Empirics of Currency Crisis

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Abstract

Empirical research is fundamental for an in-depth understanding of currency crises. With this aim, this paper studies currency crises in a simultaneous equation framework, and takes into account unobserved heterogeneity, which is expected in panel data. The results suggests that high risk countries are more susceptible to a currency crisis, and a large depreciation of exchange rate could contribute to a crisis.

1 Introduction

A currency crisis is a period of extreme pressure in the foreign exchange market, during which agents want to move their currency positions out of the affected currency as they perceive it might lose value. These crashes impose high costs on the affected country in terms of a deceleration of economic activity. Several currency crashes during the 1990s suggest that economies are still threatened by these collapses[1]. Therefore, it is important to understand these episodes so that we can outline the causes and adapt policies accordingly.

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[1]Caprio et al. (2005) discuss the possibility of such crashes happening in the future.

This topic has generated considerable interest among economists, which has resulted in a large number of theoretical and empirical papers on the subject. Overall theoretical literature has offered three generations of models to explain the instances of currency crises that occurred in different places at different times. Crises during the 1980s are explained by the 'first generation' model by Krugman (1979). In this model, under a fixed exchange rate regime with limited reserves, the government pursues expansionary polices to finance its budget deficit. This leads to an overvaluation of the exchange rate, which in turn leads to a currency crisis when reserves fall to some critical level.

The second generation model was developed by Obstfeld (1994) to explain the crises in Europe during the mid-nineties. The model argues that a government has a choice whether to defend a pegged exchange rate. The trade-off is between short-run macroeconomic flexibility and longer-term credibility. A crisis arises if investors believe that parity defense will be unsuccessful. This could happen if the cost of defense is high. For example, it might lead to a high domestic interest rate. Therefore, a speculative attack can be launched on the currency either due to predicted future deterioration of country's financial health or through self-fulfilling expectations.

The third generation model was proposed by Krugman (1998) to explain the Asian crisis of 1997. This model is focused on a moral hazard problem in which investors perceive liabilities of some (unregulated) institutions as being backed by a government guarantee, and invest heavily in these institutions. This creates inflation in the prices of financial assets. The overpricing of these financial assets is sustained by a circular process, in which the expansion of risky lending drives up the prices of these risky financial assets, falsely portraying these institutions as financially healthy. The onset of a crisis requires that this circular process is reversed: a fall in the prices of these financial assets brings the insolvency of these institutions to light, putting them out of business, and leading to a further deflation in the prices of these financial assets. From this analysis the question arises as to whether the presence of a lender of last resort helps or hurts. The existence of a lender of last resort facility is desirable if viable economic activities are destroyed by a sudden and unnecessary withdrawal of funds. However, if the presence of a lender of last resort leads to a bubble which ends in crisis, then it would be more beneficial not to have a lender of last resort.

These various theories explain specific historical episodes but do not offer a unified explanation for the occurrence of currency crises. The lack of unified theoretical explanation led economists to conduct empirical investigations to uncover the symptoms and causes of currency crises.

Kaminsky et al. (1998) undertook a univariate exercise in order to develop an *early warning system* to detect whether a country might be slipping into a currency crisis. This method involved monitoring a number of economic variables. If these variables deviate from a *normal* level beyond a certain threshold, then that is considered to be a warning signal for a potential currency crisis. However, such a univariate approach has its limitations: it cannot discriminate between more reliable and less reliable indicators, and it cannot estimate a joint contribution of these variables to the occurrence of a currency crisis.

Considering these limitations, researchers turned to estimation of single equation multivariate probit and/or logit models[2]. In such models, a dummy variable is constructed which takes a value of one when crisis is observed, and zero otherwise. This dummy variable is regressed on various regressors, and statistical inference is conducted. However, these single equation models may suffer from simultaneous equation bias, and as a result their estimation results may be inconsistent. The simultaneity arises because beliefs of agents[3] greatly influence the exchange rate. Specifically, if agents hold adverse beliefs about the prospects of the country's financial health, then they will convert their assets into a safer currency, which would in turn lead to a depreciation of the exchange rate. On the other hand, a substantial

[2]Detragiache et al. (2001), Komulainen (2003) and Falcetti (2006), among others.

[3]Agents are holders of domestic currency denominated assets.

depreciation of the exchange rate will lead to a loss in the value of domestic currency denominated assets, which will make the agents nervous. These two phenomena co-exist, giving rise to simultaneity. This simultaneity has been ignored in the previous empirical literature.

In addition, the previous literature has ignored the unobserved heterogeneity which is expected in panel data. Since no single country has had enough crises to generate a large enough sample that can be used for statistical purpose, all of the empirical studies had to combine the data of various countries over a period of time. This panel structure of the data is subject to time-specific and country-specific heterogeneity, which has been ignored in the previous literature.

This paper addresses both of these issues, namely, simultaneity and unobserved heterogeneity. I consider a two simultaneous equations framework, one equation for the beliefs of the agents and another equation for the nominal exchange rate. In this framework, unobserved time-specific and country-specific heterogeneity is taken into account through a richer error structure.

The paper is organized as follows: Section (2) describes the econometric model, which consists of a system of two simultaneous equations. Section (3) discusses the regressors for each of the equation, which is followed by description of the data in Section (4). The estimation results are presented in Section (5), and Section (6) concludes. Finally, an appendix is provided.

2 Methodology

2.1 System of Equations

Agents form belief b^* about the prospects of a country's financial health based on the macro economic fundamentals. During normal times[4] their beliefs are in a 'comfort zone', while

[4]Normal time is defined as the period without currency crisis.

during troubled times they hold adverse beliefs about the country's financial prospects. The functional form for beliefs of the agents is

$$b_{it}^* = X_{1it}\beta_1 + \delta_1 E_{it} + \mu_i^b + \mu_t^b + \epsilon_{it}^b \tag{1}$$

where b_{it}^* is agent's belief for country i in time period t.

In the above equation X_1 stands for exogenous regressors, β_1 is a vector of coefficients on the exogenous regressors, E is the exchange rate, and δ_1 is the coefficient on the exchange rate. The error structure is as follows: μ_i^b is a country-specific error, μ_t^b is a time-specific error, and ϵ_{it}^b is iid.

If agents hold adverse beliefs about a country's financial health they will withdraw their funds from the country, which would adversely affect the exchange rate (i.e. the exchange rate will depreciate), which makes exchange rate endogenous. The functional form for the nominal exchange rate is

$$E_{it} = X_{2it}\beta_2 + \delta_2 b_{it}^* + \mu_i^E + \mu_t^E + \epsilon_{it}^E \tag{2}$$

where, again, the country index is i and the time index is t.

In the above equation X_2 represents the exogenous regressors, β_2 is the vector of coefficients on exogenous regressors, b^* is belief of the agents and δ_2 is the coefficient on belief. The error structure is as follows: μ_i^E is a country-specific shock affecting the exchange rate, μ_t^E is a time-specific shock affecting the exchange rate, and ϵ_{it}^E is iid.

An econometrician, however, does not observe the actual beliefs of the agents (which is a latent variable), but only observes normal/troubled periods in a country's economy. That is, $b_{it} = 1(b_{it}^* > 0)$ when a crisis occurs, or $b_{it} = 0$ during normal times. Therefore, the system of equations involves a non-linear equation (3) and a linear equation (4).

$$Pr(b_{it} = 1|.) = Pr(X_{1it}\beta_1 + \delta_1 E_{it} + \mu_i^b + \mu_t^b + \epsilon_{it}^b > 0) \tag{3}$$

$$E_{it} = X_{2it}\beta_2 + \delta_2 b_{it}^* + \mu_i^E + \mu_t^E + \epsilon_{it}^E \tag{4}$$

If there were no country-specific and time-specific shocks, then the method described in Maddala (1983; p. 242) could be used to estimate the above system of equations. However, equations (3) and (4) refer to various countries over a period of time, so unobserved time-specific and country-specific heterogeneity is expected. Time-specific heterogeneity may be due to global economic conditions while country-specific heterogeneity may be due to policy-related factors and/or institutional factors within a given country. Therefore, to estimate the above system I need to impose more structure on the errors and modify Maddala's method. I am assuming country-specific errors in the two equations are jointly distributed as bivariate standard normal with correlation coefficient $\rho_{country}$ (i.e., $Correlation(\mu_i^b, \mu_i^E) = \rho_{country}$). A similar assumption is made for time-specific errors; time-specific errors in the two equations are distributed as bivariate standard normal with correlation coefficient ρ_{time} (i.e., $Correlation(\mu_t^b, \mu_t^E) = \rho_{time}$). The optimization will involve selecting $\rho_{country}$ and ρ_{time}, which is discussed in Section (2.4). The estimation will involve integrating the likelihood function with respect to these country-specific and time-specific errors, as detailed in the next sub-section.

2.2 Econometrics

To describe the estimation for expositional purposes let's assume that $\rho_{country}$ and ρ_{time} are known. Also assume that both ϵ^b and ϵ^E are distributed as iid standard normal. Construct $X = \{X_1, X_2\}$. The estimation is in two parts: the first step is to construct instruments for the endogenous variables by regressing each of the endogenous variables on all of the exogenous variables. In the second step, use the predicted values of these endogenous variables as regressors in equations (3) and (4), as detailed below.

2.2.1 First Step

To write the likelihood function for beliefs, some manipulation of the belief equation are necessary

$$Pr(b_{it} = 1|.) = Pr(X_{it}\Pi_1 + \mu_i^b + \mu_t^b + \epsilon_{it}^b > 0) \tag{5}$$

$$Pr(b_{it} = 1|.) = Pr(\epsilon_{it}^b > -X_{it}\Pi_1 - \mu_i^b - \mu_t^b) \tag{6}$$

$$Pr(b_{it} = 1|.) = \Phi(X_{it}\Pi_1 + \mu_i^b + \mu_t^b) \tag{7}$$

$$Pr(b_{it} = 0|.) = 1 - \Phi(X_{it}\Pi_1 + \mu_i^b + \mu_t^b) \tag{8}$$

where Φ is the standard normal distribution function.

In the first step, the likelihood function for beliefs (b) is

$$L_1^b = \int_i \int_t \Pi_{it}(\Phi(X_{it}\Pi_1 + \mu_i^b + \mu_t^b))^{b_{it}}(1 - \Phi(X_{it}\Pi_1 + \mu_i^b + \mu_t^b))^{1-b_{it}} dF(\mu_t^b)dF(\mu_i^b) \tag{9}$$

where $F(\mu_t^b)$ and $F(\mu_i^b)$ are the marginal probability distribution functions of μ_t^b and μ_i^b, respectively.

In the first step, the likelihood function for the exchange rate is

$$L_1^E = \int_i \int_t \Pi_{it} \frac{1}{\sqrt{2\pi}} e^{-\frac{\left(E_{it} - X_{it}\Pi_2 - \mu_i^E - \mu_t^E\right)^2}{2}} dF(\mu_t^E)dF(\mu_i^E) \tag{10}$$

where $F(\mu_t^E)$ and $F(\mu_i^E)$ are the marginal probability distribution functions of μ_t^E and μ_i^E, respectively.

After optimization of L_1^b w.r.t Π_1 and L_1^E w.r.t Π_2, we can obtain the predicted values of the endogenous variables. Since $E(\mu_i^b) = E(\mu_t^b) = E(\mu_i^E) = E(\mu_t^E) = 0$, the predicted values of the endogenous variables are

$$\hat{b}_{it}^* = X_{it}\hat{\Pi}_1 \tag{11}$$

$$\hat{E}_{it} = X_{it}\hat{\Pi}_2 \tag{12}$$

where $\hat{\Pi}_1$ and $\hat{\Pi}_2$ are the coefficients that maximize equation (9) and equation (10), respectively.

2.2.2 Second Step

In the second step, the likelihood function for beliefs (b) is

$$L_2^b = \int_i \int_t \Pi_{it} (\Phi(X_{1it}\beta_1 + \delta_1 \hat{E}_{it} + \mu_i^b + \mu_t^b))^{b_{it}} (1 - \Phi(X_{1it}\beta_1 + \delta_1 \hat{E}_{it} + \mu_i^b + \mu_t^b))^{1-b_{it}} dF(\mu_t^b) dF(\mu_i^b) \tag{13}$$

In the second step, the likelihood function for the exchange rate is

$$L_2^E = \int_i \int_t \Pi_{it} \frac{1}{\sqrt{2\pi}} e^{-\frac{\left(E_{it} - X_{2it}\beta_2 - \delta_2 \hat{b}_{it}^* - \mu_i^E - \mu_t^E\right)^2}{2}} dF(\mu_t^E) dF(\mu_i^E) \tag{14}$$

The optimization of these likelihood functions involve selecting β_1 and δ_1 to maximize L_2^b, and selecting β_2 and δ_2 to maximize L_2^E.

2.3 Variance-Covariance Matrix

For maximum likelihood (or simulated maximum likelihood[5] (SML)), asymptotic theory demonstrates that the negative inverse of a *Hessian* is a variance-covariance matrix of estimated parameters. However, in the simultaneous equation framework the variance-covariance matrix needs to be adjusted for the substitution of E and b^* with their consistent estimates in L_2^b and L_2^E. The detailed derivation of the asymptotic variance-covariance matrix is provided by Amemiya (1978). The derivation of covariance matrix utilizes the finding that the first step estimates, $\hat{\Pi}_1$ and $\hat{\Pi}_2$, are consistent estimates of Π_1 and Π_2, which is proved by Amemiya (1973). Then the asymptotic covariance matrix of the estimators obtained by maximizing the likelihood function $L(\hat{\theta}_1, \theta_2)$, where $\hat{\theta}_1$ is a consistent estimator of θ_2, can be obtained from the relationship[6]

$$\hat{\theta_2} - \theta_2 =^A \left(E\frac{\partial^2 log(L)}{\partial\theta_2\partial\theta_2'}\right)^{-1}\left(\frac{\partial log(L)}{\partial\theta_2} + E\frac{\partial^2 log(L)}{\partial\theta_2\partial\theta_1'}(\hat{\theta}_1 - \theta_1)\right) \tag{15}$$

where $=^A$ means both sides of the equation have the same asymptotic distribution.

In this paper only the relevant expressions for the covariance matrix are provided. For exposition purposes consider the first step equations, in vector form, without the country and time specific effects

$$b^* = X\Pi_1 + v_1 \tag{16}$$

$$E = X\Pi_2 + v_2 \tag{17}$$

Denote the variance and covariance of (v_1, v_2) by σ_1^2, σ_2^2 and σ_{12}. A normalize of $\sigma_1^2 = 1$[7] is

[5] In some cases.
[6] Proved by Amemiya (1977).
[7] Probit in the first step will be estimated under this assumption.

required because without such a normalization Π_1 (and hence some of the parameters in the second step estimation) can only be identified up to a scalar multiple, because b^* is observed as a dichotomous variable. Define $\alpha_1' = (\delta_1, \beta_1')$ and $\alpha_2' = (\delta_2, \beta_2')$, the variance-covariance matrices are

$$Var(\hat{\alpha_1}) = (G'V_o^{-1}G)^{-1} + d(G'V_o^{-1}G)^{-1}G'V_o^{-1}(X'X)^{-1}V_o^{-1}G(G'V_o^{-1}G)^{-1} \quad (18)$$

$$Var(\hat{\alpha_2}) = a(H'X'XH)^{-1} + (\delta_2)^2(H'X'XH)^{-1}H'X'XV_oX'XH(H'X'XH)^{-1} \quad (19)$$

where $a = \sigma_2^2 - 2\delta_2\sigma_{12}$, $d = \delta_1^2\sigma_2^2 - 2\delta_1\sigma_{12}$, $V_o = Var(\hat{\Pi}_1)$, $H = (\hat{\Pi}_1, J_2)$ and $G = (\hat{\Pi}_2, J_1)$. J_1 and J_2 are matrices consisting of ones and zeros such that $XJ_1 = X_1$ and $XJ_2 = X_2$.

2.4 Estimation Algorithm

Estimation of the model involves several integral evaluations, which is accomplished through simulations[8]. To implement integration through simulation, the total number of simulations must be chosen. Gourieroux and Monfort (1991) show that if N, S $\rightarrow \infty$ and $\frac{\sqrt{N}}{S} \rightarrow 0$, then simulated maximum likelihood (SML) is asymptotically equivalent to maximum likelihood[9], which implies that having a large number of simulations is important for accuracy. However, a large number of simulations lead to an increase in computational time; therefore, we need to achieve a balance between the two. Borsch-Supan and Hajivassiliou (1993) explored this issue and found that SML yields precise parameters for *limited dependent variable* models with a small number of simulations. I use S=100 for each type of heterogeneity, which is quite large in light of the findings of the aforementioned paper.

Another issue is to increase the speed of convergence, which can be achieved by optimizing

[8]This requires sampling from Bivariate Normal Density, which is detailed in Section (7.1)
[9]'N' denote number of total observations and 'S' denote total number of simulations.

over a small number of parameters at a time. For this reason, I divide the optimization into several steps the first of which is to optimize the likelihood functions with respect to $\beta_1, \beta_2, \delta_1, \delta_2$ conditional on $\rho_{country}$ and ρ_{time}. In the second step, conditional on $\beta_1, \beta_2, \delta_1, \delta_2$, optimize (i.e., maximize $L_2^b + L_2^E$) with respect to $\rho_{country}$ and ρ_{time}. The final step is to iterate until parameters converge.

After the optimization is achieved, we need to construct standard errors, which depend on $V_o = Var(\hat{\Pi}_1)$, for statistical inference. Gourieroux and Monfort (1991) show that if $\frac{\sqrt{N}}{S} \rightarrow 0$, then $\sqrt{N}(\theta_{SML} - \theta)$ converges in distribution to $N(0, -He^{-1})$, where He stands for the *Hessian* matrix. This result is used in the construction of V_o[10].

3 Regressors

This section provides motivation for the selection of the regressors in each of the two equations.

3.1 Regressors for *b*

1. Exchange rate (E) : Investment in domestic currency denominated assets, in effect, involves two types of investments: one in the country's asset market and another in the currency of the country. Changes in the value of the currency directly affects the value of the investment in that a large (expected or real) depreciation of the exchange rate will reduce the value of domestic currency denominated assets, which will make the agents/investors nervous.

2. Budget Deficit(-) or Surplus (+) as a fraction of GDP (Budgt/GDP): Budget deficit is a two edged sword: on the one hand it generates demand and thus stimulates economic

[10] The relevant Hessian is computed numerically by using formulas *25.3.24* and *25.3.26* described in Abramowitz and Stegun (1972).

activity, but on the other hand a large budget deficit can make the agents nervous. In developing economies, the role of government is important in stimulating economic activity. Faster economic activity not only provides higher standards of living for the residents of the country, but it also generates higher returns on investments, thereby providing positive outlook to the market. However, a large budget deficit can make the agents nervous, which would adversely affect country's financial health; some of the reasons for such an outcome are:

(a) In the first generation model, Krugman (1979), budget deficit is the most important cause of currency crises. In this model, under a fixed exchange rate regime with limited reserves, the government pursues expansionary polices to finance its budget deficit. This leads to an overvaluation of the exchange rate, which in turn leads to a currency crisis when reserves fall to some critical level.

(b) High levels of budget deficit increase interest rates, which in turn depresses private investment – often referred to as crowding out.

(c) High levels of budget deficit imply a high level of future taxation leading to a fall in the rate of return on investment. This fall in the rate of return will depress investment, thereby slowing down the growth rate of the economy.

(d) With high budget deficits, the government has less incentive to undertake policy reforms because successful reforms require repaying the creditors and the government will lose the captive market for its debt.

3. Country's risk rating index (Rating): An informed agent may incorporate the perception of researchers while forming beliefs about the riskiness of the country. The research findings of the professional investment advisors might influence the agents assessment of country's riskiness[11]. If a country is considered as a high-risk country

[11]This argument is supported by the fact that many big investors consult investment advisors before

by investment advisors, then the agents' beliefs about the country's financial health might be adversely affected.

4. Interest rate differential (Droi): A high domestic interest rate relative to the rest of the world[12] implies a large cost of debt servicing. But even more damaging is its implication that the country in question is a high-risk country, and hence, it would be more susceptible to crises.

5. Rate of growth of GDP (RogGDP): A high rate of GDP growth suggests buoyancy of a country's economic health. A higher growth rate reflects promising prospects for the future, and favorably affects agents' sentiments.

3.2 Regressors for Exchange Rate

1. Beliefs of the agents (b^*): The exchange rate is sensitive to agents' beliefs. If agents expect that the country might be subject to a financial problem, then they will convert their assets into a safer currency. This will lead to a depreciation of the country's exchange rate.

2. Current account balance as a fraction of reserves (CAB/RES): A large change in the current account can lead to a change in the exchange rate; surpluses in the current account might strengthen the currency (appreciation) while a current account deficit might weaken the currency (depreciation). The reason to normalize current account balance by reserves is that if changes in current account balance are not substantial with respect to the country's reserves (i.e., if changes in current account can be absorbed by changes in the reserves), then the exchange rate will not be significantly affected.

making investment decisions.

[12] For empirical analysis *reference country* is considered as the rest of the world.

3. Inflation rate differential (Dinfla)[13]: The rate of change in the price level in one country relative to the price level in another country might affect the exchange rate between the two countries' currencies. The country with higher rate of inflation will experience a devaluation in its currency, otherwise there would be an arbitrage opportunity available.

4. Money Supply relative to reserves (M/RES): An increase in the quantity of a 'good' leads to a decline in its value; following this reasoning, an increase in the quantity of domestic currency might lead to a depreciation of the domestic exchange rate.

The regressors described above are well suited for the respective equations. But for the identification of a system of two simultaneous equations model, it is necessary to have at least one exogenous regressor in each equation that is absent from the other equation. In order to address this issue, first consider money supply relative to reserves. This regressor affects exchange rate (as described above) but doesn't effect the agents' beliefs about the country's financial health. Because the agents are only concerned about the value of their investment, which is unaffected by the level of money supply. Second, consider interest rate differential. This regressor influences beliefs of the agents but doesn't influence exchange rates. Therefore, there is at least one exogenous regressor in each equation that is absent from the other equation; therefore the model is identified[14].

The model is identified if no additional information can be obtained from the regressors of exchange rate after incorporating all the information from the regressors of the belief equation. Consider, for example, money supply. An increase in money supply would lead to depreciation of exchange rate, which would in turn lead to fall in the value of domestic denominated assets. This implies an increase in money supply would adversely affect market

[13]For empirical analysis inflation rate differential of a country is inflation rate in the country minus inflation rate in the US.

[14]For identification purpose I only described two regressors (for completeness), but in the model there is no exogenous regressor that belongs to both of the equations.

sentiments. But, as soon as the news of an increase in money supply reaches the market exchange rate depreciates, as exchange rate is very quick to adjust; therefore, if agents can observe the exchange rate then there is no more information in money supply for the purpose of belief formation. Consider another example where agents expect money supply to increase in future, based on this information agents will form expectations that exchange rate will depreciate in future, which would in turn lead to a loss in the value of domestically denominated assets. Expectation of exchange rate depreciation will open up a possibility of arbitrage, which will be quickly exploited leading to a depreciation of exchange rate in the current period. Once the exchange rate has adjusted to a new level (based on the expectation of an increase in money supply), no more movement is expected in exchange rate, which implies that the value of investment has settled to a new level. Therefore, when the expectations of an increase in money supply are realized in the future there will be no consequence to the value of investment (as it has already adjusted based on the expectations). Hence, for belief formation money supply does not offer more information after information from exchange rate is incorporated. This analysis implies that for belief formation after information about exchange rate is exploited there is no more information in the regressors of exchange rate.

In addition unambiguous information about the riskiness of the economy can be obtained from risk rating; similarly, unambiguous information about the financial health of the economy can be obtained from growth rate of GDP. Therefore, we can safely conclude that the relevant information for belief formation is summarized in the regressors of the belief equation.

4 Data

The sample used in this study consists of an unbalanced panel of thirteen countries[15] at quarterly frequency from 1981:1 to 2004:4 with a total number of 1104 observations.

4.1 Crisis Identification

A crisis occur when agents hold adverse beliefs about the country's financial health, i.e., beliefs and crisis have one-to-one mapping. In the period of crisis: $crisis = 1$ and $b = 1$, and during non-crisis period: $crisis = 0$ and $b = 0$.

Currency crisis cannot be identified by the episodes of devaluations. This is because not all speculative attacks are successful; the currency may be supported through the expenditure of reserves. Alternatively, authorities may repel attack by raising interest rate. Therefore, crisis identification criterion must involve aforementioned variables.

To identify a period of currency crisis, a measure of speculative pressure is constructed as suggested by Eichengreen et al. (1996). It is a weighted average of exchange rate changes, changes in foreign exchange reserves and interest rate changes. All these variables are measured relative to a reference country, the US. The index of exchange market pressure (EMP) is

$$EMP_{it} = \lambda_e \%\Delta e_{it} + \lambda_i \Delta(i_{it} - i_{Rt}) - \lambda_r (\%\Delta r_{it} - \%\Delta r_{Rt}) \tag{20}$$

where e_{it} denotes the price of the reference country's currency in terms of country *i's* currency at time t; i_{it} is rate of interest in country i at time t; and r_{it} is the ratio of international reserves to money supply in country i at time t. The subscript 'R' stands for the reference country, the US. The weights λ_e, λ_i and λ_r, equalize the volatilities of each of the EMP

[15] Namely, Turkey, Argentina, Brazil, Mexico, Uruguay, Venezuela, Indonesia, Korea, Philippines, Thailand, Morocco, Hungary, and Slovenia.

components, and are defined as the inverse of the standard deviation of each of the individual series.

A crisis is an extreme value of EMP, i.e.,

$$\begin{aligned} Crisis_{it} &= 1 \text{ if, } EMP_{it} > \sigma_{EMP_i} + \mu_{EMP_i} \\ Crisis_{it} &= 0 \text{ otherwise} \end{aligned}$$

where μ_{EMP_i} is mean of the EMP and σ_{EMP_i} is the standard deviation of EMP for country i.

This method identifies the extreme values of EMP as episodes of crisis. In this method, chances of EMP being identified as extreme value, hence a period of crisis, is the same for all the countries in the sample. This feature is desirable as it employs uniform scale for EMP to qualify as an extreme value, and hence episodes of crisis are comparable across countries.

Specifically, for example, we expect a safer country (say Canada) to have a fewer number of crisis compared to a crisis prone country (say Brazil). This expectation should be validated by the method employed to identify crisis. If, however, the method has different criterion to identify crisis for every country, then the episodes of crisis are not comparable across countries. If the episodes of crisis are not comparable, then the empirical model of interest cannot be estimated. Hence, this method is acceptable for crisis identification.

4.2 Data Source

The data are obtained from *Euromoney* and *International Financial Statistics*, a publication of International Monetary Fund. The former source contributed the risk ratings of the countries while the latter provided the data for all other variables.

The country risk rating, published by *Euromoney*, is an index between zero and one hundred for various countries. A higher value of this index implies a low-risk country while a low value of the index implies a high-risk country. For example, a country with an index value of one hundred would be considered the safest country for investment purposes.

The exchange rate of each country is end-of-period national units per US dollar. The budget deficit (-) or surplus (+) is equal, with opposite sign, to the sum of the net borrowing by the government, plus the net decrease in government cash, deposits and securities held for liquidity purposes. The interest rate of the country is the mean of *money market rate* and *deposit rate*; this approach is adopted to minimize the number of missing values for the rate of interest.

The growth rate of GDP is computed by deflating GDP by the CPI[16], and then calculating its quarterly growth rate. Current account balance is the sum of the balance on goods, services and income, plus current transfers. The rate of inflation is based on CPI; the CPI reflects changes in the cost of acquiring a fixed basket of goods and services by the average consumer. The money supply is the sum of currency outside of bank deposits plus demand, time, savings and foreign currency deposits of resident sector excluding the central government. Reserves equal the sum of foreign exchange, reserves in the Fund, and the US dollar value of SDR holdings by the monetary authorities. Monetary authorities comprise central banks and, to the extent that they perform monetary authorities' functions, currency boards, exchange stabilization funds, and treasuries.

The data utilized in the study comes from various countries and at times there are missing values at quarterly frequency. To impute the missing values at quarterly frequency, annual data are used after appropriate adjustments[17].

[16]GDP deflator is not used because it has missing values for various countries.

[17]An in-built command in SAS, *proc expand*, is used for this purpose. For this command linear interpolation method is selected to convert annual frequency data into quarterly frequency.

5 Results

The results of the estimation are presented in Table 1. To underline the importance of proper specification, the table presents estimation results from three specifications. The estimation in Model 1 utilized probit for the *Belief equation* and OLS for the *Exchange rate equation.* The estimation of Model 2 used a simultaneous equation framework for the two equations without taking into account unobserved heterogeneity. Model 3 is the complete model advocated in the paper; in its estimation a simultaneous equation framework is employed for the two equations and unobserved heterogeneity is taken into account.

In the simplest case of Model 1, no variable is statistically significant in the *Belief equation*, which implies that agents do not base their beliefs on any characteristic of a country, which in turn implies that currency crises are random. However, when the simultaneous equation framework is employed as in Models 2 and 3, the interest rate differential and exchange rate are significant at a 5% confidence level. A positive and statistically significant coefficient on the interest rate differential, which reflects riskiness of a country, implies that the agents' beliefs are adversely affected by a rise in interest rate differential. A positive and statistically significant coefficient on the exchange rate implies that the agents get nervous when the value of their investment diminishes – a depreciation of the exchange rate leads to a loss in the value of domestic currency denominated assets. Other variables in the *Belief equation*, namely risk rating of a country, budget as a fraction of GDP, and growth rate of GDP, are statistically insignificant in all the three models.

Turning to the *Exchange rate equation*, in all the three models money supply as a fraction of reserves has a positive coefficient and is significant at a 5% confidence level, which implies that an increase in the stock of money leads to a depreciation of the currency. Another important regressor, 'beliefs', has the expected positive coefficient. Because adverse 'beliefs' of the agents' can lead to a depreciation of the exchange rate it is expected to be statistically significant. However, it is insignificant at a 5% level of confidence in all the three models, but if the right tail test is considered, which is appropriate because a positive coefficient was expected on 'beliefs' in the exchange rate equation, then it is significant at 10% level of confidence in Model 3. Other variables, namely the current account balance as a fraction of reserves and the inflation rate differential, are statistically insignificant in all the three models.

These results indicate that the simultaneous equation framework has greater explanatory power for belief formation, and therefore for episodes of currency crises, compared to the single equation framework. The latter approach suggests that crises are random, while the former approach demonstrates that a high-risk country is more susceptible to crises, and that a large depreciation of the exchange rate can contribute to a crisis.

6 Conclusion

This research studied the empirics of currency crises. The point of departure of the empirical analysis was twofold: the simultaneous equation formulation (one equation for the agents' beliefs and another equation for the exchange rate) and richer error structure (to take into account unobserved heterogeneity that is expected in panel data). The findings of this paper indicate that the agents are concerned about the riskiness of a given country, which is reflected in the country's interest rate. Another important variable is the exchange rate, because an agent making an investment in a country is essentially making two investments: one in its currency and another in its assets. The former investment is directly affected by the fluctuation in the exchange rate. A depreciation of the exchange rate leads to a loss in the value of the domestic currency denominated investment, which adversely affects market sentiments.

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Equation of	Variable	Model 1	Model 2	Model 3
b				
	$\hat{E}$		0.0015638 (4.08)*	0.002657235 (7.16)*
	E	0.0000305 (0.9)		
	Rating	-0.0023538 (-0.65)	0.0054479 (0.91)	0.007239918 (1.12)
	Budgt/GDP	0.0378535 (0.06)	0.3266448 (0.36)	0.753399138 (0.81)
	Droi	0.0000389 (1.51)	0.0000729 (2.3)*	0.000124837(2.55)*
	RogGDP	-0.0087503 (-1.63)	-0.0066845 (-0.79)	-0.012555178 (-1.37)
	cons	-1.265288 (-6.43)*	-2.379631 (-5.88)*	-4.082081373 (-9.24)*
E				
	$\hat{b}^*$		1.343933 (0.54)	24.95154125 (1.29)
	b	14.44891 (0.09)		
	CAB/RES	11.45075 (0.97)	11.50105 (0.98)	12.95885056 (1.14)
	Dinfla	-0.0683206 (-1.01)	-0.1025449 (-1.15)	-0.072600238 (-0.84)
	M/RES	0.0444407 (3.72)*	0.0441469 (3.81)*	0.046334089 (4.02)*
	cons	306.7113 (5.68)*	313.1734 (5.74)*	313.5744324 (4.07)*
	ρ_{time}			-1
	$\rho_{country}$			0.97

Table 1: Model Estimates. *Notes:* (1) The numbers in the parentheses are z-statistics. (2) The starred entries have absolute value of z-statistics greater than 1.96. (3) The estimation of Model 1 used probit for the belief equation and OLS for the exchange rate equation. (4) The estimation of Model 2 used simultaneous equation framework without taking into account unobserved heterogeneity. (5) The estimation of Model 3 used simultaneous equation framework and takes into account unobserved heterogeneity. Its estimation used 100 simulations for each type of heterogeneity.

Description of the variables:

1. Beliefs (b) equaling one imply adverse beliefs (i.e., currency crisis) while Beliefs (b) equaling zero imply 'normal' time.

2. E is exchange rate of a country.

3. Rating is country risk rating index.

4. Budgt/GDP stand for budget (revenue-expenditure) as a fraction of GDP.

5. Droi stand for interest rate differential.

6. RogGDP stand for growth rate of GDP.

7. CAB/RES stand for current account balance as a fraction of reserves.

8. Dinfa stand for inflation rate differential.

9. M/RES is the stock of money supply as a fraction of reserves.

10. Cons stands for constant.

11. $\rho_{time} = Correlation(\mu_t^b, \mu_t^E)$ as described in Section (2).

12. $\rho_{country} = Correlation(\mu_i^b, \mu_i^E)$ as described in Section (2).

7 Appendix

7.1 Bivariate Normal Density

The bivariate normal probability density function for two correlated normal distributed variables [18] x and y.

$$f(x,y) = \frac{1}{2\pi\sigma_x\sigma_y\sqrt{1-\rho^2}} \exp - \frac{1}{2(1-\rho^2)} \left[\left(\frac{x-\mu_x}{\sigma_x} \right)^2 - 2\rho \frac{x-\mu_x}{\sigma_x} \frac{y-\mu_y}{\sigma_y} + \left(\frac{y-\mu_y}{\sigma_y} \right)^2 \right] \tag{21}$$

where $f(x,y)$ bivariate normal probability distribution function, μ_x mean of x, σ_x standard deviation of x, μ_y mean of y, σ_y standard deviation of y, ρ correlation between x and y.

To sample from this density:

1. Generate two, uncorrelated standard normal variables, z_1 and z_2; $z \sim N(\mu = 0, \sigma = 1)$.

2. Compute x and y as follows:

$$\begin{aligned} x &= \mu_x + \sigma_x z_1 \\ y &= \mu_y + \sigma_y \left(z_1 \rho + z_2 \sqrt{1-\rho^2} \right) \end{aligned}$$

Thus generated x and y will have means μ_x and μ_y, standard deviations σ_x and σ_y, respectively; and correlation of ρ.

[18] Special case is standard bivariate normal probability density function, with mean zero and standard deviation of one, i.e., normalized variables $z_x = \frac{x-\mu_x}{\sigma_x}$ and $z_y = \frac{y-\mu_y}{\sigma_y}$:

$$f(z_x, z_y) = \frac{1}{2\pi\sqrt{1-\rho^2}} \exp - \frac{z_x^2 + z_y^2 - 2\rho z_x z_y}{2(1-\rho^2)}$$