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Jesús Crespo Cuaresma and Tomas Slacik

An "almost-too-late" warning mechanism for currency crises

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Editor-in-Chief Iikka Korhonen

BOFIT Discussion Papers 4/2007
23.2.2007

Jesús Crespo Cuaresma and Tomas Slacik: An "almost-too-late" warning mechanism for currency crises

ISBN 978-952-462-854-9
ISSN 1456-4564
(print)

ISBN 978-952-462-855-6
ISSN 1456-5889
(online)

Multiprint Oy
Helsinki 2007

An "Almost-Too-Late" Warning Mechanism For Currency Crises*

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Abstract

We propose exploiting the term structure of relative interest rates to obtain estimates of changes in the timing of a currency crisis as perceived by market participants. Our indicator can be used to evaluate the relative probability of a crisis occurring in one week as compared to a crisis happening after one week but in less than a month. We give empirical evidence that the indicator performs well for two important currency crises in Eastern Europe: the crisis in the Czech Republic in 1997 and the Russian crisis in 1998.

Keywords: Currency crisis, term structure of interest rates, transition economies.

JEL classification: F31, F34, E43.

*We would like to thank Raimund Alt, Peter Backe, Balazs Egert, Doris Ritzberger-Gruenwald, Peter Mooslechner and participants in an internal seminar at the Oesterreichische Nationalbank for very helpful comments. The views expressed in this paper are those of the authors and do not necessarily represent the position of the Oesterreichische Nationalbank.

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1 Introduction

The abundance and severity of currency crises and speculative attacks over the past 15 years has spawned a rebirth of interest among researchers, politicians and central bankers in these events. Currency crises tend to be painful and costly for the affected economy and usually afflict the population immediately. Two recent cases illustrate this. The Argentine financial turmoil of 2002, one of the most violent currency crises on record, induced an increase in the poverty rate of more than 50% and drove nearly two out of three Argentines below the poverty line. Indonesia's crisis in 1998 caused a drop in GDP of more than 13% within a year.

Considering the spectrum of distinct exchange rate arrangements, ranging from totally flexible exchange rates to monetary unions and currency boards, there seems to be ample evidence that intermediate regimes such as fixed and crawling pegs or fluctuation bands are most prone to speculative attack. For this reason, countries have increasingly abandoned intermediate regimes for arrangements at the extremes (see e.g. Fischer, 2001).[1] Yet today an unraveling of current global imbalances threatens even a large and closed economy with a flexible exchange rate regime like the United States with abrupt and significant currency depreciation (see Roubini and Setser, 2005). While admittedly experts who consider this possibility as remote likely outnumber proponents of the view that the Bretton Woods 2 system of exchange rates is unsustainable (see e.g. Dooley et al, 2004; or Hausmann and Sturzenegger, 2005), there are undoubtedly countries whose fundamental macroeconomic and/or political conditions make them vulnerable to speculative attack. Hungary, for example, which still maintains an intermediate exchange rate arrangement, was running a current account and fiscal deficit in 2005 roughly 2.5 times greater than Argentina before its devastating crisis hit.

Motivated by the damaging potential effects of currency crises, both the theoretical and empirical literature has received renewed attention from researchers. Not only have new generations of currency crisis models been developed in response to unsatisfactory theoretical instruments to describe and explain causes and frequency of crises in the 1990s, economists have also started pondering ways to predict the timing of such events (e.g. both the Mexican crisis in 1994

[1] Notwithstanding the fact that *de jure* exchange rate regimes need not coincide with *de facto* regimes (see Calvo and Reinhart, 2002).

and the Asian crisis in 1997 essentially caught the international community flat-footed). Unfortunately, the forecasting models proposed over the past few years have generally demonstrated only fair-to-middling predictive accuracy.

Kaminsky, Lizondo and Reinhart (KLR) pioneered quantitative currency crisis early-warning systems (EWS) with their "indicator" model developed in a series of papers (see Kaminsky, Lizondo and Reinhart, 1998). The KLR approach monitors the evolution of several economic variables (indicators) such that when a variable deviates from its "normal" level beyond a threshold value, a signal is said to issue. The threshold value is chosen so as to minimize the noise-to-signal ratio given the data available. Eventually, a composite indicator is constructed as an average of indicators, weighted by frequency of correct predictions.

Following KLR, academics and economists working in the private sector produced a wide range of currency crisis forecasting models. Unlike the indicator approach, most are variations of logit or probit regressions. It is noteworthy that all such models, including the KLR model, use fundamental data such as current account, exchange rate overvaluation or export growth as explanatory variables. The variable choices are predominantly inspired by the three generations of theories of balance-of-payment crises, but they tend to be limited by availability of data. The academic models tend to be long-sight approaches with forecasting horizons of up to two years, while their private-sector counterparts usually focus on a brief windows of one to three months.

Berg et al. (2004) not only give a very helpful overview of the abundant literature on EWS, they also address the question of how much, if any, out-of-sample forecasting value derives from EWS. They put particular emphasis on the potential performance of models in real time and reach rather disappointing conclusions. Only one of the long-horizon forecasts under consideration (the KLR model forecast) provides better accuracy compared with pure guesswork and non-model based predictions, while short-horizon private-sector approaches by and large perform poorly. Anzuini and Gandolfo (2003), when testing whether the KLR would have forecast the Thai crisis of 1997, conclude the indicator approach has strong ex-post explanatory power but quite limited predictive abilities.

In this paper, we propose exploiting the term structure of relative interest rates to obtain estimates of changes in the timing of a currency crisis as perceived by market participants. To our knowledge, only a handful of researchers have used this approach. The essence of our model is based on the seminal work by Collins (1984), who applied her analysis to the March 1983 devaluation of the French franc relative to the German deutschmark. The Collins approach was also used in Anzuini and Gandolfo (2003), who compare the predictive power of the KLR approach and the Collins model. They conclude that the Collins non-structural approach forecasts well but does not explain, while the opposite is true for the structural KLR model. This approach does not rely on the estimation of thresholds (eventually common to a group of countries) based on fundamentals, but instead extracts expectations on the timing of the crisis from country-specific interest rate data. Compared with the KLR and other EWS, this approach has several important advantages. First, it requires no definition of a crisis in terms of percentage devaluation/depreciation, which, as the literature shows is rather arbitrary anyway. Moreover, no pooling of data is necessary to obtain a sample of a usable size. For each country in question, only its own specific data may be used. In addition, as the model uses only very basic data such as interest and exchange rates; it is not heavily limited by data availability. We construct an early warning indicator that can be used to evaluate the relative probability of a crisis occurring in one week as compared to a crisis happening after one week but in less than a month. Subsequently, we provide empirical evidence that the indicator performs well for the currency crises in the Czech Republic in 1997 and in Russia in 1998.

The paper is structured as follows. In the next section the theoretical model is developed. In sections three and four, we apply the indicator to the crisis of the koruna and ruble crises in 1997 and 1998, respectively. Section 5 concludes and sets up paths of further research.

2 Uncovered interest rate parity and currency crises

Recent research on the predictive power of markets suggests that markets can aggregate disperse information and that market-based forecasts of uncertain events are usually fairly accurate. Moreover, such forecasts typically outperform alternative forecasting tools, including highly sophisticated forecasting models, polls or expert surveys (see e.g. Wolfers and Zitzewitz, 2004). The basic objective of our analysis is to examine the ability of foreign exchange markets to foresee exceptional exchange rate devaluations. In substance, the following model is based on the work by Collins (1984) (see also Anzuini and Gandolfo, 2003), designed to study the behavior of speculators prior to the French franc realignment in 1983. Our theoretical setting extends and generalizes the original model in several aspects.

The aim of our study is to construct an indicator based on basic economic theory (the uncovered interest rate parity, henceforth UIP) to proxy the change in the time structure of the underlying expected probabilities of devaluation implied by the relative term structure of interest rates. Assuming perfect capital mobility, risk neutrality, and arbitrage, the UIP can be written as

$$\frac{(1+i_{t,k})}{(1+i^*_{t,k})} = \frac{E(e_{t+k}|\Omega_t)}{e_t} + \rho_{t,k}, \tag{1}$$

where e_t is the spot exchange rate at time t, defined as the price of foreign currency in domestic currency units, $i_{t,k}$ and $i^*_{t,k}$ are, respectively, the domestic and foreign interest rates at time t on deposits with maturity k. $E(e_{t+k}|\Omega_t)$ stands for the expected exchange rate in period $t+k$ given the information available at time t (the information set Ω_t) and $\rho_{t,k}$ represents a premium for risks not immediately related to the exchange rate movements (e.g. country default risk).[2]

Equation (1) states that the relative yield on domestic deposits of a given maturity is equal to the expected exchange rate movement and some well-defined country risk premium. Rewriting (1) to obtain an explicit relationship between exchange rate expectations and the interest rate structure, we obtain

[2] In our specification, the risk premium is assumed to be unrelated to the exchange rate. In certain cases, it may be reasonable to assume that the exchange rate level has an effect on the risk premium. For instance, if domestic debt is denominated mostly in the currency of the foreign country, one might expect that after a substantial devaluation, the probability of default and thus the risk premium in the domestic country would rise. This effect can be easily incorporated in the model by specifying a functional form linking the exchange rate to the risk premium. If the relationship is assumed to be linear in the exchange rate with a slope that is not maturity-dependent, the results presented in this section remain unchanged. For a general functional specification of this relationship, the model could still be applied after calibrating some extra parameters. We do not follow this avenue in the present study, although this generalization is proposed as an interesting future path of research.

$$E(e_{t+k}|\Omega_t) = \left[\frac{(1+i_{t,k})}{(1+i^*_{t,k})} - \rho_{t,k}\right] e_t. \tag{2}$$

From the perspective of the market agent forming expectations in time t, the exchange rate can remain stable, appreciate, or depreciate. Therefore, the exchange rate expected as of t for the period $t+k$ is a weighted average of these scenarios, where the weight assigned to each possible exchange rate movement is the subjectively perceived probability of these events. Formally, this implies that

$$E(e_{t+k}|\Omega_t)) = (1-\pi_{t,k})s_{t,k} + \pi_{t,k}z_{t,k}, \tag{3}$$

where $z_{t,k}$ is the expected exchange rate in period $t+k$ in case of devaluation, $z_{t,k} = \gamma_{t,k}e_t$, where $\gamma_{t,k} > 1$, and $s_{t,k}$ is the expected exchange rate conditional on no devaluation (in other words, the exchange rate remains stable or appreciates), and $s_{t,k} = \delta_{t,k}e_t$, where $\delta_{t,k} \leq 1$. The subjective probability of devaluation having occurred after k periods is therefore $\pi_{t,k}$. In addition, along the lines of Collins (1984), we assume that the rate of depreciation or appreciation does not depend on the temporal horizon, so that $\delta_{t,k} = \delta_t$ and $\gamma_{t,k} = \gamma_t$. It follows that

$$E(e_{t+k}|\Omega_t) = [\delta_t + (\gamma_t - \delta_t)\pi_{t,k}]\, e_t, \tag{4}$$

which can be substituted in (2) so as to establish the link between relative yields and the subjective devaluation probability

$$\alpha_{t,k} = \delta_t + (\gamma_t - \delta_t)\pi_{t,k} + \rho_{t,k}, \tag{5}$$

where $\alpha_{t,k} = (1+i_{t,k})/(1+i^*_{t,k})$. The essential term in equation (5) is the perceived probability of a devaluation between time t and $t+k$, $\pi_{t,k}$. Anticipating the empirical application of the method, we restrict ourselves to devaluations occurring within each of the time intervals corresponding to the maturities of the available time deposits. If there are $J-1$ different maturities of deposits ordered from the shortest to the longest, there are J possible states of the world at time t. An exceptional devaluation might occur before the time implied by the shortest maturity available, between maturities of deposits k and $k+1$ or, finally, there might be a devaluation after the longest deposit matures. Defining as $\eta_{t,j}$ the probability of a devaluation happening between period $t+j-1$ and $t+j$,

$$\pi_{t,k} = \sum_{i=1}^{k} \eta_{t,i}, \tag{6}$$

which implies that

$$\frac{\alpha_{t,k} - (\delta_t + \rho_{t,k})}{(\gamma_t - \delta_t)} = \sum_{j=1}^{k} \eta_{t,j}. \tag{7}$$

For the sake of illustration let us suppose that there are two maturities $k = 7$ and $k = 30$ days (this will be the case in the empirical illustration in the following section). Then, it can be easily shown that

$$\eta_{t,7} = \frac{\alpha_{t,7} - (\delta_t + \rho_{t,7})}{(\gamma_t - \delta_t)}, \tag{8}$$

$$\eta_{t,30} = \frac{\alpha_{t,30} - \alpha_{t,7} - (\rho_{t,30} - \rho_{t,7})}{(\gamma_t - \delta_t)}. \tag{9}$$

By taking ratios or log-ratios of the expressions above, we can identify changes in the time structure of subjective probabilities of a devaluation implied by the term structure of interest rates. Furthermore, the ratios are independent of the assumed size of the devaluation, γ_t. In particular, the indicator proposed, $I_{j,s,t}$, aimed at comparing the probabilities of devaluation at horizons j and s ($j < s$), corresponding to two observed maturities, is

$$I_{j,s,t} = \begin{cases} \log\left(\frac{\alpha_{t,j}-\alpha_{t,j-1}-(\rho_{t,j}-\rho_{t,j-1})}{\alpha_{t,s}-\alpha_{t,s-1}-(\rho_{t,s}-\rho_{t,s-1})}\right) & \text{for } j, s > 1, \\ \log\left(\frac{\alpha_{t,j}-(\delta_t+\rho_{t,j})}{\alpha_{t,s}-\alpha_{t,s-1}-(\rho_{t,s}-\rho_{t,s-1})}\right) & \text{for } j = 1, s > 1. \end{cases} \tag{10}$$

In order to make (10) operational, the expected appreciation parameter, δ_t and the respective risk premia for each maturity need to be imputed. If we assume that $\delta_t = 1$ and $\rho_{t,i} = 0 \ \forall i$, (10) boils down to the expression put forward in Collins (1984). The problem with this setting is that it can lead to negative probability estimates for empirical applications, and thus log-ratios that are not defined. The inclusion of risk premia and potential appreciation expectations in (10) allows us to elaborate corrections of the basic indicator to avoid negative probability ratios.

The problem of negative probability ratios is particularly important when dealing with data from Eastern European transition economies. Taking the simple case without risk premium (i.e. setting $\rho_{t,s} = 0\ \forall s$ above) and $\delta_t = 1$, it can be easily seen that for a relatively flat yield curve in the foreign economy, if $i_t, 7$ tends to be higher than $i_t, 30$ negative values can be obtained in the numerator of (9). This constellation, caused by a downward-sloping yield curve in the domestic economy, is not unusual in the recent history of Eastern European economies, where sustained disinflationary experiences rendered a term structure of interest rates with lower nominal interest rates in longer maturities.

A simple correction to the simple setting based on future expected inflation can be put forward to link the setting including risk premium to a yield curve that is potentially negatively sloped. In a disinflationary framework, with $E(\lambda_{t,30}|\Omega_t) < E(\lambda_{t,7}|\Omega_t)$, we can correct the interest rate with longer maturity (we denote the corrected rate by $i_{t,30}^{corr.}$) by subtracting $E(\lambda_{t,30}|\Omega_t) - E(\lambda_{t,7}|\Omega_t)$ from the original rate, so that the corrected numerator of equation (9) for the case without risk premium is given by

$$\begin{aligned}
\alpha_{t,30}^{corr.} - \alpha_{t,7} &= \frac{1 + i_{t,30}^{corr.}}{1 + i_{t,30}^{*}} - \frac{1 + i_{t,7}}{1 + i_{t,7}^{*}} = \\
&\quad \frac{1 + i_{t,30} + E(\lambda_{t,7}|\Omega_t) - E(\lambda_{t,30}|\Omega_t)}{1 + i_{t,30}^{*}} - \frac{1 + i_{t,7}}{1 + i_{t,7}^{*}} = \\
&= \frac{1 + i_{t,30}}{1 + i_{t,30}^{*}} - \frac{1 + i_{t,7}}{1 + i_{t,7}^{*}} + \frac{E(\lambda_{t,7}|\Omega_t) - E(\lambda_{t,30}|\Omega_t)}{1 + i_{t,30}^{*}} = \\
&\quad \alpha_{t,30} - \alpha_{t,7} + \frac{E(\lambda_{t,7}|\Omega_t) - E(\lambda_{t,30}|\Omega_t)}{1 + i_{t,30}^{*}}.
\end{aligned}$$

In other words, $\rho_{t,7}$ and $\rho_{t,30}$ in equation (9) may be interpreted as, respectively, $\frac{E(\lambda_{t,7}|\Omega_t)}{1+i_{t,30}^{*}}$ and $\frac{E(\lambda_{t,30}|\Omega_t)}{1+i_{t,30}^{*}}$ if the basic setting is employed and long-maturity interest rates are corrected for expected disinflation. In practice, this correction could be carried out for maturities of 7 and 30 days, for instance, by replacing $E(\lambda_{t,7}|\Omega_t)$ with the realized inflation level at time t and using a time series model to obtain forecasts for $\lambda_{t,30}$. In our empirical application below, we report the results of such a correction based on inflation forecasts.

3 The warning mechanism in action in the Czech and Russian currency crises

In this section, we apply the indicator put forward above to data from two recent currency crises in Eastern Europe: the Czech Republic crisis in May 1997 and the Russian crisis in 1998.[3] In both cases, we describe the economic frameworks in which the currency crises took place and present the real-time estimates of our indicator for both economies during the crisis period.

3.1 The 1997 Czech Republic crisis

In the early 1990s, the Czech Republic introduced a tight peg of the koruna to the deutschmark (DM) and the US dollar (USD) that used a currency basket made up of 65% DM and 35% USD from May 1993. The peg had fluctuation bands of ± 0.5% up to February 1996 and ± 7.5% from February 1996 until May 1997 crisis, which materialized with the abandonment of the peg on May 26, 1997 for a managed floating regime. The trade balance in the Czech Republic, which had been systematically positive since the break-up of Czechoslovakia, turned negative in 1996, with a corresponding slowing of economic growth. Horváth (1999) interprets the current account deficit in the Czech Republic as a reflection of insufficient private savings, which, coupled with the institutional framework Czech banking at that time, made the deficit unsustainable. Furthermore, the real exchange rate appreciated persistently and continuously in the period 1992-1997. Although trend appreciation is a common phenomenon in transition economies, which can be (at least partly) explained through the Balassa-Samuelson effect by differential productivity increases, Begg (1998) and Horváth (1999) argue that the real exchange rate dynamics implied a loss of competitiveness of the Czech economy. The adverse macroeconomic framework, together with an unstable political environment, led to a speculative attack on the koruna and a change in the exchange rate regime in May 1997.

Figure 1 shows the daily exchange rate of the Czech koruna against the basket in the period January-June 1997. The vertical line corresponds to the abandonment of the peg. As it can be seen in Figure 1, the exchange rate remained inside the ± 7.5% bands during the turmoil preceding the change in the exchange rate regime, and depreciated strongly as soon as the managed

[3] The choice of the crises is exclusively based on data availability.

float regime was in place. The fact that the monetary authorities were able to keep the koruna inside the fluctuation bands was mainly due to the heavy central bank interventions taking place in the week preceding the breakdown of the peg (see Horváth, 1999).

We calculated the indicator given by (10) using three different maturities for the Czech koruna exchange rate against both the DM and the USD for the period ranging from January 1st, 1997 to the abandonment of the peg on May 27th, 1997. We used the daily interbank rates with maturity one week ($i_{t,7}$ and $i^*_{t,7}$) and one month ($i_{t,30}$ and $i^*_{t,30}$) for the Czech Republic and, alternatively, Germany and the US.[4] The yield curve implied by the term structure of interbank rates in the Czech Republic is downward-sloping for most of the sample. If we were to obtain an indicator based on the assumptions imposed in Collins (1984) (that is, imposing $\delta_t = 1$ and $\rho_j = 0 \; \forall j$ in (10)), the results would imply negative values in the argument of the log-ratio corresponding to $\eta_{t,30}$, since $\alpha_{t,30}$ tends to be systematically smaller than $\alpha_{t,7}$ for the sample at hand. A possible way of overcoming this problem would be to redesign the log-ratio of probabilities by adding a constant to the numerator and denominator of the expressions in the log of (7) after setting $\rho_{t,i} = 0 \; \forall i$. In our setting, this can be reconciled with the existence of a certain maturity structure in the risk premium, such that, for example, $\rho_{t,j} - \rho_{t,j-1} = \rho_{t,s} - \rho_{t,s-1} = c < 0$ $\forall j > 1, j < s$, coupled with appreciation expectations (so that $\delta < 1$). In Figure 2 we show the resulting indicator after adding 0.3 to the nominator and denominator of the expression for $I_{7,30,t}$ in (7), so as to keep the structure of relative changes in the original estimates of $\eta_{t,7}$ and $\eta_{t,30}$ but avoid negative relative probabilities. The results presented in Figure 2 correspond to using the US as the foreign economy, but are identical to those using Germany. The results are also qualitatively identical for constants different from 0.3, as long as they avoid negative values in the argument of the log ratio. Furthermore, the results are also similar if the indicator is constructed under the assumption that $k = 7$ is not the shortest maturity.

Changes in the indicator can be interpreted as changes in the perceived probability of a crisis occurring in the following week as compared to a crisis happening in the period delimited by day seven and day thirty. The indicator remains practically constant from January to mid-May, and starts increasing dramatically on May 16th, reflecting a strong change in the perceptions of investors

[4]The source of the data used in this study is Datastream.

on the potential timing of a devaluation. The increase is strong and sustained until May 28th, and from that day onwards the indicator slowly decreases to a low level, comparable with the pre-crisis period. The indicator performs therefore extraordinarily as a (very-)short-term indicator of the crisis, and could be used ex-post as a device for dating the *de facto* occurrence of the crisis (since, *de jure*, the change of the exchange rate regime would be the corresponding indicator).

Alternatively, we also made use of the daily one month forward rates ($e^f_{t,30}$) for the koruna/USD exchange rate, which are available for the period under study, in order to get real-time estimates of $\rho_{t,30}$, given by

$$\rho_{t,30} = \frac{(1+i_{t,30})}{(1+i^*_{t,30})} - \frac{e^f_{t,30}}{e_t}. \tag{11}$$

Using these estimates we can include the dynamics of the risk premium in the indicator. Since due to lack of data we do not have estimates of $\rho_{t,7}$ for the pre-crisis period, let us assume that the dynamics of $\rho_{t,7}$ are similar to those of our estimate of $\rho_{t,30}$, although the level may be different, so that we assume $\rho_{t,30} < \rho_{t,7}$ in order to avoid negative probabilities, keeping the assumption $\delta_t = 1$. [5] The resulting indicator is plotted in Figure 3. We also computed the corresponding indicator for the German case, using a synthetic forward rate (since forward rates for the koruna/DM are not available for the period) obtained from other forward cross-rates and the resulting graph is similar to Figure 3.

The results concerning the leading indicator properties of the log-ratio are qualitatively similar to those obtained without the risk premium adjustment, although the indicator series is now relatively more volatile in the pre-crisis period.

We also performed the correction based on inflation expectations as follows. We used the realized inflation rate at time t (denote λ_t as the inflation rate in period t based on monthly data) as a proxy for $E(\lambda_{t,7})$, and for each period we estimated different models in order to obtain forecasts of $\lambda_{t,30}$ (π_{t+1} in monthly notation) using data up to time t. The dynamic behaviour of the corrected indicator is similar to that reported in Figure 2 if simple autoregressive processes

[5] Seven-days forward exchange rates for the crisis period are available, and confirm that the resulting risk premium for seven days was higher than $\rho_{t,30}$.

with and without deterministic trends are used as forecasting models. Since these parsimonious models tend to forecast future inflation relatively well, the correction is not able to render positive values of $\eta_{t,30}$ unless the data generating process assumed for inflation contains nonlinear deterministic trends that systematically produce strong disinflationary forecasts.[6]

Until now, no reference has been made to the size of the change in the indicator leading to a crisis signal. While several methods can be used to evaluate the threshold leading to significant signals, an extremely simple one based on the standarization of changes in the indicator seems to perform well. In Figure 4 we present the changes in the indicator at each period t standarized using the average change and standard deviation realized up to period $t-1$. We start the exercise in April 1997 based on indicator changes ranging from January 1997 and we also plot the 5% critical values corresponding to a standard normal distribution. The first significant change takes place on April 16th, and no false signal is sent before the crisis.

While the aim of the indicator proposed is to serve as a short-term leading indicator for exchange rate crises, we will study whether also in tranquil times relative changes of the indicator contain information about future changes in the exchange rate. This will be done by performing a simple out-of-sample forecasting exercise for the pre-crisis sample. The forecasting abilities of an autoregressive model on the first difference of the (log) exchange rate of the Czech koruna against the USD and the DM will be compared to those of a simple vector autoregressive (VAR) model including changes in the exchange rate and the indicator with risk premium adjustment.

The forecasting exercise is carried out as follows. Using data from January 1st to April 1st, 1997, an autoregressive model is estimated for the log changes in the exchange rate, together with a VAR for the vector of log changes in the exchange rate and the first difference of the indicator. In both cases, the lag length of the model is chosen so as to minimize AIC for the sample. Using the estimated models, out-of-sample forecasts are obtained for 1 to 30 (working) days ahead, and the forecasting errors are computed by comparing the forecasts with the real data. The observation corresponding to April 2nd is added to the sample, the models are estimated again and new out-of-sample forecasts are obtained. This procedure is repeated until all available observations have been used. In our case, since we are interested in the informational

[6] Detailed results on the correction are available from the authors upon request.

content of the indicator in the pre-crisis period, the full sample used ranges from January 1st to May 20th. With the forecasts, we compute the root mean square forecasting error (RMSFE) for each forecasting horizon, defined as $\text{RMSE}_h = \sqrt{\sum_{n=1}^{N_h}(e_n - \hat{e}_n)^2/N_h}$, where N_h is the number of h-steps ahead forecasts computed, e_n is the actual value of the exchange rate and $\hat{e}_n$ is the corresponding forecast.

Table 1 presents the results of the forecasting exercise. For each exchange rate considered, the improvement of RMSFE for the VAR model over the simple autoregression is presented for different forecasting horizons. The results of the corresponding Diebold-Mariano test (DM test, Diebold and Mariano, 1995) for equality of forecasting ability is also reported in each case. The forecasting abilities of the model including information on the indicator are superior to those of the autoregressive model for all forecasting horizons in the case of the US dollar, with marginal improvements on the forecasting error averaging 0.75% over the 30-day forecasting horizons. Although the improvement is very modest, it should be pointed out that the particular exchange rate regime of the Czech Republic for the period considered limited significantly the volatility of exchange rate movements for the period. The improvements are furthermore statistically significant for forecasting horizons over 5-days ahead. The results are not so positive for the DM, where our indicator does not seem to possess information on future exchange rate developments for quiet periods. For the one-month forecast horizon the model including the indicator improves in RMSFE over the simple AR model, albeit not significantly.

3.2 The 1998 crisis in Russia

The Russian Central Bank announced in November 1997 that, starting January 1998, the ruble would be targeted at a central rate of 6.2 rubles/dollar, with a fluctuation band of $\pm$ 15%. However, the volatility of the ruble/dollar exchange rate was minimal in the months preceding the crisis (the standard deviation of percentage changes in the exchange rate was 0.002 in the period January-August, 1998). On August 17th, 1998, the Russian government announced the devaluation of the ruble by the end of the year, defaulted on its government debt and declared a 90-day moratorium on foreign debt. On August 26th the Russian Central Bank declared that the fixed exchange rate could not be supported any longer and on September 2nd, 1998 the Russian ruble was

Exchange rate: Czech koruna/USD			
Steps ahead	RMSFE difference	DM test	Observ.
1	-1.271 %	-0.705	34
5	-0.998 %	-1.845**	30
10	-0.408 %	-1.687**	25
15	-0.686 %	-1.955**	20
20	-0.757 %	-2.496***	15
25	-0.773 %	-1.370*	10
30	-1.267 %	-3.474***	5
Exchange rate: Czech koruna/DM			
Steps ahead	RMSFE difference	DM test	Observ.
1	0.156 %	1.053	34
5	0.062 %	0.866	30
10	0.052 %	0.679	25
15	0.050 %	0.787	20
20	0.027 %	0.509	15
25	0.066 %	0.867	10
30	-0.044 %	-0.967	5

The column "RMSFE difference" is the difference between the RMSFE of the VAR model and the AR model as percentage of the RMSFE of the AR model. The column "DM test" refers to the Diebold-Mariano test for equal forecasting error (Diebold and Mariano, 1995). *(**)[***] stands for significance at the 10%(5%)[1%] level.

Table 1: Pre-crisis forecasting exercise: Czech koruna/US dollar

floated.[7]

Using the corresponding interbank interest rate data for Russia and the US, we construct the indicator for the dynamics of the relative probability of a crisis occurring in seven days as compared to the crisis taking place in the interval delimited by seven and thirty days. The same problems as for the case of the Czech Republic come up if the indicator proposed by Collins (1984) is used, since the probability ratio turns negative in some periods due to the downward-sloping term structure of Russian interbank rates. Figure 5 presents the Russian ruble/USD exchange rate together with the indicator $I_{7,30,t}$ for the period April-September, 1998, after assuming $\delta_t = 1$, $\rho_7 = 0$ and adding a

[7] For an excellent account of the Russian crisis, see Kharas et al. (2001)

constant (one in this case) to the denominator of the expression in (10) so as to avoid negative implied probabilities. The shaded area delimits the period of time starting with the announcement of the devaluation and ending with the floatation of the ruble.

The first relevant feature of $I_{7,30,t}$ is the fact that it has a positive trend in the period under study. This implies that investors systematically changed their expectations of the timing of an exchange rate crisis in the months preceding the actual occurrence of the Russian crisis. In this sense, as the crisis approached, they tended to consider the event increasingly imminent. Apart from this medium-run trend in $I_{7,30,t}$, the indicator presents relevant increases in the end of May, mid-July and a global peak following the announcement of the devaluation, which precedes the change in the exchange rate regime by seven (working) days. The first peak, on May 28, takes place right after the central bank increased key interest rate to 150%. This is followed by a series of interventions (involving the expenditure of $1 billion in reserves) in a successful attempt to defend the ruble (see e.g. Chiodo and Owyang, 2002). The indicator declines in the following days, and follows the positive trend that dominates the full period. The second signal of a shift in expectations to an imminent devaluation takes place in early July. The start of the increase coincides with the Russian parliament's postponement of policy reforms needed to qualify for IMF loans. Expectations of crisis timing shift away from one week with the final approval of an IMF emergency loan to Russia in mid-July. Finally, our indicator increases dramatically in the period August 10-18 in parallel to the collapse of the stock and bond markets (August 13) and in spite of Boris Yeltsin's declaration that "there will be no devaluation" of the ruble following an emergency parliamentary session on August 14. Our indicator stabilizes on August 21, when the Russian crisis can already be felt in markets all around the world. Although our indicator peaks when the crisis is already being felt, the increase in $I_{7,30,t}$ is quite evident up to seven days before the devaluation announcement. The dynamics of the indicator remain unchanged after performing the inflation expectation correction.[8]

Figure 6 presents the standardized changes in the indicator computed with information up to period t for each observation. The indicator data used for the standardization starts in January 1997, and the values corresponding to the sample under study are presented in the figure together with the 5% critical

[8]Detailed results are available from the authors upon request.

values. The two peaks of the indicator that did not result in a crisis do not appear significant at the 5% level, while the crisis signal does.

The minimal volatility of the ruble/US dollar exchange rate in the pre-crisis period makes an out-of-sample exercise such as the one carried out for the Czech Republic useless in this context. To sum up, our indicator is able to identify both speculative pressures that were successfully combated by the central bank in the pre-crisis period, and starts signaling the impending crisis six days before the official announcement of the devaluation.

4 Conclusions and further paths of research

The increased frequency and strength of currency crises in recent years has motivated researchers in both public and private institutions to develop effective early-warning systems for currency crises. A vast majority of existing approaches uses similar macroeconomic variables to forecast the timing of financial distress. In our opinion, fundamental data are perfectly suited to identifying the set of potentially vulnerable countries and, possibly, to explaining crises after the fact. However, in our opinion, the desired forecasting instrument needs to focus strongly on market sentiment as it is the participants on foreign exchange markets who eventually trigger a crisis. Investor sentiment is much more sensitive to short-term news and incoming signals than to underlying long-term fundamentals. Along these lines, recent research suggests that market-based forecasting tools possess fair predictive power and usually outperform alternative instruments in terms of accuracy.

Thus, based on simple economic theory and exploiting the term structure of relative interest rates, we constructed a very short-term early-warning indicator to evaluate relative probabilities of a crisis occurring in different time horizons. Subsequently, we applied the indicator to data from two recent Eastern European currency crises: the Czech koruna crisis in 1997 and Russia ruble crisis in 1998. We found that our indicator performs extraordinarily as a (very) short-term predictor of a crisis in both considered cases. We also provided evidence that the indicator contains extra information about future short-run exchange rate changes.

As seen in the Russian case study, even false alarms from the market need to be taken seriously by central bankers and governments and all available short-term measures should be implemented. Likening our indicator to a thermometer, a high body temperature does not necessarily imply serious illness, but is *always* a reason for concern. In that sense, our indicator is useful for monetary policy institutions as an extra signalling instrument to complement long-run warning mechanisms. Several improvements to the methodology used in this piece of research can be implemented to refine the indicator. Among possible avenues of research, using information on the time-varying nature of interest rate volatility to proxy for developments in the risk premium may lead to improvements in the signalling properties of the estimator.

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Appendix

Figure 1 Czech Koruna: Exchange rate, January 1997-June1997

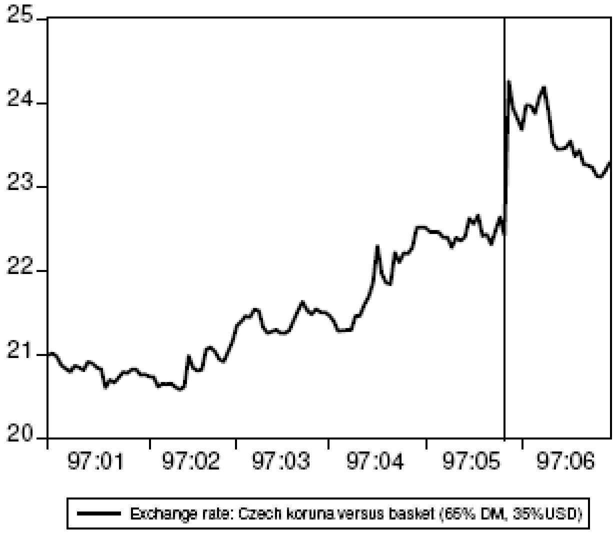


Figure 2 Czech Koruna: Exchange rate, January 1997-June1997 and $I_{7,30,t}$

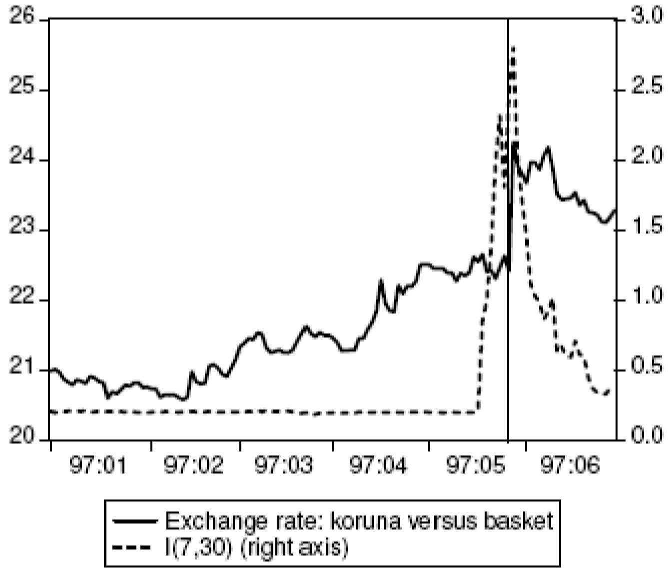


Figure 3 Czech Koruna: Exchange rate, January 1997-June1997 and $I_{7,30,t}$ with risk premium adjustment

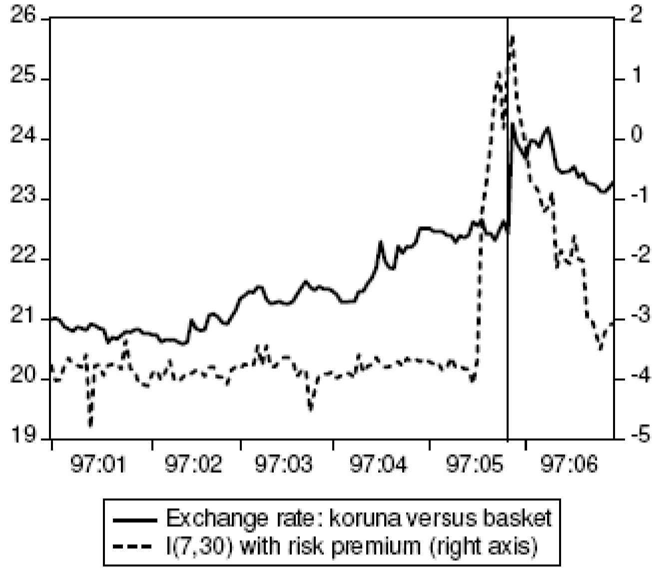


Figure 4 Standarized $I_{7,30,t}$ changes: Czech Republic

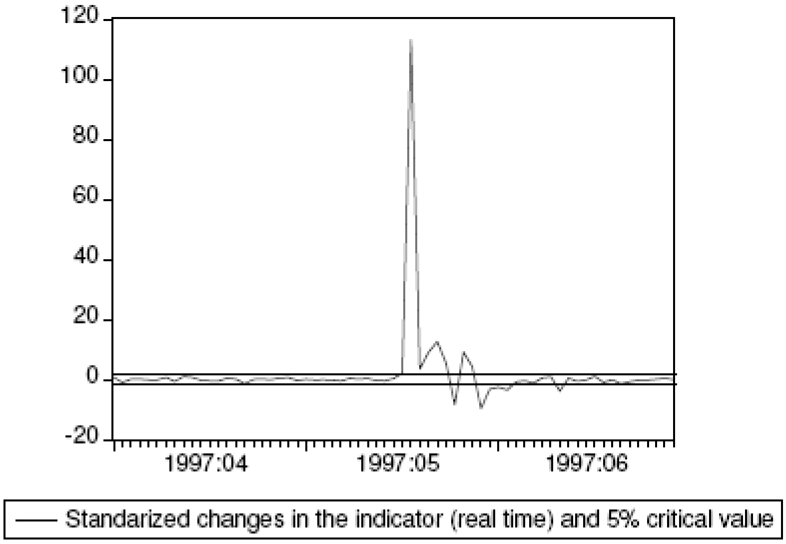


Figure 5 Russian ruble: Exchange rate, April 1998-October 1998 and $I_{7,30,t}$

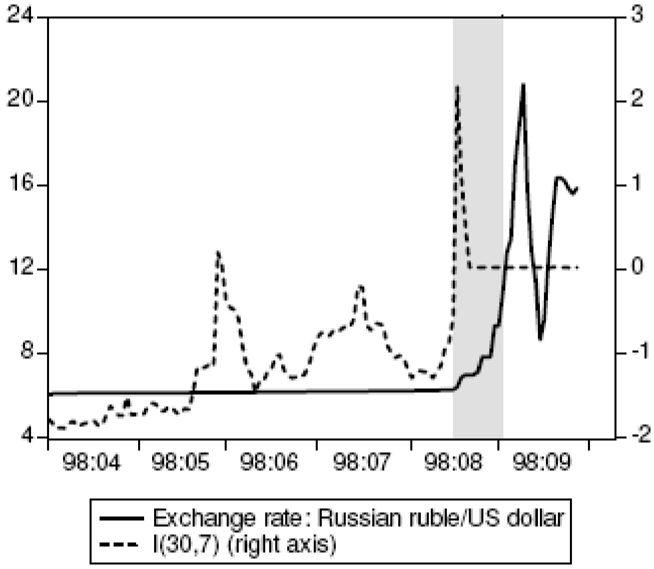
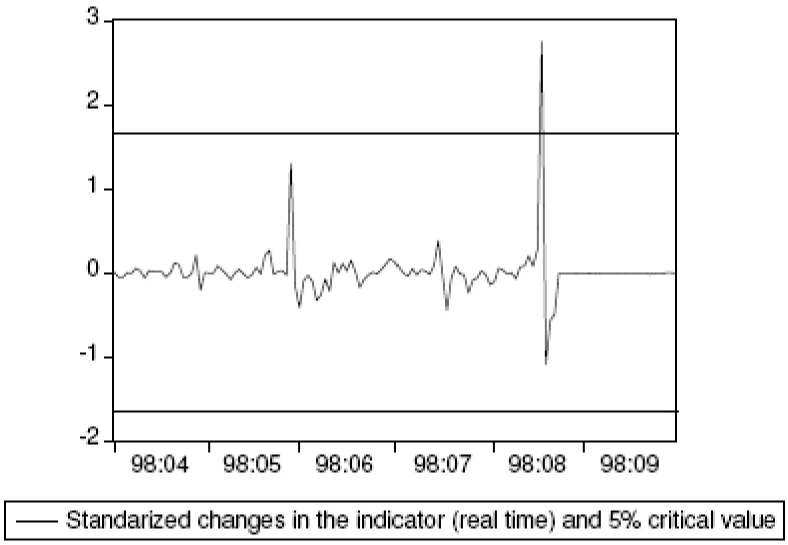


Figure 6 Standarized $I_{7,30,t}$ changes: Russia



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