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Predicting Currency Crises, the Ultimate Significance of Macroeconomic Fundamentals in Linear Specifications with Nonlinear Extensions

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Abstract

Informative content of macroeconomic fundamentals with respect to currency crisis prediction is reassessed for the period of 1990s on the panel of 46 developed and emerging economies.

In the first part the paper develops a model for currency crisis prediction. The distinction is made between variables emphasized by 'first generation' and 'second generation' models. Special attention is directed towards multiple equilibria and contagion phenomena. Considerable amount of predictability is found, particularly on behalf of standard leading crisis indicators, such as overvaluation of the real exchange rate and the level of foreign exchange reserves. Multiple equilibria don't get much support from the data while contagion effect is obviously working – apparently through various channels.

In the second part the relationship between model specification and the significance of coefficients is investigated in the attempt to ultimately evaluate what can be expected from empirical implementation of crisis prediction. An average predictive power of such models and employed variables is assessed.
Introduction

This paper reassesses the informative content of macroeconomic fundamentals with respect to currency crisis prediction for the period of 1990s on the panel of 46 developed and emerging economies. The distinction is made between variables emphasized by "first generation" and "second generation" models. Special attention is directed towards multiple equilibria and contagion phenomena.

In the second part of the paper the relationship between model specification and the significance of coefficients is investigated. This is done in an attempt to ultimately evaluate what can be expected from empirical implementation of crisis prediction.

From theoretical point of view the idea that currency crises need not necessarily be irrational and unpredictable events, as they might have been regarded, emerged around Krugman (1979). The so-called "first generation" models have been developed – in which unsustainable policies of the authorities led to a currency crisis. The theory emphasized a set of variables that were responsible for crisis eruption – they are called "hard fundamentals" and include domestic credit (expansion), foreign exchange reserves, budget balance (deficits) etc. Starting in mid-1980s but especially after unexpected ERM crisis in 1992–93 economists switched attention to so-called "second generation" models, which introduced an optimizing government and an "escape clause" in its policy. Second generation models identified a new set of variables that could be responsible for crises – actually any variable that enters government decision whether to defend the exchange rate or not, especially domestic economic and political situation (inflation, unemployment) should be monitored. New and interesting phenomena these models could account for include multiple equilibria and contagion. They have been particularly popular in explaining recent crisis and obtain special attention in this paper. Finally, after Asian, Russian and Brazilian crisis some economist claim that a new brand of crises emerged – "third generation" – one of their characteristics is an important role played by microeconomic factors. For more extensive treatment of the theoretical background of currency crises see Antczak (2000).

Empirical literature concerning systematical prediction and explanation of currency crises has flourished recently but is rather limited in success. Tomczyńska (2000) as well as Kaminsky, Lizondo and Reinhart (1998) provide a good survey.
1. Predicting Currency Crises

1.1. Model Specification

In this chapter the model for crisis prediction and explanation is built.

Theory provides the list of fundamentals that can be endowed with an informative content. As both the two main approaches to currency crises presented by the "first" and the "second" generation models are encompassed – the model includes the standard "hard" and measurable fundamentals (the usual macroeconomic variables) as well as some approximation of multiple equilibria and contagion.

In the analysis following instruments are employed:
- **Real exchange rate**, measured as a deviation from purchasing power parity;
- **Foreign exchange reserves level**, measured in years of import that can be purchased by it;
- **Trade balance**, expressed as a dummy variable of one if the deficit exceeds 5%, a number roughly regarded as a frontier of safe sustainability;
- **Government surplus**, as a surplus to GDP ratio;
- **Domestic credit**, described relatively to GDP;
- **Inflation**;
- **Unemployment**;
- **Output level**, in a form of a squared output gap (deviation of the GDP from a linear trend in % squared). The basis for such specification is a priori presumption that both economic depression and a state of excessive economic boom can be potentially unattractive and supposedly dangerous for the investor in a given currency;
- **Short term foreign liabilities** expressed as a ratio of foreign private bank claims due within a year to foreign exchange reserves. The unbalanced maturity of foreign obligations became the most direct cause of the Mexican crisis in 1994–95;
- The level of **non-bank financial institution activity** measured as a percentage of total country's deposits in hands of those institutions. The moral hazard exercised by such financial intermediaries in the absence of sufficient banking control is frequently blamed for the severity of the Southeast Asian collapse in 1997–98;
- The level of **international interest rate** as the average of the US and German treasury bill rate. This variable can supposedly account for contemporaneous breakdown of many exchange rates, what can seemingly look like a contagion, and what actually is not a contagion;
– Exchange rate regime type in a form of a set of two dummy variables – one for managed float and one for currency peg leaving purely flexible exchange rate as a reference category [1];
– Multiple equilibria as dummy variable of one if there exist a possibility of self-fulfilling currency crash;
– Sensitivity to contagion due to trade link measured as the impairment of competitiveness caused by the crisis elsewhere;
– Sensitivity to contagion due to informational spillovers and herding behavior.

The last three instruments require further explanation.

1.1.1. Multiple Equilibria

This variable is obtained from the extension of Jeanne (1997) model to all countries included in this study. There is barely any fundamental so hard to measure as the possibility of multiple equilibria. However Jeanne argues that specific behavior of the short-term interest rate, regarded as the reflection of the devaluation expectations can be interpreted as the manifestation of multiple equilibria. In what follows I track Jeanne's model as well as Lyrio and Dewachter's (1999) application.

In many second generation models with optimizing government the net benefit of maintaining fixed exchange rate at period t can be expressed as

\[ B_\tau = b_\tau - \alpha \pi^e_{\tau-1} \] (1)

where \( b_\tau \) is the gross benefit of the fixed peg depending solely on underlying macroeconomic fundamentals, and \( \pi^e_{\tau-1} \) is the probability that the government decides to abandon exchange rate evaluated by the private sector in the preceding period. This is only the simplest formulation of the fact that net benefit of the peg depends also on how credible is the peg itself. To illustrate that point suppose that unemployment (the fundamental) enters (negatively) into government objective function. Unemployment itself is determined (at least partly) by the nominal arrangements made within private sector (let's say workers and employers). These arrangements are conditioned on the expectations concerning government action (to devalue or not). So the only way to increase employment above natural level is to surprise private sector with unexpected devaluation. Facing high devaluation expectation and not devaluing is equivalent to unexpected revaluation, which in turn drastically raises unemployment. Such

\[ [1] \text{Currency board dummy doesn't exhibit enough variation to be included.} \]
interaction of expectations is a common way of obtaining multiple equilibria.

We assume that the net benefit of the peg (the state of fundamental) obeys the following simple stochastic process.

\[ b_\tau = E_{\tau-1}b_\tau + \varepsilon_\tau \] (2)

where the innovation \( \varepsilon_\tau \) is independently and identically distributed and characterized by typical, well behaved, bell shaped density function and associated cumulative distribution function \( F \).

It is common knowledge that government devalues if and only if net benefit is negative and at the same time the government has such a political will. This will is observable and happens with a probability \( \mu \). If the government doesn't exhibit such a will it defends the exchange rate at every cost.

Therefore we can express the probability at time \( \tau \) of a currency crisis in the next period as:

\[ \pi_\tau = \mu \Pr_\tau (B_{\tau+1} < 0) \] (3)

but from (1) and (2) \( B_{\tau+1} < 0 \) is equivalent to

\[ \varepsilon_{\tau+1} < \alpha \pi^c_\tau - E_\tau b_{\tau+1} \] (4)

hence

\[ \pi_\tau = \mu \Pr_\tau (\varepsilon_{\tau+1} < \alpha \pi^c_\tau - E_\tau b_{\tau+1}) \] (5)

In the rational expectations we have to assume that \( \pi^c_\tau = \pi_\tau \). Private sector’s expectations must be validated in equilibrium, otherwise they would be altered. Denoting \( \phi_\tau = E_\tau b_{\tau+1} \) which represents the overall (expected next period) state of the economy – "the" fundamental – equation (5) becomes

\[ \pi_\tau = \mu F_\sigma (\alpha \pi^c_\tau - \phi_\tau) \] (6)

We introduce two simplifying assumptions:

\[ -F \equiv F_\sigma (\phi) = \frac{1}{\sqrt{2\pi \sigma}} \int_{-\infty}^{\phi} e^{\frac{-s^2}{2\sigma^2}} ds \] , i.e. the innovation to fundamental has normal distribution with mean zero and standard deviation \( \sigma \).
Because $\phi$ is a compounded fundamental it is always possible to scale down $\alpha$ to unity by scaling at the same time the composition weights as well. It is not only a simplification – the necessary condition for parameter identification requires an additional constraint on one of the parameters in the argument of $F$.

Nonlinear equation (6) can have one, two (not generic, so we ignore this), or three solutions. This idea can be summarized in the following way:

1. If the slope of a distribution function at inflection point does not exceed unity [2] the number of solutions to this equation is always one for the whole range of fundamentals. No multiple equilibria exist.

2. If the slope (at inflection point) exceeds unity three cases are possible:
   - for the fundamental lower (worse) than some critical value $\phi_l$ only one equilibrium $\pi$ exist – it is high (bad) equilibrium when the probability of devaluation is high,
   - for the fundamental higher (better) than some critical value $\phi_h$ only one equilibrium $\pi$ exist – it is low (good) equilibrium when the probability of devaluation is low,
   - for fundamentals between $\phi_l$ and $\phi_h$ that is in the certain and well specified range there are three solution corresponding to three equilibria $\{\pi_1, \pi_2, \pi_3\}$ high, medium and low [3].

Figure 1 presents the reasoning more clearly. On the left panel straight $45^\circ$ line and a curve of the normal cumulative distribution represent respectively left and right hand side of equation (6) and must equal at solution. Right panel is the same analysis transferred into $\phi - \pi$ space. The curve consists of all pairs $(\phi, \{\pi_1, \pi_2, \pi_3\})$ or $(\phi, \pi)$ that solve (6).

For every country in my sample I estimate the following model:

\[
\begin{align*}
\pi_{\tau} &= \hat{\pi}_{\tau} + \eta_{\tau} \\
\hat{\pi}_{\tau} &= \mu F(\hat{\pi}_{\tau} - \phi_{\tau}) \\
\phi_{\tau} &= \gamma \cdot x_{\tau}
\end{align*}
\]  

(7) \hspace{1cm} (8) \hspace{1cm} (9)

where the vector $x_{\tau}$ contain relevant components of macroeconomic fundamental, such as real exchange rate, trade balance to GDP ratio, the level of foreign exchange reserves measured in billions of dollars and a constant, $\gamma$ is a vector of parameters, parameter $\mu$ is the probability of the occurrence of a political will to devalue, $\sigma$ is a parameter for the standard deviation of the cumulative distribution function. $\eta_{\tau}$ is a prediction error which is assumed to be independently, identically, normally distributed with mean zero and a standard deviation of $\sigma_{\eta}$.

[2] The slope is maximal at the inflection point, so in this case the slope never exceeds unity.

[3] The medium equilibrium $\pi_2$ has an undesirable property of positive correlation between the fundamental and the devaluation probability. It is also dynamically unstable and mainly for that reason it will be ignored in the rest of the analysis.
There is a need for a time series of devaluation probabilities ($\pi'$s) to exercise the estimation. These probabilities are assumed to be roughly equal to the interest rate differential on short maturities (money market rate) [4].

It is also essential to make assumption about the magnitude of devaluation expected by private sector to happen at the crisis. It was set to unconditional mean real overvaluation of the currency [5].

The estimation was carried over by means of the maximum likelihood method by maximizing:

$$\max_{\mu, \sigma, \gamma} \left( \frac{1}{2\sigma^{\gamma}} \sum_{\tau=1}^{T} \min \left( \left( \pi^{\tau} - \hat{\pi}^{W} \right)^{2}, \left( \pi^{\tau} - \hat{\pi}^{d} \right)^{2} \right) \right)$$

(10)

[4] To get "pure" devaluation probabilities interest rate differentials have to be adjusted by expected change in the (explicit or implicit) trend – this is particularly important in the case of a crawling peg or a managed float. Where the trend (rate of currency depreciation) is not explicitly stated by the monetary authorities the implicit trend has been first estimated. It would be also reasonable to adjust interest rates for the expected rate change relative to the trend. Although the exact theoretical behavior of the exchange rate within bands (at least in target zone models) is highly nonlinear, Bertola and Svensson (1993) argue that this behavior is characterized by strong mean (trend) reversion and can be well approximated by the first order autoregressive process. To correct for this they propose so-called "drift adjustment" method. This method is not, however, used in this paper as it produces implausible values for devaluation probabilities.

[5] If that turned out to be negative – to the average realized devaluation provided it exceeded two standard deviations of the usual rate change. The minimum and maximum expected devaluations have been constrained to 5% (10% for currency boards) and 25% respectively.
where $T$ equals number of observations and $\pi^u_\tau$, $\pi^d_\tau$ are two extreme $\pi$'s solving (8) at $\tau$ given $\gamma$, $\mu$ and $\sigma$. If necessary (if only one equilibrium exists) $\pi^u_\tau = \pi^d_\tau$.

After the coefficients have been obtained the critical range and fitted values of the fundamental were computed. The dummy variable capturing multiple equilibria possibility was set to one if and only if inferred compounded fundamental for a given country in a given period was between critical values $\phi_l$ and $\phi_h$.

The analysis has, of course, many drawbacks. First, it assumes that changes in interest rate differentials without respective changes in the fundamental are necessarily reflections of the multiple equilibria phenomenon but it does not have to be the case [6]. Second, it assumes a specific, namely normal, distribution function for innovation to the fundamental – this assumption is rather crucial for obtaining multiple equilibria. Finally in some cases, judging from log-likelihood comparison, just the linear model of devaluation probability performed apparently better.

Some sample results from estimating the model are presented in Figure 2 on the following page. Vertical axis indicates devaluation probabilities, horizontal axis represents the value of compounded fundamental [7]. Curves represent inferred relationship between devaluation probability and fundamentals, dots – observations.

1.1.2. Contagion

This paper distinguishes between two sources of contagion, namely trade-link contagion and informational spillovers.

The idea that trade links play important role in the spread of currency crises is well justified theoretically [e.g. Gerlach and Smets, 1994; Masson, 1999] and empirically [Glick and Rose, 1999] as well. There are several types of links that can be identified. For our analysis let's denote by $X$ the country in question and by $N$ the set of all other countries engaged in the foreign trade, $\Psi_{XY}$ the trade (export) volume that goes from $X$ to $Y$, $\Delta Y$ devaluation of country $Y$ (measured in relation to $X$).

Let's also denote $\omega_{XY} = \frac{\Psi_{XY}}{\sum_{J \in N} \Psi_{XJ}}$ – the importance of country $Y$ for country $X$ measured as $Y$'s weight in $X$'s export basket.

[6] For example in credible currency boards changes in the interest rate may reflect fluctuations in liquidity, as the authorities do not engage in interest rate smoothing – see the case of Estonia in Figure 2.

[7] The axis is scaled by the maximization procedure to fit the shape of the curve, so absolute values of the fundamental are country-specific and have no meaning for comparison between countries.
Figure 2. Sample results from multiple equilibria estimation. (Dots represent observations, curves represent inferred relationship between the fundamental and devaluation probability. If slope at inflection > 1 there is a possibility of multiple equilibria)
The simplest channel of contagion is the direct loss of competitiveness in bilateral trade. It can be expressed as:

\[ Tc^1_X = \sum_{Y \in N} \omega_{XY} \Delta_Y \]  \hspace{1cm} (11)

This simple formula says that country X's loss of direct bilateral competitiveness is equal to the amount X's partner has devalued times the importance of that partner in X's export basket and this summed over all X's trade (export) partners. Other, more comprehensive measure of trade links is the index of a competitiveness loss on export markets. It is expressed as

\[ Tc^2_X = \sum_{K \in N} \omega_{XK} \frac{\sum_{Y \in N} \Psi_{YK} \Delta_Y}{\sum_{Y \in N} \Psi_{YK}} \]  \hspace{1cm} (12)

Country K is X's export partner. The right fraction represents the (minus) average price of K's import. It is equal to total K's import volume weighted by its (minus) prices, (i.e. exchange rates of countries exporting to K) divided by total K's import volume. When countries that export to K devalue, and X does not – X's competitiveness become severely impaired. This is again multiplied by the importance of K in X's export basket and summed over all X's trade partners.

This index can be refined to control for the extent to which countries compete on export markets:
It exploits the fact that not all X’s competitors are of equal importance. Countries of a very different size seldom fiercely compete (on average) in the world trade. X would be mostly concerned about competitors that are of similar size, from similar region, producing similar goods for similar markets. Y is X’s competitor. The term inside brackets expresses the degree of similarity of X’s and Y’s export volume to country K. It is presupposed that similar export volume to K can approximate similar export patterns of X and Y and therefore the degree of their competition on K’s market. For given Y, it is weight-summed over all markets K that X and Y compete on, and then multiplied by Y’s devaluation (X’s loss of competition) and again summed over all X competitors.

Further possibilities to refine the index of competitiveness loss, e.g. by splitting total trade into sectors, introducing export elasticities into the analysis, etc., are, of course, unlimited.

I employ the last formulation as the approximation of exposure to trade-link-caused contagion. It seems the most sophisticated and appealing out of the mentioned three. For example trade links between Southeast Asian region are by no means that developed, as the links of individual SE Asian countries with the rest of the world [8]. Additional (but not very significant) three modifications are made:

– instead of devaluation itself, I’m using my 0–1 crisis index (as explained below) to make it compatible with the rest of the analysis;

– as I’m not interested in competitiveness loss contemporaneous to the crisis (that would severely bias the analysis towards finding trade link contagion) I proceed as follow: X’s competitor devaluation (crisis) is set to one if and only if that country has had a crisis during past three periods;

– one has also to notice that different countries react differently to equal devaluation by the whole set of countries (this happens for example because not all 200 or so world countries are included in the analysis). To correct for that I divide by

$$ Tc_X^3 = \sum_{Y \in N} \Delta Y \sum_{K \in N - \{Y\}} \omega_{XYK} \left( 1 - \frac{|\Psi_{XY} - \Psi_{YK}|}{\Psi_{XY} + \Psi_{YK}} \right) $$

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$$ Scale_X^3 = \sum_{Y \in N} \sum_{K \in N - \{X, Y\}} \omega_{XYK} \left( 1 - \frac{|\Psi_{XY} - \Psi_{YK}|}{\Psi_{XY} + \Psi_{YK}} \right) $$

[8] For example, Thai export to its biggest trade partner in the region and a neighbor – Malaysia (excluding Singapore and Hong-Kong for a moment) – was in 1997 equal roughly 12% of a combined export to the US and Japan – the biggest importers from Southeast Asia.
Another source of contagion can be so-called informational spillovers. That factor arises due to following reasons:

– it is costly to monitor possibly infinite set of relevant macroeconomic fundamentals. Instead investor can rely on the behavior of other presumably better informed market participants. Calvo and Mendoza (1996) notice that the more diversified the investor is the less become the marginal gain from gathering information about portfolio components. That makes investors very sensible to small amount of information and can result in "herding behavior" or "information cascades";

– the rules of the game in financial market, or the state of common knowledge, the level of expectations, or the government response function, or other important piece of information can be unclear or missing. Krugman (1996) shows that if the authorities preferences are not publicly observed investors might test it by a speculative attack - then observe which attack has been successful and which has failed, and learn on that basis. In Shiller (1995) investors differently interpret information and are unsure about other investors interpretation. Therefore market reaction to a piece of news provides information about the way how other information should be interpreted and can possibly lead to drastic changes in expectations and to overreaction.

I know of no empirical paper testing such a contagion channel. This is an ad-hoc attempt to fill the gap.

I base my informational-spillover-caused-contagion-possibility index on the assumption that a crisis in country $X$ reveals information that crises in general are more likely in countries characterized by similar fundamentals as $X$. Countries that are similar to a crisis country $X$ are immediately attacked by investors trying to profit (or escape capital losses) from possible crisis - before others turn against that country as well. It is computed as:

$$Inf_{spill_X} = \sum_{f \in F} \frac{1}{N + 1} \sum_{x \neq \text{crisis}} \sum_{j \neq x} \min(f_X/f_Y, f_Y/f_X) \Delta_Y$$

where $f_X$ is a value of fundamental $f$ in country $X$, $\Delta_Y$ (as in trade contagion case) equals one if $Y$ has had a crisis during past three periods, and zero otherwise. Before I sum over all fundamentals $f \in F$ (the set of fundamentals) I scale it to achieve comparability between fundamentals.

### 1.1.3. The Dependent Variable – Crisis Index

The problem with a choice of crisis period is obvious and not trivial. The key decision is either crisis periods should be hand-picked by experienced researcher
basing on his knowledge, financial press and common beliefs, or should they be an outcome of a rigorous procedure in which only objective and measurable characteristic enter the choice function. Both methods have advantages and disadvantages, and the conflict between them if far from being resolved. This paper takes the latter approach.

This decision is, of course not, the end of a difficult and controversial selection process. There is a need to find a method to transform macroeconomic fundamentals into crisis indicator.

As Eichengreen, Rose and Wyplosz (1996) correctly note "currency crises cannot be identified [only] with actual devaluations (...) for two reasons: First, not all speculative attacks are successful. The currency may be supported through the expenditure of reserves (...). Alternatively the authorities may repel attacks by rising interest rates. (...) Ideally, an index of speculative pressure would be obtained by employing a structural model of exchange rate determination, from which one would derive the excess demand for foreign exchange."

So the speculative attack can manifest itself via three not mutually exclusive channels: currency devaluation, foreign exchange reserves losses and sharp increases in (short term) interest rates. It became somehow common in the literature to use so-called exchange market pressure index [after Girton and Roper, 1977]. It is an average of the changes in the above mentioned three components weighted by respective standard deviations (so their contribution become comparable). Crisis is said to happen if that index exceeds certain threshold – usually its mean plus some number times its standard deviation. It is not very surprising that different authors use different version. Eichengreen, Rose and Wyplosz use the mean plus 1.5 times the standard deviation; Kaminsky, Lizondo and Reinhart (1998) require the index to be 3 standard deviations above its mean. Some authors regress the index itself.

In defining crisis I proceed as follows:
– I construct exchange market pressure index as the standard-deviation-weighted average of changes in (log) exchange rate, (log) reserves (with a minus sign), and short term interest rate. At period \(\tau\) change is measured not from period \(\tau-1\), but from the average of periods \(\tau-3, \tau-2\) and \(\tau-1\). That is because in times of turmoil these variables get unusually volatile – it smooths the behavior of the index and make it consistent with itself. For currency boards exchange rate change doesn't enter the index.
– crisis dummy variable is set to one if and only if exchange market pressure index exceeds 2.25 its standard deviation above its mean (2.25 is halfway in-between 1.5 and 3) and at least one of the components has an absolute change of at least 1.5% (that excludes small changes in very stable countries, e.g. Netherlands, from being interpreted as crises).
1.2. Data, Methodology and the Results

I'm working on an unbalanced panel of 46 developed and emerging economies [9] observed monthly from January of 1990 until March 1999.

Most of the data comes from International Monetary Fund's *International Financial Statistics* CD-ROM. Another large part is taken from OECD's *Main Economic Indicators*. Data on short-term debt comes from BIS/IMF/OECD/WB project. Some of the data are taken from financial informational services like Reuters or Bloomberg. IMF's reports *Exchange Arrangements and Exchange Restrictions* have been studied to extract information about exchange rate arrangement for regime dummy variables. Data on foreign trade comes from IMF *Directions of Trade Statistics*. A lot of missing observation has been completed thanks to Internet sites of National Central Banks and National Statistical Offices.

Still, the data is severely constrained by missing observation, and the requirement that all variables' time series must be of the same length within the country – all the incomplete observations has been discarded.

The data has been then visually inspected for notorious mistakes, which has been corrected. There were some problems with data frequency – mainly with GDP, which usually is not collected monthly. It has been overcome by approximating GDP with industrial production.

This basis has been further contracted by the requirement of comparability. Particularly:
– data on emerging countries from Central and Eastern Europe has been restricted not to begin before January 1994,
– data on some Western European countries that entered the EMS or started a peg (reasonably short period) after January 1990 has been cut to start at their accession (beginning of the peg),
– data on emerging countries from Latin America start right after they have suppressed the hyperinflation and implemented stabilization plans,
– for some countries data has been set to begin at the time that a country in question abandoned dual exchange rate system, and unified both rates,
– for countries that presently form the EMU time series end on December 1998,
– some data has been additionally dropped in the estimation procedure due to insufficient variation.

[9] Argentina, Australia, Austria, Belgium, Bolivia, Brazil, Bulgaria, Canada, Colombia, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Greece, Hong-Kong (SAR), Hungary, Iceland, India, Indonesia, Ireland, Israel, Italy, Korea, Lithuania, Malaysia, Mexico, Netherlands, New Zealand, Norway, Pakistan, Peru, Philippines, Poland, Portugal, Russia, Singapore, Slovak Republic, Slovenia, South Africa, Spain, Sweden, Thailand, Turkey, United Kingdom.
The statistical method of the analysis has naturally far reaching consequences for the results. Apart from the graphical analysis, "visual" or "narrative" approaches, or univariate maximizations there are two main and popular methods for estimating currency crisis prediction models, namely: simple linear regression and probit models.

In this study I employ panel data fixed effects linear specification. The motivation is as follows:

- such model allows the appreciation of differences between countries and sufficiently exploits within as well as between dimension of the data,
- it is of no importance that this model allows the inferred crisis index to exceed one, or to be negative, as long as one doesn't interpret crisis index as the probability of a crisis,
- linear and probit/logit based binary choice models usually give similar qualitative results unless the variable in question is of low or no significance,
- probit/logit models put rather tight distributional assumptions on the error term structure.

Nevertheless, as a benchmark, I also employ also a probit model.

Summing up I estimate the following models:

\( \text{Crisis}_{i,\tau} = \kappa + \alpha_i + x_{i,\tau}' \beta + \eta_{i,\tau} \)  \hspace{1cm} (16)

where \( x_{i,\tau} \) denotes the vector of regressors (macroeconomic fundamentals, constant excluded), \( \beta \) denotes the vector of coefficients, \( \alpha_i \) denotes country specific intercept term, \( \kappa \) is a constant, \( \eta_{i,\tau} \) is an error term – distributed independently and identically over time and over countries, with mean zero and a standard deviation of \( \sigma_\eta \). The model is estimated by means of the OLS.

as well as

\( \text{Crisis}_{i,\tau} = \Pr(\text{Crisis}_{i,\tau} = 1) + \eta_{i,\tau} \)  \hspace{1cm} (17)

\( \text{Crisis}_{i,\tau} = \begin{cases} 
1 \leftrightarrow C^* > 0 \\
0 \leftrightarrow C^* < 0 
\end{cases} \)  \hspace{1cm} (18)

\( C^* = \kappa + x_{i,\tau}' \beta + \varepsilon_{i,\tau} \)  \hspace{1cm} (19)

(probit model) with \( C^* \) as a latent state variable, and \( \varepsilon_{i,\tau} \) distributed standard normally, independently and identically over time and over countries. The model is estimated with the maximum likelihood.

I also estimate the model for each of the two subsamples i.e. emerging and developed economies for better inference and interpretation.
The results are summarized in Table 1.

In interpretation that follows I will base myself mainly on the coefficients obtained from linear regression.

First of all, it is clearly visible that real exchange rate and the level of foreign exchange reserves – standard and well identified variables of the "first generation" models as well as any empirical model employed to predict crises – has allover the predicted sign and unquestionable significance. This finding is in line with almost all empirical testing of crisis determinants. It is also important to recognize the differences in magnitude and significance of those two variables between subsamples. The RER overvaluation impact and importance is much lower for the emerging markets comparing to those developed. The explanation that comes to mind is the well known Balassa-Samuelson effect [10]. The opposite (but not as clear) story is with the reserves – sudden drop in reserves is more likely to harm developing economies – they ability to acquire emergency liquidity injection is limited.

Trade balance in probit specification has both the predicted sign and sufficient significance. We should however admit that different countries have different levels of current account sustainability [11]. Consequently if we allow for country-specific level of sustainability the implications of trade balance for currency crisis prediction shrink to nil.

Two measures of government policy stance – government budget surplus and domestic credit creation – are clearly proven to have its significant impact on the exposure to the currency crisis. Expansionary fiscal policy reflected in budget deficits, and its financing by domestic credit expansion is – as "first generation" models predict – a shortcut to foreign exchange market crash. This is especially evident in the case of emerging markets that usually don't have sufficient capacity to absorb additional domestic credit.

I find only weak backing for the thesis that variables entering (according to early "second generation" models) the government’s utility function (inflation and unemployment) play certain role in attracting crises – they are usually only properly signed.

The data doesn't support the view that the output gap (in absolute values) plays any important role. That might be due to somehow unusual specification.

Short-term debt level and the degree of non-bank financial institution activity coefficients are accurately signed and have some significance for the whole sample and for emerging markets.

---

[10] Emerging markets use to have (seemingly) overvalued real exchange rates due to faster economic growth and divergence in tradable and non-tradable goods sectors' productivity.

[11] For example CEE economies like Estonia or Poland use to run enormous trade deficit, not having suffered up to the present any severe currency crisis – the deficit is financed by the inflow of FDI.
Table 1: Fixed effects linear regression and probit results

<table>
<thead>
<tr>
<th>Regressors</th>
<th>Whole sample</th>
<th>Emerging markets</th>
<th>Developed economies</th>
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<tr>
<td></td>
<td>linear</td>
<td>probit</td>
<td>linear</td>
</tr>
<tr>
<td>RER</td>
<td>• 0.4254</td>
<td>!</td>
<td>• 0.1684</td>
</tr>
<tr>
<td>Fx Reserves</td>
<td>• 0.1599</td>
<td>!</td>
<td>• 0.0197***</td>
</tr>
<tr>
<td>Trade balance</td>
<td>• 0.0122</td>
<td>• 0.0417</td>
<td>!</td>
</tr>
<tr>
<td>Govnmt surplus</td>
<td>• 0.8346</td>
<td>!</td>
<td>0.0679</td>
</tr>
<tr>
<td>Domestic credit</td>
<td>• 0.1259</td>
<td>!</td>
<td>• 0.0432</td>
</tr>
<tr>
<td>Inflation</td>
<td>• 0.4160</td>
<td>!</td>
<td>0.0157</td>
</tr>
<tr>
<td>Unemployment</td>
<td>• 0.0007</td>
<td>• 0.0001</td>
<td>!</td>
</tr>
<tr>
<td>Output gap</td>
<td>• 0.2452</td>
<td>• 1.4927***</td>
<td>-0.6657</td>
</tr>
<tr>
<td>Short term debt</td>
<td>• 0.032 ***</td>
<td>• 0.0045</td>
<td>*</td>
</tr>
<tr>
<td>Non-bank instit.</td>
<td>• 0.3575</td>
<td>-0.0185</td>
<td>0.3464</td>
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<td>Int’l interest rate</td>
<td>-0.3145</td>
<td>-0.7063</td>
<td>**</td>
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<td>Managed float</td>
<td>-0.0412</td>
<td>-0.0105</td>
<td>!</td>
</tr>
<tr>
<td>Peg</td>
<td>• 0.0021</td>
<td>-0.0096</td>
<td>-0.0141</td>
</tr>
<tr>
<td>Multp equilibria</td>
<td>• 0.0085</td>
<td>• 0.0093</td>
<td>!</td>
</tr>
<tr>
<td>Trade contagion</td>
<td>• 0.1591</td>
<td>!</td>
<td>• 0.0668***</td>
</tr>
<tr>
<td>Inform. spillover</td>
<td>• 0.0085</td>
<td>• 0.0093</td>
<td>!</td>
</tr>
<tr>
<td>No of observ.</td>
<td>2355</td>
<td>2355</td>
<td>999</td>
</tr>
<tr>
<td>within/pseudo R²</td>
<td>0.0978</td>
<td>0.1229</td>
<td>0.2022</td>
</tr>
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</table>

Probit estimated with maximum likelihood. Probit coefficients expressed as derivatives of the probability to change in underlying fundamental evaluated at mean (∂F/∂x | x=x-bar). For discrete variables (marked with ☯) derivative is to discrete change in the variable. Country specific intercepts of fixed effects estimation not reported. • - coefficient signed as predicted. Significance level: • 25%, ** 10%, *** 5%, ! 1% and higher, based on t-statistics (z-statistics) for hypothesis of no effect. Slopes correctly signed and significantly different from zero at the 0.05 are shaded.
The coefficient accompanying the international interest rate poses some puzzle. Its importance is undoubtfully clear only in the case of emerging markets. The result for developed countries is a kind of anomaly.

I presupposed the exchange rate regime dummy variables to have positive coefficients, i.e. any attempt of the authorities to control the exchange rate exposes a country to increased market pressure ("currency peg is the accident waiting to happen"). The data doesn't provide much support for that.

Also multiple equilibria dummy has apparently no significance in the model. It seems that Jeanne's (1997) idea of practical application of the notion of self-fulfilling crisis has mainly theoretical appeal; its potential empirical reflection must be overridden by other factors.

Last but not least come two contagion indexes. The results on trade contagion reinforce the view that trade links have indeed crucial meaning in the spread of currency crises (compare Glick and Rose (1999), who find parallel relationship). This effect is much stronger in the case of emerging markets.

The category contagion due to informational spillovers is also proven to be important – a crisis in a similar country raises the probability of a crisis in a given country. The contagion effect works through (at least) two distinct channels [12].

In general a currency crisis spreads much more easily among emerging markets.

Rather clear picture arises from the analysis. There is a set of variables – that is to say real exchange rate overvaluation, foreign exchange reserves deficit, domestic credit expansion, government budget deficit, trade links or similarities with countries suffering crises, and others – that have indeed apparent predictive potential with respect to currency crisis. The overall fit of the employed models is not very impressive but reasonable – it ranges from 7 to 27%. There is much more predictability in the emerging markets – perhaps the sophistication of the policy instruments available to them to counteract mounting problems – and wipe out this way some of the predictability – is limited. Some results of a predicting performance of the model are presented in Figure 3. It includes the predictions from the linear fixed effect regression. The horizontal axis indicates time, the vertical axis – inferred severity of the crisis index. Crisis periods are indicated with a circle [13].

[12] The two indexes exhibit analogous qualitative patterns. It may suggest that both reflect just the basic relationship that crisis elsewhere has an impact on probability of a crisis in home country. However the correlation between these two variables is only 0.09 and a quantitative comparison of relative magnitudes of their coefficients gives much room for the hypothesis that contagion effect works indeed through distinct channels.

[13] Because the model is linear and because each country has it specific constant (fixed effects) the inferred "probabilities" are not necessarily between 0 and 1. Instead they should rather be treated as a "vulnerability to crises" index – comparable between countries. Within countries only relative changes matter (absolute values should be compared with an average for a given country).
2. The Universality of the Results

One is right to retain some degree of reservation with respect to such analyses. Although there are some common findings in the empirical literature, there are also many differences. In recent years various researchers have claimed success in systematically predicting currency crises with different methods and approaches, and to have discovered different variables responsible for foreign exchange market events. They usually back their claims with regressions having significant coefficients on variables in question.

There is a point in assessing the reliability of such findings – to what extent are they "true", common, similar and to what extent fall they prey to data mining biases (data-set overusing), departures from actual a priori null-hypothesis specification, etc.

In other words – what can expect the researcher setting off in pursuit for crisis predictability assessment.

2.1. Crisis Definition

When a researcher has made a decision that the data, not he himself, would decide what qualifies as a crisis and what doesn't, he faces a choice of a selection algorithm. The trade-off in such mechanism is obvious: the more "true" crises it captures the more "tranquil" period it marks as crises.

I proceed as follows: basing on the financial press, journal articles, common knowledge, my experience and on the visual analysis of the data I manually select months that can be called crisis periods. Then I construct market pressure index (as described above) using the following parameters:

– number of index components (three or two – without interest rate),
– length of moving average from which the change in fundamental is assessed (from one-just first difference, to twelve),
– weights for underlying index component,

When the index has been constructed I define crises to exist when it satisfies certain conditions with parameters as follows:

– threshold it has to exceed to be qualified as a crisis (from 1,25 to 2.5 its standard deviation above its mean),
– number of periods between and after a crisis to be set to crisis or to missing (from 0 to 6),
Figure 3. Successes and failures in predicting crises. Predictions from the linear fixed effect regression. On the horizontal axis – time, on the vertical axis – inferred severity of the crisis index ("probability" of a crisis). Crisis periods are indicated with a circle.
The combination of these criteria gives at least several dozen thousand of algorithms – I compare them on the basis on how precisely they have identified crises periods relative to my hand-picked specimen.

The outcome is presented in the Figure 4. On the horizontal axis I mark how many percent of the total sample has been covered with bad predictions (indicating crisis in a tranquil period). On the vertical axis – how many percent of total crisis periods have been called (good predictions). Each dot represents one algorithm.

The figure portrays a typical trade-off problem. It has a "Pareto optimal" frontier. The implication is the fact that there are better and worse ways of selecting crises periods from the sample. The best algorithms minimize the number of bad predictions for a given accuracy (percent of crisis periods correctly called). The researcher has to decide what is his trade-off between good and bad predictions (his "indifference curve") and choose the appropriate algorithm (on the "Pareto" frontier).

The straight line represents my "indifference curve". Judging from visual inspection of its prediction this paper's crisis index does a good job in calling all major and medium crises and at the same time it has a low dispersion. Of course the above analysis is very subjective – economists differ in what events they call crisis [14].

[14] This issue is somehow analogous to the interdependence between type-I and type-II errors in econometric hypothesis testing – their probability cannot be simultaneously minimized.
2.2. The Significance of Fundamentals

Afterward I estimate my two models with regressors modified in various ways and in different configurations.

 Modifications include:
  – various computations of real exchange rates: CPI based, relative normalized unit labor cost based, real export value based etc.,
  – foreign reserves represented as a ratio to GDP or to import,
  – trade balance as it is, squared (sign corrected), as a dummy (sign corrected) equal to one when exceeding five different thresholds,
  – government surplus treated similarly,
  – domestic credit and short term debt represented as a ratio to GDP or to reserves,
  – different computations of the output gap,
  – different composition of international interest rate,
- "drift adjustment" (in a sense of Bertola and Svensson), no adjustment, different trend specifications in the multiple equilibria dummy,
- different versions of trade link contagion index with different lags, and it is combined with
- different crises selection algorithms,

Around 5000 regressions are exercised in total. Since the coefficients are not directly comparable [15] I present only sample distributions of t-statistics (for null hypothesis of no effect) obtained from those regressions. I also report a sample distribution of the R² 's. Densities for subsamples have been scaled down by the factor of two, not to obscure figures. Averages are indicated with a dashed line. The results are presented in Figure 5 [16].

Given the large amount of the literature on currency crises prediction and various results obtained by the authors this exercise was meant to reconcile these differences by assessing what is an "average" prediction, regardless of variables used, regressors' specification, methods employed and other variations and definitions [17].

3. Conclusions

The study found quite considerable amount of predictability, particularly on behalf of standard leading crisis indicators, such as overvaluation of the real exchange rate and the level of foreign exchange reserves. Multiple equilibria don't get much support from the data while contagion effect is obviously working – apparently through various channels.

The predictability is especially evident in the case of emerging economies.

What is the explanation for that relatively large predictable component in currency crises probability assessment – and, more generally, what is, if any, the role for currency crises prediction?

After deeper inquiry one may well be tempted to conclude that if currency crises increase (as they most probably do) social loss function, and the authorities have any

[15] Common interpretation of the slope coefficients is \( \frac{\partial E(y)}{\partial x} = \beta_x \). However the magnitude of \( E(\Delta x) \) can vary substantially from model to model obscuring comparison between them.

[16] For example a typical study should, on average, find that, say, trade balance deficit (current account) has a positive influence on the probability of the crisis but it is usually not very significant (average t-statistic=0.5). It should have no significance for emerging economies (t-statistic=0, i.e. current account doesn't matter) and be highly significant for developed countries (t-statistic around 2).

[17] There is, however, the possibility for further extensions: the sample composition, time period, etc. can also be altered to check for the sensitivity and the significance of the results.
power to influence the state of the economy – so there should be no room for currency crises prediction from the point of view of the policymaker. Any information contained by any variable should be immediately and continuously incorporated into government's (or market's) reaction function in the attempt to avoid currency crash (capital losses) and to return on the "balanced path".

But such a conclusion would be, naturally, premature. When we allow for self-fulfilling crises and for problems with expectations coordination then there is nothing wrong with a situation that everybody knows the probability of a crash is significant and yet nobody withdraws. It is a Perfect Bayesian Nash equilibrium based on a balance of beliefs. No one wants to be the first to leave profitable market, especially when the timing of a crisis is indefinite (compare with an interesting model of Caplin and Leahy (1994)).

On the side of the policymaker – at any moment the decision to devalue is the outcome of his maximization problem [18]. The probability of a crisis usually enters a trade-off with the state of the economy the policymaker desires. As a consequence he does not want this probability to be zero in general. Instead, he weights costs (sacrifice ratios) of adjusting the economy against benefits of the present state, net of the expected costs of a crisis.

This is why we can have significant variables in predicting crisis. This is also precisely the role of currency crisis prediction – i.e. to discover the dynamics (statistical properties) of such interplay of expectations and its expected outcome (the probability and expected magnitude of a crash) conditional on the state of fundamentals.

The scale of surprise with which the Mexican and especially the Asian crises has been welcomed indicates that the job is far from being completed. But on the other hand there is not enough data (in quantity and quality), so to speak, not enough well described crises episodes so far, to draw precise inferences.

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[18] In words of Obstfeld and Rogoff (1995) "most central banks have access to enough foreign exchange resources to beat down a speculative attack of any magnitude, provided they are willing to subordinate all the other goals of monetary policy." (italics on behalf of OR).
Figure 5. The ultimate significance of macroeconomic fundamentals in currency crises prediction. (Sample distribution of t-statistics obtained from regressions with different specification of dependent and explaining variables)
Figure 5. The ultimate significance of macroeconomic fundamentals in currency crises prediction. (Sample distribution of t-statistics obtained from regressions with different specification of dependent and explaining variables) - continued
Figure 5. The ultimate significance of macroeconomic fundamentals in currency crises prediction. (Sample distribution of t-statistics obtained from regressions with different specification of dependent and explaining variables) - continued
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