of one over another
5	Essential or strong importance
7	Very strong importance
9	Extreme importance

Note: Intermediate values (2, 4, 6, 8) are allowed, when compromise is needed. Zero (0) is not allowed.

2.2 Forecasting using Time Series Models

There are lots of models in the time series including linear, nonlinear, univariate and multivariate, but to forecast the individual indicator in this paper we use autoregressive integrated moving average (ARIMA) models. Before getting on the cycle, the first step to take is to examine the time plot of

the data and to judge whether it is stationary or not. Lots of time series are nonstationary and ARIMA model supports the type of nonstationarity by simple differencing. In fact, one or two levels of differencing are frequently enough to reduce a time series.

The three parameters in the ARIMA model are d (the number of differencing), p (the number of autoregressive) and q (the number of moving average). A general model of ARIMA is written in the form

$$x_t = A + \varphi_1 x_{t-1} + \varphi_2 x_{t-2} + \ldots + \varphi_p x_{t-p} + b_t - \theta_1 b_{t-1} - \theta_2 b_{t-2} - \ldots - \theta_q b_{t-q} \qquad (1)$$

where t is the periodic time, x_t is the numerical value of an observation, φ_i for $i = 1, 2, \ldots, p$ are the autoregressive parameters, θ_j for $j = 1, 2, \ldots, q$ are the moving average parameters and b_t is the shock element at time t.

In this paper, the following procedures will be used to model an ARIMA: (i) Conduct Dickey-Fuller tests to get the suitable degree of differencing by repeat the test until the result appears to be stationary; (ii) Eliminate any nonzero mean; (iii) Use the approximation of ACF and PACF of the differenced zero mean time series to determine p and q; (iv) Approximate the coefficients $\varphi_1, \ldots, \varphi_p, \theta_1, \ldots, \theta_q$ by using maximum likelihood estimation (MLE); and finally (v) Produce future forecast for the individual indicators in 2010 and 2011.

2.3 Fuzzy Optimization

Fuzzy Optimization is a method that optimizes problem with the fuzzy objective function or constraints. But in this paper, it will be modeled to predict the occurrence of currency crisis. Since we only take 5 early warning indicators to predict the crisis, therefore the data matrix:

$$\begin{bmatrix} Y_{11} & Y_{12} \ldots & Y_{1m} \\ \vdots & \vdots \cdots & \vdots \\ Y_{51} & Y_{52} \ldots & Y_{5m} \end{bmatrix} = (Y_{ij}) \qquad (2)$$

where m is the number of cross-section observation sets and Y_{ij} is the value of the ith indicator at the jth time period, i=1,2,3,4,5; j=1,2,…,m. Then, the formula below is applied in determining its relative membership grade, u_{ij}. For indicators that are positively related to crisis:

$$u_{ij} = \frac{Y_{ij} - \min(Y_i)}{\max(Y_i) - \min(Y_i)}, i = 1, 2, ..., 5 \tag{3}$$

On the contrary, the subsequent formula will be used:

$$u_{ij} = \frac{\max(Y_i) - Y_{ij}}{\max(Y_i) - \min(Y_i)}, i = 1, 2, ..., 5 \tag{4}$$

Using the equation (3) and (4), the data matrix (Y_{ij}) will be transformed into the subsequent matrix, relative membership grade (U_{ij}):

$$U = \begin{bmatrix} u_{11} & u_{12}... & u_{1m} \\ \vdots & \vdots\cdots & \vdots \\ u_{51} & u_{52}... & u_{5m} \end{bmatrix} \tag{5}$$

where $0 \leq u_{ij} \leq 1$, $i = 1,2,..,5$, $j = 1,2,..,m$.

The largest and the smallest risk-based relative membership grade indicate as $f = (f_1, f_2,\ldots,f_5)' = (1,1,\ldots,1)'$ and $a=(a_1,a_2,\ldots,a_5)'= (0,0,\ldots,0)'$, respectively. By using fuzzy optimization theory, the general risk-based relative membership grade at time j will be analyzed as below:

$$r_j = \frac{1}{1 + \left(\frac{\sum_{i=1}^{n} | w_i (f_i - u_{ij}) |^2}{\sum_{i=1}^{n} | w_i (a_i - u_{ij}) |^2} \right)} \tag{6}$$

where $j = 1,2,..,n$ and r_j is the relative degree of assessment risk and w_i is the weight for the ith indicator. The higher the value of r_j, then the higher the chances for currency crisis

3. RESULTS AND DISCUSSION

3.1 Weights of Indicators

From previous studies conducted by *Kaminsky et al.* (1998) on leading indicators of currency crisis, they found out that some macroeconomic variables like national output (GDP), exports, real effective exchange rate (REER), stock index and international reserves are effective as individual

leading indicators as well. In this paper, we use these variables in predicting the currency crisis. Before applying fuzzy optimization on the quarterly data from 1996-2009 that we collected via DataStream, we need to find weight for each indicator. Weights for indicators are assigned based on their role in affecting currency crisis: REER > Exports > International reserves > Stock index > National output. To obtain weight for each indicator, we employ the Analytic Hierarchy Process (AHP) and the result is as in the Table 2;

TABLE 2: The weight value of individual indicator

Indicators	Weight
Real effective exchange rate	0.306
Exports	0.225
International reserves	0.225
Stock index	0.204
National output(GDP)	0.040

3.2 Forecasting using ARIMA Models

Previously, we had explained about the procedure in order to perform forecasting using ARIMA (p,d,q) models. After forecasting the value for 2010 and 2011 of each indicator, we use equations (3) and (4) to obtain its relative membership grade. By using SAS software, we obtain the best possible ARIMA (p,d,q) models and its forecasting results for every indicator will be included in our data analysis as eight quarters ahead forecasts.

3.3 Risk Assessments by using Fuzzy Optimization

We allocate those five indicators in one particular quarter to a group and hence we have 56 sets of indicators between 1996 and 2009 and 8 sets for 2010 and 2011 from the forecasting results that we get by ARIMA analysis. Subsequently, we obtain the matrix of optimal relative membership grade by using equation (6) by Microsoft Excel. Results from the computational are plotted as in the Figure 1 together with logit results to show the comparison.

As we can see from the graph, our model can detect currency crisis almost accurately for Indonesia and Malaysia only. While for other countries like Argentina and Thailand, the signal is still can be seen even it detects quite late after the crisis occurred. For the rest of our sample countries, the signal detection is somehow bad where it gives wrong signal and detect crisis before the actual crisis happened.

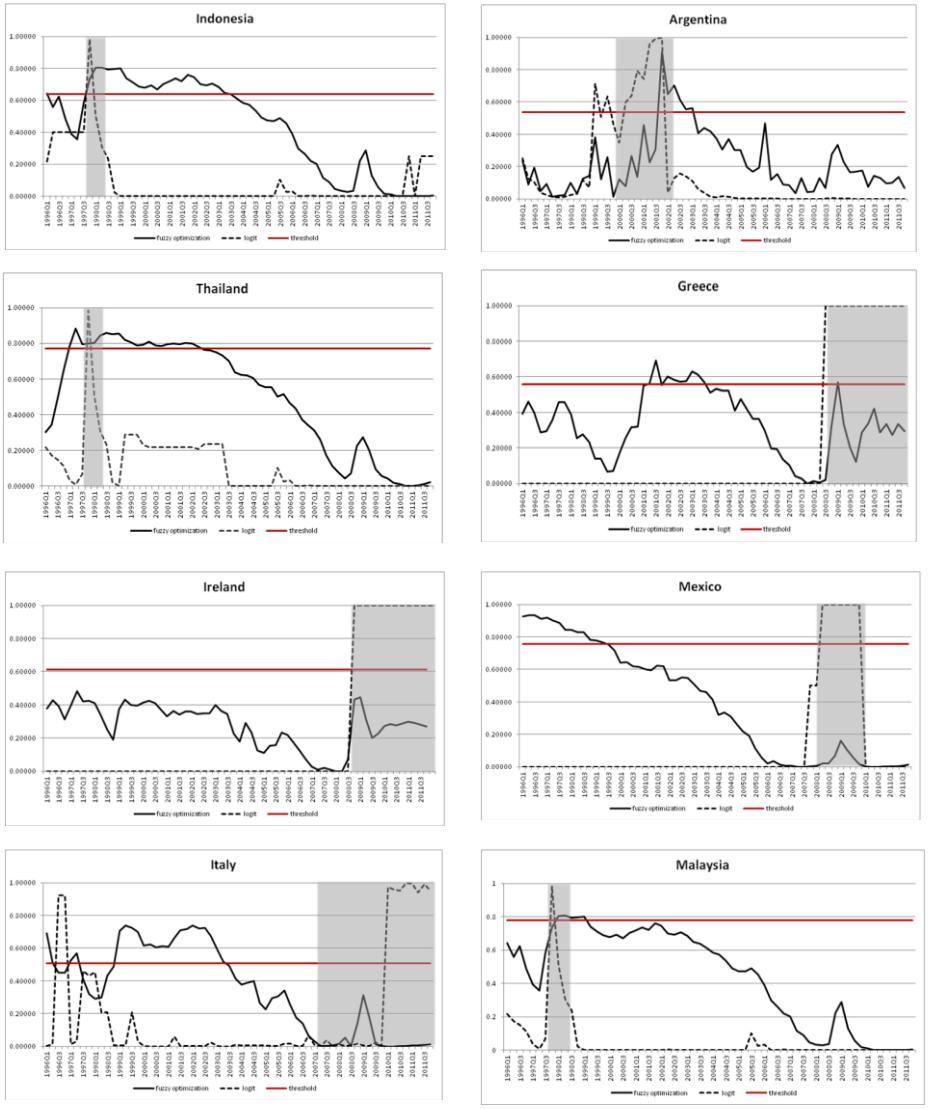

Figure 1: Predicted probabilities

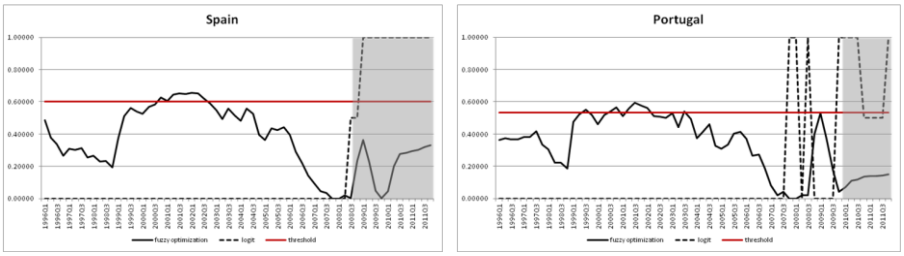

Figure 1(continued): Predicted probabilities

3.4 Comparison with the Existing Methods in Previous Research

It is not an easy task to do the comparison between new methods with existing empirical studies on the currency crisis prediction. Mostly, from previous researches, the ability of models to predict the currency crisis was evaluated using predicted probabilities plot for the countries. It is almost impossible to find any of previous studies that using the forecast error as a method of comparison. In this paper, we will plot the predicted probabilities and use its results to compare with logit model in predicting the crises.

Firstly, the currency crisis is defined using exchange market pressure (EMP) variable which for each country *i* and period *t*:

$$\mathrm{EMP}_{i,t} = \frac{\mathrm{REER}_{i,t} - \mathrm{REER}_{i,t-1}}{\mathrm{REER}_{i,t-1}} - \left(\frac{\sigma_{\mathrm{REER}}}{\sigma_{\mathrm{res}}}\right)\frac{\mathrm{res}_{i,t} - \mathrm{res}_{i,t-1}}{\mathrm{res}_{i,t-1}} \quad (7)$$

$\mathrm{EMP}_{i,t}$ consists of change in real effective exchange rate (REER) and international reserves (res). Meanwhile, the weight used is ratio of standard deviation of REER to standard deviation of res. The benefit of using EMP measure is that it can confine both successful and unsuccessful speculative attacks. Then, currency crisis ($\mathrm{CC}_{i,t}$) is defined as the episode when the $\mathrm{EMP}_{i,t}$ variable is three standard deviations (σ) or more above its threshold;

$$\mathrm{CC}_{i,t} = \begin{cases} 1, \mathrm{if} \mathrm{EMP}_{i,t} > \mu + 3\sigma \\ 0, \mathrm{if otherwise} \end{cases} \quad (8)$$

The basic of the logit model is presented as

$$Y = \begin{cases} 1 \text{with probability} \Pr(Y=1) = P \\ 0 \text{with probability} \Pr(Y=0) = 1-P \end{cases} \tag{9}$$

where Y is the binary dependent variable. In logit model, the probability of a crisis is a non-linear function of the indicators:

$$\Pr(Y=1) = F(X\beta) \tag{10}$$

where X is a vector of explanatory variables and β is a vector of parameters. If Y=1 when a crisis occurs and Y=0 on the contrary, then the probabilities that a crisis occurs is;

$$\Pr(Y=1) = F(X\beta) = \frac{e^{X\beta}}{1+e^{X\beta}}, \mathrm{P}(Y=0) = \frac{1}{1+e^{X\beta}} \tag{11}$$

Table 3 indicates the performance of the logit model and Table 4 is the same measures for our model. From the table, we can see the percentage of observations and crisis correctly called, the percentage of false alarm and other relevant ratios for every country.

TABLE 3: Performance of logit model

Country	% of observations correctly called	% of crises correctly called	% of false alarms	% probabilities of crisis given an alarm	% probabilities of crisis given no alarm
Indonesia	79	98	52	7	25
Malaysia	79	100	44	0	25
Thailand	62	65	57	47	32
Argentina	91	94	70	30	6
Greece	100	100	100	0	0
Ireland	100	100	100	0	0
Spain	100	100	100	0	0
Portugal	100	100	100	0	0
Mexico	100	100	100	0	0
Italy	100	100	100	0	0

TABLE 4: Performance of model that used in this study

Country	% of observations correctly called	% of crises correctly called	% of false alarms	% probabilities of crisis given an alarm	% probabilities of crisis given no alarm
Indonesia	63	97	8	33	38
Malaysia	91	97	20	67	7
Thailand	70	100	14	0	31
Argentina	81	86	33	80	7
Greece	66	76	10	93	18
Ireland	78	78	0	100	0
Spain	66	75	0	100	16
Portugal	75	86	0	100	14
Mexico	66	84	0	100	25
Italy	38	55	0	100	45

Finally, the probabilities of the logit model are plotted for every county in the same graph with fuzzy optimization results. Figure 1 in Appendix A show estimates of eight-quarters-ahead crisis probabilities. Probabilities are plotted for the year 1996 until 2012 where the solid line represents the crisis probability based on our model which is the combination of fuzzy optimization and time series models using the entire data set, meanwhile the dotted line shows probabilities plots based on logit model. From the graph, logit model gives more accurate signal for a currency crisis than our model.

4. CONCLUSION

In order to avoid unprepared turmoil and shocking economic spoil due to any crisis, more researches involving developing an early warning system from new method should be done. Like in this paper, we have constructed an early warning system by using fuzzy optimization for assessing various currency crisis risks and ARIMA models to forecast individual EWS indicators. By using quarterly data from 1996 to 2009 on five leading indicators of currency crisis, we found that the results from a combination of ARIMA and fuzzy optimization models are quite poor especially in predicting future crises.

It is probably due to fewer indicators included in our analysis and lack of historical data. These results maybe can be improved if more macroeconomic variables included in the analysis and also if the data is analyzed by out-of-sample and in-sample. To conclude, this study emphasizes that developing a stable model that can predict currency crisis accurately is a challenging task.

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