



## MODELLING AN EARLY WARNING SYSTEM FOR CURRENCY CRISES: A DYNAMIC PANEL PROBIT MODEL

DOI: 10.17261/Pressacademia.2019.1125

JBEF-V.8-ISS.3-2019(5)-p.181-187

### Gulden Poyraz

Istanbul University, Department of Economics, Beyazit 34452, Istanbul, Turkey.

[poyrazgulden06@gmail.com](mailto:poyrazgulden06@gmail.com), ORCID: 0000-0002-8324-6270

Date Received: June 19, 2019

Date Accepted: September 18, 2019

### To cite this document

Poyraz, G., (2019). Modelling an early warning system for currency crises: a dynamic panel probit model. Journal of Business, Economics and Finance (JBEF), V.8(3), p.181-187

Permament link to this document: <http://doi.org/10.17261/Pressacademia.2019.1125>

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### ABSTRACT

**Purpose-** The probability of currency crisis is attempted to be predicted by analysing the lagged binary crisis variable and some macroeconomic indicators.

**Methodology-** A new generation of early warning system model is developed in order to determine the leading indicators of the financial crises of 17 developing countries and the dynamic structure of the crises are examined by using the dynamic random effects probit model.

**Findings-** The results show that the 12th ( $C_{1t-12}$ ), 3rd ( $C_{1t-3}$ ), 2nd ( $C_{1t-2}$ ) and 1st ( $C_{1t-1}$ ) lags of the dependent variable have a statistically significant effect in explaining the probability of the currency crisis.

**Conclusion-** The results of the model show that *true* state dependence has a significant effect on the probability of currency crises in the short term. This clearly indicates that sources of endogenous persistence of crises should be taken into account in order to improve a new generation of EWS on the predictability of currency crisis.

**Keywords:** Currency crises, dynamic panel probit models, early warning systems (EWS), developing countries, state dependence.

**JEL Codes:** E44, C25, C23

## 1. INTRODUCTION

Despite noticeable progress in the literature on early warning system (EWS) in past years, the recent financial crisis has revived the interest in the EWS literature among researchers and politicians. An EWS consists of the quantitative definition of crisis and a set of variables that may help predict crises and an econometric method to obtain an early warning signal from those variables. Different models have followed different approaches to address a number of conceptual and practical issues that arise concerning both the quantitative definition of crisis and the modelling of the method to predict a crisis. The most important issues in the design of an early warning system are the quantitative definition of the crisis, the methodology to be applied, the scope of the country, the time dimension and the choice of explanatory variables (Berg et.al., 1999, p. 10). The model of an EWS defines a link function relating leading indicators to the occurrence of currency crises. One of the first EWS is proposed by Kaminsky et. al. (1998) and relies on a signalling approach. This is a pioneering paper both for the study of the determinants of banking and currency crises and for the literature on EWS for financial crises. In the EWS literature, another most preferred approach to empirical studies on currency crises are the discrete-choice EWS models (logit/probit). Most previous empirical studies using discrete choice models (see, Eichengreen, Rose and Wyplosz 1996, Frankel and Rose 1996) have used probit models. Later, Berg and Pattillo (1999) compared the forecast performance of the probit model with the signals approach and found that the probit model has exhibited superior performance in that forecasting the currency crisis. These studies paved the way for a large number of papers examining the determinants of currency crises. Kumar et.al. (2003) propose logit models instead of the probit model. Bussiere and Fratzscher (2006) propose a multinomial logit model to account for post-crisis bias. In spite of important differences between each other, most existing models share a noticeable characteristic. They are static models, *i.e.* these models assume that the crisis probability

depends on a set of macroeconomic and financial variables representing the applied economic policies. Contrary to previous studies that have used static logit/probit models, this study examined the dynamic structure of currency crises *i.e.* the intertemporal linkages between crises. For this purpose, it is used a new generation of EWS that combines the discrete-choice character of the crisis indicator and the dynamic dimension of this phenomenon. More precisely, in the study, examined not only the exogenous source of crisis persistence, *i.e.* explanatory variables but also sources of endogenous persistence of crises. Candelon et.al. (2014) and Dumitrescu (2012) indicate that endogenous dynamic of crises can be captured in three different ways. The first dynamic model includes the only lagged dependent variable ( $y_{it-1}$ ). The second dynamic model includes the only lagged index ( $EMPI_{it-1}$ ). Finally, the dynamic model includes both the lagged dependent variable ( $y_{it-1}$ ) and the lagged index ( $EMPI_{it-1}$ ). They estimate three models that address the endogenous dynamics of crises. As a result, they indicate that the dynamic model including the lagged dependent variable outperforms the other specifications. Hence in the study, following Candelon et.al. (2014) and Dumitrescu (2012), is used as a dynamic model including the lagged dependent variable. By inclusion of the lagged dependent variable on the model, assess the impact of the regime prevailing in the previous period on the crisis probability. The study is also investigated whether the endogenous dynamics of currency crises, (unobserved) country-specific factors or true state dependence. The results of the model show that *true* state dependence has a significant effect on the probability of currency crises in the short term.

The rest of the paper is organized as follows: section 2 describe the dataset, the definition of currency crises and the methodology, while the findings and discussions are presented in section 3, and finally conclusion on final part.

## 2. DATA AND METHODOLOGY

### 2.1. The Data

The first issue in the modelling of an EWS relates to defining the scope of the model and time dimensions. The study covers the period 1991- 2017 for 17 developing countries.<sup>1</sup> The countries included in the study consist of 5 different regions: Latin America, Asia, Eastern Europe, Middle East, and Africa. The explanatory variables which constitute another issue of the EWS, are selected from 4 economic sectors.

1.External Sector: Real effective rate overvaluation, import growth, export growth, current account balance as a percentage of nominal GDP, the growth rate of international reserves.

2.Financial Sector: M1 growth rate, the growth rate of domestic credit to GDP, the ratio of M2 to international reserves (level), the growth rate of M2 to international reserves.

3.Real Sector: Industrial production index

4.Global Sector: US interest rate and US inflation rate

Except for real effective rate overvaluation, US interest rate, current account balance as a percentage of nominal GDP and the ratio of M2 to international reserves (level), all other variables are defined as the annual percentage change.

While annual and quarterly data can give access to a larger set of variables, countries and time periods, monthly data is preferred to be able to capture the sudden nature of the money market. The data of these variables are obtained from the database Datastream, BIS and IMF-IFS. These variables are transformed into a monthly frequency by using the Chow and Lin interpolation method since the variables of GDP and current account balance are observed at a quarterly frequency. REER overvaluation is defined as a deviation of the real effective exchange rate from a linear trend. The measure of overvaluation of REER is calculated using the Hodrick-Prescott filter method.

### 2.2. Currency Crisis Definition

The most common method of identifying currency crisis periods implies the computation of an exchange market pressure index (EMPI). A modified version of the EMP index as suggested by Kaminsky et. al. (1998) and Kaminsky and Reinhart (1999), which

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<sup>1</sup>Argentina, Brazil, Chile, Colombia, Czech Republic, Indonesia, Malaysia, Mexico, Peru, Philippines, Poland, South Africa, South Korea, Israel, Turkey, Thailand and Venezuela.

captures both successful and unsuccessful speculative attacks on the domestic currency is used in this chapter. Accordingly, the pressure on the domestic currency of country  $i$  at time period  $t$  is measured as:

$$EMP_t^i = \omega_e \left( \frac{e_t^i - e_{t-1}^i}{e_{t-1}^i} \right) + \omega_r (r_t^i - r_{t-1}^i) - \omega_{res} \left( \frac{res_t^i - res_{t-1}^i}{res_{t-1}^i} \right) \quad (1)$$

The  $EMP_t^i$  index is defined as the weighted average of the relative changes in the real exchange rate ( $e_t^i$ ), domestic interest rate ( $r_t^i$ ), and international reserves ( $res_t^i$ ). The weights assigned to three component, denoted by  $\omega$  are calculated as the inverse of their standard deviations over the in sample period, in a manner that gives a larger weight to the variable with lower volatility. In this paper, nominal interest rates are used instead of real interest rates, following Hagen and Ho (2003), because nominal interest rates are those the monetary authorities can directly control in order to prevent speculative attacks (Hagen and Ho, 2003). In addition, real exchange rate is used instead of the nominal exchange rate, so that nominal depreciation resulting from inflation differentials should not be considered as currency crises.

Next step, the specific crisis events in the country  $i$  at time  $t$  ( $C1_{i,t}$ ) are identified when its EMP index crosses a certain threshold level. This threshold is calculated as the sum between the mean of the EMP index ( $\mu EMP_{i,t}$ ) and the product between a coefficient 2 and the standard deviation of the EMP index ( $\sigma EMP_{i,t}$ ). The threshold equals two standard deviations above the mean. Accordingly,  $C1_{i,t}$  can be defined as:

$$C1_{i,t} = \begin{cases} 1, & \text{If } EMP_{i,t} > 2\sigma EMP_{i,t} + \mu EMP_{i,t} \\ 0, & \text{Otherwise} \end{cases} \quad (2)$$

### 2.3. METHODOLOGY

A dynamic probit unobserved-effects model for the dependent variable  $y_{it}$  for individual  $i$  ( $i = 1, \dots, N$ ) at time period  $t$  can be written as:

$$y_{it}^* = \gamma Z_{it} + \rho y_{it-1} + c_i + u_{it}, \quad u_{it} \sim N(0,1). \quad (3)$$

$$y_{it} = 1(y_{it}^* > 0) \quad (4)$$

The latent outcome variable  $y_{it}^*$  in equation (3) expresses the chances of experiencing a particular status for unit  $i$  ( $i = 1, \dots, N$ ) at time  $t$  as a function of a set of time-varying explanatory variables  $Z_{it}$  that are considered strictly exogenous, conditional on the unit-specific unobserved effect  $c_i$ .  $y_{it-1}$  captures (*true*) state dependence, while  $u_{it}$  is an error term. In the model, it is assumed that  $c_i$  is normally distributed and sometimes that is independent of all  $Z_{it}$ . Based on Rabe-Hesketh and Skrondal (2013), the unit-specific unobserved effect  $c_i$  can be written as follows:

$$c_i = \alpha_0 + \alpha_1 y_{i0} + \alpha_2 \bar{Z}_i + \alpha_3 Z_{i0} + \alpha_i \quad (5)$$

In this equation,  $y_{i0}$  and  $Z_{i0}$  represent the initial value of the dependent variable and of the time-varying explanatory variables respectively.  $\bar{Z}_i = \frac{1}{T} \sum_{t=0}^T Z_{it}$ , stands for the within-unit averages of the explanatory variables where the averages are based on all periods  $t = 0, \dots, T$ . Finally,  $\alpha_i$  is a unit specific time-constant error term, normally distributed with mean 0 and variance  $\sigma_{\alpha}^2$ . Holding the assumption that unobserved heterogeneity is captured by  $c_i$ , the lagged dependent variable can be interpreted as *true* state dependence. In terms of this study, *true* state dependence can be interpreted as the probability that a crisis occurred in period  $t$  affecting the emergence of another crisis in period  $t+1$ . The dynamic model in Equation (3) is estimated as a standard Random Effects (RE) probit.

### 3. FINDINGS AND DISCUSSIONS

In this section reports the results of the estimation by dynamic probit model binary dependent variable specified in equation (2) and a set of exogenous macroeconomic variables. Since a nonlinear method is used in this paper, it is difficult to interpret the coefficients. Although the respective sign shows the direction of the impact exerted by the independent variable on the dependent variable, the parameter values themselves do not allow a conclusion to be made regarding the strength of the relationship.

According to the model I estimation results, the growth of international reserves is affected the probability of occurrence of currency crises. The estimated coefficient is statistically significant at the 1% level and has a negative sign. This confirms the economic theory, which indicates that the growth of international reserves is decreased in the probability of the occurrence of currency crises. Similarly, the probability of occurrence of currency crisis is supposed to escalate if an expansion of the ratio of M2 to reserves is noticed in the previous period. In other words, if the growth of the amount of money in circulation overruns the growth of international reserves, the currency is perceived as unstable and therefore, a speculative attack is predictable. Thus, a positive coefficient of the ratio of M2 to reserves is expected. In accordance with these expectations, the estimated coefficient is significant at the 5% level and has a positive sign. However, the M2/reserves growth rate and the M1 growth emerge a result that does not coincide with the economic theory. In addition to this, they have a significant effect on the probability of currency crises at 5% and 10% respectively. Both real effective exchange rate overvaluation and domestic credit /GDP growth rate are significant at the 1% and have a positive sign. The current account balance as a percentage of nominal GDP has the correct sign – a higher current account balance is associated with a decline in crisis incidence – but the coefficient estimates are not significant. Export and import growth, which are the sub-items of the current account, has not an important role in explaining the possibility of currency crises. In particular, this result of the export growth is not consistent with the findings of the study by Kaminsky et. al. (1998), Berg and Pattillo (1999). It is observed that the real GDP growth, which is an indicator of real economic activity, has a significant effect on the probability of currency crisis at a level of 10% and the sign of its coefficient is consistent with expectations. A negative coefficient is considered to be a signal that growth in real GDP decreases the probability of currency crises. In this study, the industrial production index, which is compiled at a monthly frequency, is used to represent the real GDP growth. In the model used two indicators representing the global economy. Developing countries are affected by changes in global macroeconomic conditions. An increase in the level of international interest rates or in the level of deflation across the globe significantly increases the probability of currency crises. US inflation has no significant effect on the probability of currency crises in developing countries. This result does not support the predictions of Moreno and Trehan (2000) and Falcetti and Tudela (2006) who argue that a deflationary shock in the US can have a direct effect on economies that are exporters to the US market. International interest rates reflect the impact on the debt repayment capacity of a country. In the study, US 3 months treasury bill interest rate which serves as the representative international interest rate is used. The estimated coefficient has a significant effect at the 5% level on the probability of currency crises and has a positive sign.

**Table 1: The Results for Dynamic Panel Probit Model - Model I**

<b>Dependent Variable: C1</b>	<b>Coef.</b>	<b>Std. Err.</b>	<b>z</b>	<b>P&gt; z </b>
The Lagged dependent variable (C1 <sub>t-1</sub> )	0.931	0.143	6.49	0.000
M2 / reserves (level) (x2)	0.242	0.107	2.27	0.023
M2 / reserves growth rate(x3)	-0.005	0.002	-2.35	0.019
Real GDP growth rate (x4)	-0.011	0.006	-1.71	0.088
Domestic credit / GDP growth rate (x5)	0.252	0.056	4.47	0.000
M1 growth rate (x6)	-0.111	0.057	-1.93	0.054
REER overvaluation (x7)	0.013	0.005	2.57	0.010
Export growth rate (x8)	0.002	0.002	0.75	0.453
Import growth rate (x9)	0.002	0.002	0.94	0.349
Current account / GDP (x10)	-0.008	0.012	-0.69	0.490
International reserves growth rate (x11)	-0.010	0.002	-3.71	0.000
International interest rate (x12)	0.106	0.044	2.40	0.016
US CPI inflation (x13)	0.025	0.051	0.49	0.624
Constant	-5.057	3.59	-1.41	0.159
Log-likelihood	-453.384			

LR test statistic	73.36
p-value (LR test statistic)	0.0000
Wald chi2 (40)	134.08

Note: Model outputs including the set of unobserved heterogeneity coefficients can be obtained from the author on request. All explanatory variables are lagged by one period unless otherwise specified.

The inclusion of the lagged value of the dependent variable in the model provides to test for the presence of state dependence. The state dependence has obvious policy implications: if a country experienced a crisis in the past, the probability of observing another crisis may likely depend on that previous crisis event. This is due to the fact that, as a result of the crisis experienced in the past, the restrictions or conditions regarding the emergence of another crisis may be changed in the future (Falcetti and Tudela, 2006, p. 446). In this case, past experience has a true behavioral effect, in that an otherwise similar country that did not experience the event would behave differently from the country that experienced the event (*true* state dependence) (Falcetti and Tudela, 2006, p. 454). The state dependence can be explained in an example: The country which X has often experienced crisis and the country that Y which does not experience crises have similar fundamentals. In this example, it is hard to know whether the difference between X and Y is due to unobserved effects that make X more vulnerable than Y, or whether X' s repeated crises are due to the fact that the first crisis rendered this country more vulnerable to future shock. The presence of unobserved effects suggests that results in state dependence should be interpreted with caution (Bussiere, 2007, p. 6). According to Heckman (1981) a *spurious* state dependence may emerge from the fact that in the idiosyncratic effects which may in fact reflect the unobserved individual effects such as country-specific characteristics. Therefore, it is not possible to assess the presence of the true state dependence by including solely the lagged dependent variable ( $y_{it-1}$ ) in the model. State dependence is based on the assumption of no correlation between unobserved heterogeneity and the dependent variable ( $y_{it}$ ) (Heckman, 1981). In a dynamic model, may also occur an issue which called to an initial condition problem in case of which there is a correlation between the initial observation of dependent variable ( $y_{i0}$ ) and unobserved heterogeneity (Grotti and Cutuli, 2018, p. 1). For all the countries which are included in the study, the initial values of the binary dependent variable are ( $t = 0$ ). Therefore, the initial conditions problem for the estimation of a dynamic discrete choice model including the lagged dependent variable does not arise. By conditioning on the initial observation of dependent variable ( $y_{i0}$ ), Wooldridge (2005) models unobserved heterogeneity by including in the model the values of the time-varying explanatory variables at each period excluding the initial period. Other authors such as Stewart (2007) and Biewen (2009) models unobserved heterogeneity through the inclusion of within-unit averages computed on the time-varying explanatory variables. Even if the use of the within-unit averages does not require a balanced panel, such a model specification tend to provide biased estimates (Grotti and Cutuli, 2018). Rabe-Hesketh and Skrondal (2013) are showed that this problem can be solved by including in the model the initial period of the explanatory variables ( $Z_{i0}$ ). Based on the assumption that unobserved heterogeneity is captured by the initial period value of the dependent variable and the initial period and within-unit averages of time-varying explanatory variables, lagged dependent variable can be interpreted as true state dependence. In this context, when the unobserved heterogeneity is corrected by the method proposed by Rabe-Hesketh and Skrondal (2013), the coefficient associated with the lagged dependent variable is statistically significant at the 1 % level and has a positive coefficient. A positive coefficient indicates that when a speculative attack or currency crisis occurs, the probability of observing another speculative attack or currency crisis one month ahead increases. This result can be interpreted as an indicator that prudence must not be weakened after a first crisis has happened. When examined the set of coefficients of the variables capturing unobserved heterogeneity, it is seen that the coefficients do not have a significant effect on the probability of currency crises. To see the effects of working with a dynamic model, Table 2 shows the results performed with the same variables as in Table 1 and including up to 12 lags of the dependent variable (more lags were not significant). The results show that the 12th ( $C1_{t-12}$ ), 3rd( $C1_{t-3}$ ), 2nd( $C1_{t-2}$ ) and 1st ( $C1_{t-1}$ ) lags of the dependent variable have a statistically significant effect in explaining the probability of the currency crisis. The lagged dependent variable enter the specification with a significant and positive sign, especially in the very short term (one and three months). The 12th lag of the dependent variable ( $C1_{t-12}$ ) has a significant impact on the probability of a currency crisis at the %10 level and has a negative sign.<sup>2</sup> A negative coefficient implies that once a crisis has occurred, the probability of observing another crisis 12 months ahead decreases. This can be interpreted as a sign that policymakers are taking action to prevent the crisis from occurring or at least mitigate its impact. To sum up, *true* state dependence has a significant impact on the

<sup>2</sup> In this model estimated by using the lags of the dependent variable from 1 month to 12 months, there is a weak evidence of unobserved heterogeneity. The initial value of the M2/reserves growth rate ( $x3$ ) has a significant impact on the probability of a currency crisis at the 10 % level and has a positive sign. In the study, while 12 months period is short-term, 6 months period is very short-term.

probability of a currency crisis in the short-term. This clearly indicates that sources of endogenous persistence of crises should be taken into account in order to improve a new generation of EWS on the predictability of currency crisis. A similar result is reported by Falcetti and Tudela (2006), Dumitrescu (2012) and Candelon et. al. (2014). When the results are evaluated in term of explanatory variables, it is seen that the growth of M1 has lost its significance in model II where 12 months lag value of the dependent variable is used. While real GDP growth is significant at the 10% level in Model I, it is significant at the 5% level in Model II and has a negative sign. Similarly, the international reserves are significant at the 1% level in Model I, significant at the 5% level in Model II and have a negative sign. Other explanatory variables remain significant on the possibility of a currency crisis.

**Table 2: The Results for Dynamic Panel Probit Model - Model II**

Dependent Variable: C1	Coef.	Std. Err.	z	P> z
C1 <sub>t-1</sub>	0.746	0.151	4.91	0.000
C1 <sub>t-2</sub>	0.693	0.162	4.27	0.000
C1 <sub>t-3</sub>	0.363	0.178	2.04	0.042
C1 <sub>t-4</sub>	0.268	0.187	1.43	0.152
C1 <sub>t-5</sub>	0.281	0.196	1.43	0.151
C1 <sub>t-6</sub>	-0.185	0.240	-0.77	0.441
C1 <sub>t-7</sub>	-0.203	0.254	-0.80	0.425
C1 <sub>t-8</sub>	0.156	0.235	0.67	0.505
C1 <sub>t-9</sub>	-0.060	0.266	-0.23	0.821
C1 <sub>t-10</sub>	-0.400	0.326	-1.23	0.220
C1 <sub>t-11</sub>	-0.116	0.284	-0.41	0.683
C1 <sub>t-12</sub>	-0.763	0.431	-1.77	0.077
M2 / Reserves (level) (x2)	0.264	0.111	2.36	0.018
M2 / Reserves growth rate(x3)	-0.005	0.002	-1.99	0.046
Real GDP growth rate (x4)	-0.014	0.007	-2.03	0.043
Domestic credit / GDP growth rate (x5)	0.203	0.060	3.36	0.001
M1 growth rate (x6)	-0.073	0.061	-1.21	0.228
REER overvaluation (x7)	0.016	0.005	2.77	0.006
Export growth rate (x8)	0.002	0.002	0.81	0.418
Import growth rate (x9)	0.003	0.003	1.04	0.299
Current account / GDP (x10)	-0.017	0.013	-1.32	0.186
International reserves growth rate (x11)	-0.007	0.002	-2.53	0.011
International interest rate (x12)	0.104	0.046	2.27	0.023
US CPI inflation (x13)	0.065	0.055	1.19	0.235
Constant	-3.352	3.405	-0.98	0.325
Log-likelihood	-419.258			
LR test statistic	74.22			
p-value (LR test statistic)	0.0000			
Wald chi2 (40)	167.58			

Note: Model outputs including the set of unobserved heterogeneity coefficients can be obtained from the author on request. All explanatory variables are lagged by one period, unless otherwise specified.

#### 4. CONCLUSION

There are significant differences between the existing models in the literature. In spite of this, most of these models are based on a static specification that does not allow the intertemporal links between crises. In this context, contrary to existing literature that are used static models, currency crises are considered in a dynamic structure. In an econometric model, the dynamic structure of the crisis is captured by including the lagged dependent variable in the model. The inclusion of the lagged value of the dependent variable in the model allows the analysis of the presence of the state dependence. However, the estimation of state dependence is complicated in the presence of unobservable heterogeneity (country-specific factors). Therefore, the role of state dependence and unobserved heterogeneity in the study investigated and it is concluded that the lagged dependent variable (C1<sub>t-1</sub>) can be

interpreted as *true* state dependence. Several lags of the dependent variable are also included in the model to see the effects of working with a dynamic model. In this direction 12th, 3rd and 2nd lags of the dependent variable are found to have a statistically significant effect in explaining the probability of the currency crisis. This result clearly indicates that sources of endogenous persistence of crises should be accounted for in order to improve a new generation for currency crises EWS.

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