THE SIGNALS APPROACH AS AN EARLY WARNING SYSTEM FOR CURRENCY CRISES

AN APPLICATION TO TRANSITION ECONOMIES

- WITH SPECIAL EMPHASIS ON POLAND

Keywords	Early Warning System, Vulnerability Indicator, Financial Crises, Central and Eastern Europe
JEL Classification	F31 (International Finance: Foreign Exchange), F47 (International Trade and Finance: Forecasting and Simulation), and 057 (Transition Economies)

Name	Christoph Pasternak (M.A.)
Contact	Institute of Economics University of Erlangen-Nürnberg Kochstr. 4/17 91054 Erlangen (Germany)
Tel. (private)	++49 (0) 9131 203570
Tel. (office)	++49 (0) 9131 852-2381
Fax	++49 (0) 9131 852-2060
E-Mail	christoph.pasternak@web.de
Internet	http://www.ekonomia.de

ABSTRACT

Objectives
The objectives of this empirical study are: firstly, to modify and extend the 'signals approach', developed by *Kaminsky/Lizondo/Reinhart* (1997) as an early warning system for currency crises, secondly, to apply it to transition economies in Central and Eastern Europe, and, thirdly, to calculate and measure the risk potential of currency crises in those countries.

Data and Methods
The method utilised in this study is a modified version of the 'signals approach' presented by *Goldstein/Kaminsky/Reinhart* (2000). The sample period is January 1992 to December 2001, with calculations of relevant indices up to August 2002. The country sample consists of all politically relatively stable transition economies in Central and Eastern Europe: Estonia, Latvia, Lithuania, Poland, the Slovak Republic, Hungary, Slovenia and Albania as non-crises economies and the Czech Republic, Bulgaria, Romania, Moldova, Ukraine, Belarus and the Russian Federation as crises economies. First, a market pressure index is constructed using nominal devaluations and reserve losses to determine the relevant currency crises. Second, a number of monthly and annual indicators are calculated using data from those economies which have faced balance-of-payment crises. Third, a country-specific composite currency crises index is constructed and statistically tested. The construction of the composite index is modified compared to the original 'signals approach' by taking into account the ratio of available indicators. The basic aim of this move is to smooth fluctuations in the number of available indicators; a step which seems to be especially important during the early stages of the transition process. Fourth, the composite index is transformed into country-specific conditional probabilities for currency crises. Fifth, three composite sub-indices are constructed based on theoretical considerations. Additionally, based on the results determined in the crises sample, the 'signals approach' is also applied to non-crises countries, such as Poland, Estonia, etc.

Results
The results show that the currency crises included in this study can be explained *ex-post* using the 'signals approach'. Although differences in individual crises remain, they have nonetheless much in common with currency crises in other emerging markets. The extended 'signals approach' seems to have enough explanatory power to assess the current vulnerability to currency crises in this country sample. Both the composite indicator and statistics based on it give a reasonably clear picture of the risk of currency crises. For instance, even though the indicators were calculated based on the sample of crises countries, which does not include Poland, the composite index and the conditional probabilities of currency crises show a high risk for this economy throughout the year 2001. Looking at the current situation (11/2001) the highest vulnerability can be found in the three largest new EU-member states and future participants in the EMS/EMU (Hungary, Czech Republic, and Poland).

Conclusion
The results of this study show that the 'signals approach' is useful both for assessing a country's risk potential and for a structured *ex-post* analysis. Even for non-market economies such as Moldova and Belarus statistically reasonable results can be obtained. However, one cannot realistically expect to derive detailed information on the occurrence and impacts of crises from this study.

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LIST OF ABBREVIATIONS AND SYMBOLS

aop	average of period
AWS	Akcja Wyborcza Solidarność
BIS	Bank for International Settlements
DB	Deutsche Bank Research
e	nominal exchange rate
EMS	European Monetary System
EMU	European Monetary Union
e.g.	exempli gratia
eop	end of period
et al.	et alii
etc.	et cetera
EU	European Union
FDI	Foreign Direct Investments
GDP	Gross Domestic Product
i.e.	id est
IFS	International Financial Statistics
IMF	International Monetary Fund
n.a.	not available
p.a.	per annum
RES	foreign reserves
t	time
δ	standard deviation
μ	arithmetic mean

1 Introduction

The objectives of this empirical study are: firstly, to modify and extend the 'signals approach', developed by *Kaminsky/Lizondo/Reinhart* (1997) as an early warning system for currency crises, and, secondly, to apply it to transition economies in Central and Eastern Europe. The aim of the third section is to calculate and measure the risk potential of currency crises in those countries using different key figures.

The paper is based on the sophisticated 'signals approach', as presented in *Goldstein/Kaminsky/Reinhart* (2000). However, to adapt the 'signals approach' to the requirements of Central and Eastern European economies certain modifications have been implemented by smoothing fluctuations in the number of available indicators; a step which seems to be especially important during the early stages of the transition process.

The structure of the paper is as follows: The first section deals with the 'signals approach' itself, introducing its main characteristics. The second section concentrates on issues such as the country sample, the relevant currency crises, and variables. Following this introduction, we move on to the results: the single indicators utilised, the composite index, the conditional probabilities and three disaggregated sub-indices, which are constructed based on theoretical considerations. The results allows for an assessment of the vulnerability to currency crises of selected economies in transition.

2 Foundations of the 'Signals Approach'

The fundamental idea behind the 'signals approach' is that the performance of certain, primarily macroeconomic, factors varies in the run up to a currency crisis from that of tranquil periods, thus, enabling observers to identify the main reasons behind the increase in risk potential of currency crises. The 'signals approach' was first presented by *Kaminsky/Lizondo/Reinhart* in their 1997 'Leading Indicators of Currency Crises' and extended by *Goldstein/Kaminsky/Reinhart (2000)*. Based on their considerations, a performance analysis of various indicators is conducted in a previously defined signalling window prior to a currency crisis. In our case, a signalling period of 24 months is implemented. If a certain threshold value is crossed in this signalling window, it is considered as an indication of a possible currency crisis. Since the threshold value is expressed as a percentage of the country-specific distribution of the indicator, varying (absolute) threshold values exist in individual countries.[1]

Tab. 1: 'Signals Approach'

	Crisis within the signalling window	*No crisis within the signalling window*
Signal	A	B
No signal	C	D

Source: Goldstein/Kaminsky/Reinhart (2000), p. 30

An optimal distribution for an early warning system occurs, when all signals are cumulated in sections A and D, since in such a case either signals are sent when currency crises take place eventually (A); or no signals are conveyed in crisis-free times (D). However, two sources of error remain: if a crisis occurs and no signal was sent beforehand (C) or a signal was transmitted, even though no crisis happens (B). Each type of error has an opposite effect, i.e. increasing the threshold value results in fewer errors of type B but more C-type errors. In order to minimise the error potential the Noise-to-Signal-Ratio (NSR) is introduced, defined as

[1] For instance, if the increase in short-term debt was higher than 30.6% in Albania respectively 21.3% in Bulgaria, a signal is transmitted.

[B/(B+D)]/[A/(A+C)]. Thus, the Noise-to-Signal-Ratio measures the relative proportion of 'bad' to 'good' signals, with values near zero indicating a high quality of indicator.

Apart from the Noise-to-Signal-Ratio, the crises probability P(C) is also worth calculating.[2] This is also true of the conditional crisis probability P(C|S), i.e. the probability of a currency crisis provided that a signal was sent [A/(A+B)]. In analysing the results, calculating the difference between these figures might also be useful, since only those indicators are helpful which forecast a higher crisis probability than the unconditional probability in the sample.

3 Data and Methods

This section deals with issues such as the country sample, the choice of relevant currency crises, and the theoretical foundations of the variables involved.

3.1 Country Sample

The sample period is January 1992 to December 2001 (out-of sample up to August 2002). The country sample consists of all politically relatively stable transition economies in Central and Eastern Europe: Estonia, Latvia, Lithuania, Poland, the Slovak Republic, Hungary, Slovenia and Albania as non-crises economies; and the Czech Republic, Bulgaria, Romania, Moldova, the Ukraine, Belarus and the Russian Federation as crises economies. The distinction between crises and non-crises countries will be explained later. Owing to doubts as to functioning market structures in Belarus and Moldova, all calculations regarding crises countries were conducted twice: based on an enlarged country sample with Moldova and Belarus, and on a reduced country sample without these economies.

3.2 Market Pressure Index

To determine all relevant currency crises a market pressure index is constructed using nominal devaluations and reserve losses. Implementing nominal devaluations enables an identification of those periods in which the economies faced severe pressure on their national currencies. The exchange rate system itself is not relevant to our analysis, be it a currency board or a flexible exchange rate arrangement, as all major fluctuations cause distress to an economy. Adding reserve losses to the market pressure index seems to be valid, as even prevented currency crises generate economic adjustment processes with negative effects e.g. on employment, growth perspectives or financial intermediaries. Therefore, the monthly available market pressure index is calculated as:

$$I = \left(\left(e_t / e_{t-12}\right) - 1\right) - \left(\sigma_e / \sigma_{\mathrm{Re}s}\right) \cdot \left(\left(RES_t / RES_{t-12}\right) - 1\right) \tag{1}$$

$$I = \left(\left(IMFAE_t / IMFAE_{t-12}\right) - 1\right) - \left(\sigma_e / \sigma_{\mathrm{Re}s}\right) \cdot \left(\left(IMF1LD_t / IMF1LD_{t-12}\right) - 1\right)^{3} \tag{2}$$

The two variables are weighted by their standard deviations. As an alternative approach, a second market pressure index was constructed, measuring the monthly change in variables.[4]

$$I = \left(\left(e_t / e_{t-1}\right) - 1\right) - \left(\sigma_e / \sigma_{\mathrm{Re}s}\right) \cdot \left(\left(RES_t / RES_{t-1}\right) - 1\right) \tag{3}$$

$$I = \left(\left(IMFAE_t / IMFAE_{t-1}\right) - 1\right) - \left(\sigma_e / \sigma_{\mathrm{Re}s}\right) \cdot \left(\left(IMF1LD_t / IMF1LD_{t-1}\right) - 1\right) \tag{4}$$

[2] Specified as (A+C)/(A+B+C+D).

[3] The second line gives the data source: in this case the *IMF* International Financial Statistics, Indicators AE and 1LD, i.e. exchange rate and foreign reserves.

[4] The year-to-year change is suitable for excluding seasonalities and including partially anticipated currency pressure, while the month-to-month change reveals the first occurrence of a currency crisis more exactly.

A separate market pressure index was constructed for high inflationary periods, i.e. periods witnessing inflation rates higher than 150% p.a.[5] A currency crisis is considered to have occurred, when the market pressure index crosses a threshold value of its arithmetic mean plus 2½ times its standard deviation:

(5) $C = 1 \quad \text{for} \quad I > \mu_I + 2.5\sigma_I$

(6) $C = 0 \quad \text{for} \quad I \leq \mu_I + 2.5\sigma_I$

However, to smooth out erratic shifts in market pressure indices, it was defined that a currency crises had to be revealed in both market pressure indices.

Tab. 2: Currency Crisis: Occurrence

Country	*Occurrence*
Bulgaria	January 1997
Moldova	September 1998
Romania	January 1997
Russian Federation	August 1998
Czech Republic	May 1997
Ukraine	September 1998
Belarus	December 1998

Source: own calculations

Similar results were obtained by *Árvai/Vincze (2000)*, *Brüggemann et al. (2000)*, *Brüggemann/Linne (2002)*, *Jakubiak (2000),* and *Siwińska (2000)*.

3.3 Variables

The following variables were chosen as appropriate for the 'signals approach':

- *Fiscal variables* such as 'Overall Budget Deficit' and 'General Government Final Consumption Expenditure', being especially important in first-generation models of currency crises. These have placed emphasis on a lack of fiscal discipline, monetary expansion and, consequently, a falling-short of exchange rate goals. However, these explanatory variables also play a limited role in third-generation models. These models focus, among others, on the stability of the financial sector, thus, also on implicit and explicit guarantees from state agencies.
- *Monetary variables* such as 'Real Interest Rate', 'Domestic-Foreign Real Interest Rate Differential', 'Foreign Reserves', 'M2 pro Foreign Reserves Growth' and 'M2 Multiplier', some of which have their roots in first-generation models (monetary expansion) and others in third-generation models (instability of financial intermediaries).
- *Banking supervision variables* such as 'Banking Crises', 'Banking Deposits Growth', 'Domestic Credit pro GDP Growth', 'Claims on Governments', 'Claims on Private Sector' and 'Lending-to-Deposit Rate Differential'. The second-generation models emphasis the importance of cost-benefit analyses between stabilising and devaluating the domestic currency, thus, in turn affecting the domestic economy and especially their financial intermediaries. However, third-generation models also concentrated on moral hazard issues, which are considered to be particularly prevalent in the financial sector.

[5] *Goldstein/Kaminsky/Reinhart* (2000) used a similar approach. For further details concerning this aspect feel free to contact the author, as this is just an introductory paper and, thus, limited in scope.

- *Current account variables* such as 'Export Growth', 'Import Growth', 'Current Account Balance pro GDP', 'Gross Capital Formation pro Capital Account Balance' and adjusted 'Real Exchange Rate' reveal weaknesses in the domestic economy.
- *Capital account variables* such as 'Foreign Direct Investment (in % GDP)', 'Foreign Direct Investment (in % Gross Capital Formation)' and 'Short-Term Debt' were *inter alia* integrated in second-generation approaches, modelling the trade-off situation government agencies are confronted with in the case of a speculative attack between prevailing domestic weaknesses and the negative effects of exchange rate adjustments.
- *Other variables* such as 'Output Growth' and 'Gross Capital Formation' reflecting once again instable economic situations, or 'Geographical Clusters', especially suitable for modelling spillover and contagion effects of currency crises in similar economies.

As not all variables are available on a monthly basis, the subsequent calculations were separated into two groups depending on the common data frequency. The results on the annual indicators are not entirely displayed in this paper due to limited space. These indicators respectively calculations based on them are a suitable tool for assessing currency crises *ex-post*; yet, owing to data frequency issues they are not eligible as an early warning system. Therefore, this paper concentrates on monthly data.

Moreover, some data transformation procedures were used: for instance, linear interpolations of monetary aggregates because of a few cases of missing data; or regressions of the real exchange rate because of productivity gains.[6]

Data was taken from International Financial Statistics by the IMF and the BIS, as well as the CD-ROM version of the United Nations Statistical Yearbook.

4 Results

4.1 Single Indicators

The table below depicts the Noise-to-Signal-Ratios determined in the crisis economies of Belarus, Bulgaria, Moldova, the Russian Federation, the Ukraine, the Czech Republic, and Romania in the period 01/1992 to 12/2001. It gives in the first column the threshold value, which was selected intuitively and then gradually optimised by iteration, being particularly important for detecting potential currency crises. The second column shows the ratio of crises accurately called, which is obviously dependent on the threshold value. The third column displays the Noise-to-Signal-Ratio as the ratio of 'bad' to 'good' signals, allowing a minimisation of first and second-grade errors and providing the key figure in assessing the applicability of the indicators.

[6] For further information on this subject or the results on annual data, feel free to contact the author, as the space here is limited.

Tab. 3: Monthly Indicators: Threshold Value and Noise-to-Signal-Ratio

	Threshold Value[(1)]	*Ratio of Crises Accurately Called*	*Noise-to-Signal-Ratio*
Short-Term Debt	0.820	0.345	0.290
Real Interest Rate	0.950	0.113	0.300
M2/Foreign Reserves	0.910	0.179	0.380
Domestic-Foreign Real Interest Rate Differential	0.790	0.399	0.395
Export Growth	0.270	0.423	0.515
Foreign Reserves	0.130	0.208	0.530
Domestic Credit pro GDP	0.850	0.222	0.579
Real Exchange Rate	0.490	0.655	0.634
Banking Deposits Growth	0.110	0.143	0.730
Output Growth	0.310	0.298	0.761
Lending-to-Deposit Rate Differential	0.340	0.771	0.800
M2 Multiplier	0.320	0.738	0.892
Import Growth	0.380	0.394	0.952
Note: (1) in percent of distribution			

Source: own calculations

Given the enlarged country sample with Moldova and Belarus, all monthly available indicators disclose Noise-to-Signal-Ratios lower than one, indicating a rather high explanatory power.[7] The indicator 'Short-Term Debt' displays the lowest Noise-to-Signal-Ratio at 0.290, followed by the 'Real Interest Rate' at 0.300. The 'Domestic-Foreign Real Interest Rate Differential' reveals quite similar results, which is not surprising due to its related composition and, therefore, expected correlation. Indicators based on foreign reserves also deliver (very) good results. Satisfactory scores are achieved by variables reflecting the weaknesses of the banking sector, as, for instance, the domestic credit, banking deposits or the lending-to-deposit rate differential. Current account related indicators reveal rather divergent results. With import growth being the worst variable, export growth can be considered as a good indicator. Unusually unsatisfactory scores are reported by the indicator 'Real Exchange Rate', which in various papers scored significantly higher and used to be viewed as the best indicator.[8] The unsuspectingly bad performance might be due to a rather simplistic purchasing power parity approach applied in this study in calculating the real exchange rate.[9] The ratio of crises accurately called has a rather limited explanatory power, since, on the one hand, crises are identified correctly, thus, limiting the previously mentioned C-type errors, but, on the other hand, excluding the important errors of type B completely. Notwithstanding these drawbacks, the table displays an interesting correlation between the threshold value and the number of identified crises.

[7] The statistics on the smaller country sample are not shown, since the results differ only slightly.

[8] See, among others *Kaminsky/Lizondo/Reinhart* (1997), *Brüggemann/Linne* (2002), *Edison* (2000), or *Esquivel/Larraín* (1998).

[9] First, just two reference economies, Germany and the United States were selected, and, second, the calculations were conducted using the consumer price indices.

The following table displays, *inter alia*, the (simple) probability of crisis P(C) - calculated on the basis of the given data - as well as the conditional probability of crisis P(C|S), i.e. the probability of a crisis under the precondition that a signal was transmitted. Moreover, the differential between these probabilities is calculated, representing yet another key figure for assessing the quality of an indicator, as the conditional probability should display higher scores than the simple probability of crisis. This is primarily the case for the best seven indicators, with a forecasting probability higher by more than two digits. Due to a high correlation between these two key figures, the conditional probability and the Noise-to-Signal-Ratio, the latter was chosen as the main statistical score for assessing the quality of an indicator.

Tab. 4: Monthly Indicators: Probability of Crisis

	Noise-to-Signal-Ratio	*P(C)*	*P(C|S)*	*P(C|S)- P(C)*
Short-Term Debt	0.290	0.272	0.563	0.291
Real Interest Rate	0.300	0.222	0.487	0.266
M2/Foreign Reserves	0.380	0.251	0.469	0.218
Domestic-Foreign Real Interest Rate Differential	0.395	0.222	0.419	0.197
Export Growth	0.515	0.260	0.406	0.146
Foreign Reserves	0.530	0.246	0.380	0.135
Domestic Credit pro GDP	0.579	0.279	0.400	0.121
Real Exchange Rate	0.634	0.220	0.308	0.088
Banking Deposits Growth	0.730	0.249	0.312	0.063
Output Growth	0.761	0.134	0.169	0.035
Lending-to-Deposit Rate Differential	0.800	0.243	0.286	0.043
M2 Multiplier	0.892	0.251	0.273	0.022
Import Growth	0.952	0.264	0.274	0.010

Source: own calculations

4.2 Construction of the Composite Index

Based on the annual and monthly indicators separate monthly and annual composite indexes (I) were constructed in the following way as the sum of Noise-to-Signal-Ratio (NSR) weighted signals (Z). A method in line with *Goldstein/Kaminsky/Reinhart (2000)* allowing for a higher weight of 'good' indicators in the composite index.[10]

$$(7) \qquad I_t = \sum_{i=1}^{n} Z_t^i \,/\, NSR^i$$

Due to fluctuations in the number of available indicators, a bias in the results might be expected. Therefore, the previously described composite index was modified by setting it in relation to the number of available and therefore as signals valid, and with the Noise-to-Signal-Ratio (NSR) weighted data (D).

$$(8) \qquad F_t = \sum_{i=1}^{n} D_t^i \,/\, NSR^i$$

[10] The NSR of the geographical cluster being zero, thus, not suitable for weighting, it was replaced by the second highest NSR.

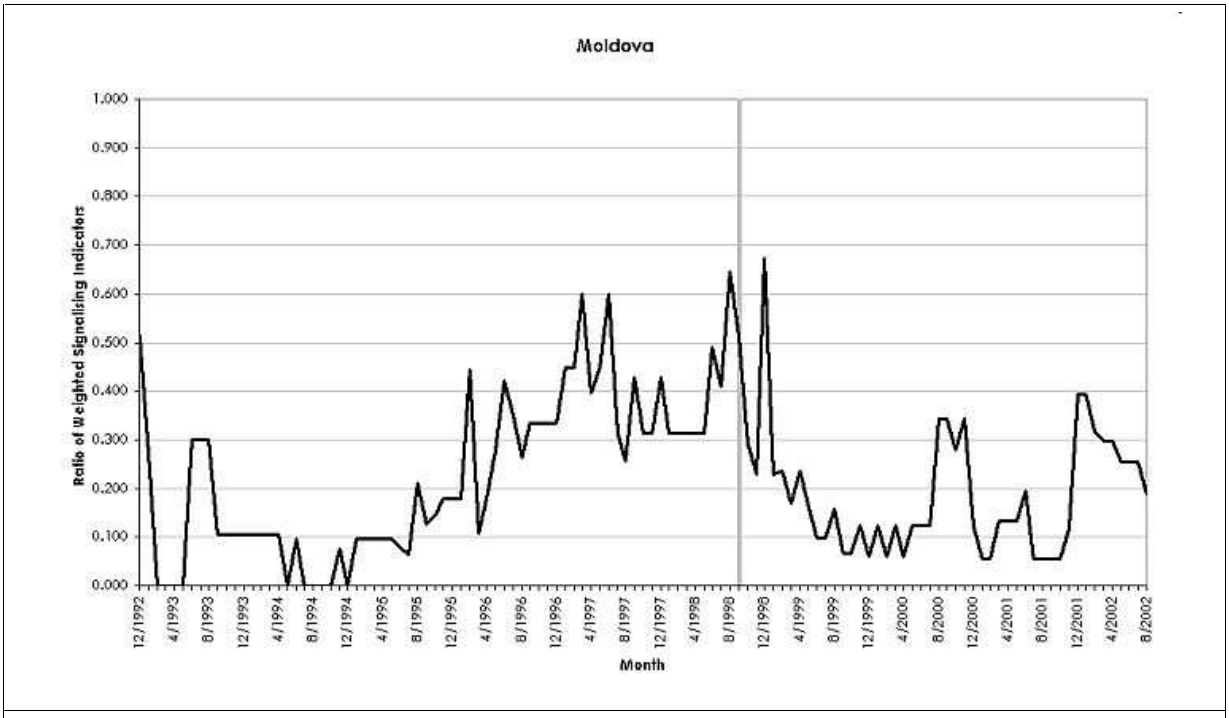
Here, D is a dummy variable reaching a value of one when data was available at the time. This step seems to be essential owing to the fluctuating number of available variables, primarily at the beginning of the transition process. Modifying the original composite index allows a stabilisation of the performance of the index.

(9) $$S_t = I_t / F_t$$

Thus, the composite index (S) indicates the proportion of indicators, weighted with the Noise-to-Signal-Ratio and transmitting signals, from all the available and weighted indicators. Due to this construction, the composite index should not be directly compared with a probability of crisis, even though the index itself reaches values between zero and one.

Below, the monthly composite indicator for Moldova is shown.[11]

Fig. 1: Monthly Composite Index: Moldova



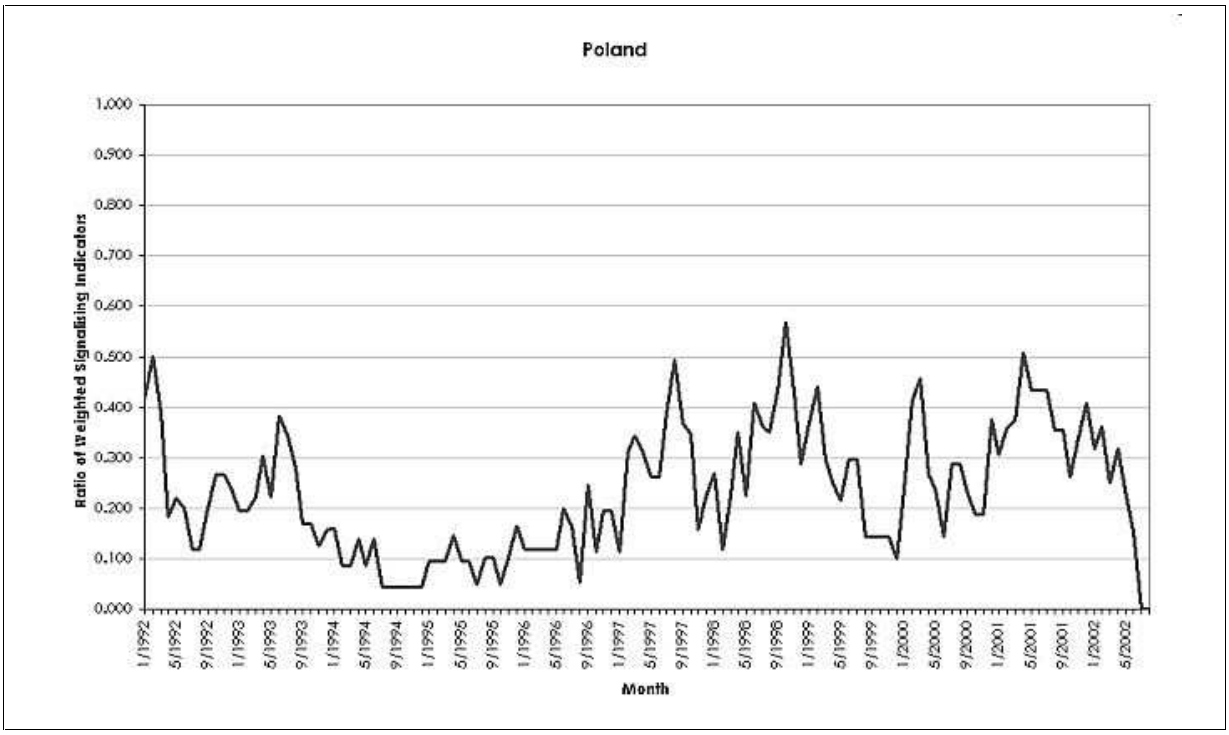
Note: The shaded line depicts the month, in which the currency crisis occurred.

Source: own illustration

Moreover, it might also be of interest to compare the monthly composite index of a crisis country with a non-crises economy such as Poland. In doing so, it should also be stated that the Noise-to-Signal-Ratio, which is constitutive for weighting signals, has been minimised based only on the crises countries data (in-sample). A composite index for non-crises economies such as Poland was constructed with the use of the Noise-to-Signal-Ratio determined in-sample, which results in an index for all non-crises countries which is itself not in-sample.

[11] Due to limited space composite indices for crises countries other than Moldova can be downloaded from http://www.ekonomia.de.

Fig. 2: Monthly Composite Index: Poland



Source: own illustration

Compared with the previously displayed crisis country Moldova, fewer fluctuations of the monthly composite index can be identified in Poland. At the same time, the economic difficulties of the conservative government under the rule of the nowadays replaced AWS at the end of 2000 and throughout 2001 are clearly exposed in the above figure. These difficulties were *inter alia* caused by the disinflationary policy of the monetary authorities designed to break the inflation bias in the Polish economy and to reduce the inflation rates to European levels. This approach, by curbing economic growth, generated e.g. high budget deficits, pressure on financial intermediaries, and, at times, a substantial increase in the real exchange rate provoking negative effects on the trade balance.[12]

Figures for monthly composite indicators for other economies can be downloaded from http://www.ekonomia.de.

4.3 Significance of the Composite Index

Aside from this visual analysis as presented in the preceding chapter, it is also worth measuring here the quality of the composite index using the previously established Noise-to-Signal-Ratio.

[12] The massive drop in the composite index in July 2002 is rather caused by lacking indicators, thus, creating instable results. This is the case in a number of other analysed economies both at the end of the sample period and partly also at the beginning, e.g. in the Czech and Slovak Republic due to their split in 1992/1993.

Tab. 5: Composite Index: Noise-to-Signal-Ratio

	Noise-to-Signal-Ratio
'Signals Approach' with Moldova and Belarus	
monthly	0.230 (0.291)
annual	0.333 (0.377)
'Signals Approach' without Moldova and Belarus	
monthly	0.212 (0.300)
annual	0.333 (0.396)

Note:

(1) The Noise-to-Signal-Ratio (NSR) was calculated using a method identical to that used with individual indicators. However, the threshold value was kept constant for all analysed economies and was not allowed to exceed a level of 0.90 due to comparison reasons. Without this limitation the NSR would be even lower.

(2) The terms in brackets are the Noise-to-Signal-Ratios in the general country sample, while those without brackets are the Noise-to-Signal-Ratios in the crises countries´ sample.

Source: own calculations

In view of this information, the following conclusions can be drawn with regard to the Noise-to-Signal-Ratio: first, the monthly composite index is of a relatively high quality, and, second, values for the Noise-to-Signal-Ratio of the composite indices are even better than for the best single indicators such as 'Short-Term Debt'. Third, in three out of the four possible cases, the figures for the enlarged country sample display at least the same or even better scores than for the smaller country sample.

The information content of the Noise-to-Signal-Ratio notwithstanding, the performance of the composite index should be tested by means of various criteria. For instance, naive forecasts might have a better explanatory power than more complex fundamentally oriented approaches such as the 'signals approach'. To prove the usefulness of the 'signals approach', random data sets were generated based on a beta-distribution. A beta-distribution is appropriate for continuously distributed random variables. It is defined as:

$$B(\beta_1, \beta_2) = \int_0^1 S^{\beta_1 - 1} \cdot (1 - S)^{\beta_2 - 1} dS \tag{10}$$

The parameters β_1 and β_2 define together skewness and kurtosis of the distribution. If $\beta_1 < \beta_2$, the distribution becomes skewed to the right. Since currency crises are single events with crises-free periods being the norm, the data set based on the random model should have a distribution skewed to the right. Generating random variables for each individual country, values of 0.9 for β_1, 2.3 for β_2 and an arithmetic mean equal to the unconditional crisis probability were assumed to ensure such a distribution. The resulting random variables with values between zero and one were considered as probabilities of crisis and therefore as comparable to the results of the composite indicator.

Following the method used in *Goldstein/Kaminsky/Reinhart (2000),* the Quadratic Probability Score (QPS) was calculated to assess the goodness-of-fit of both the 'signals approach' and the naive forecast based on the beta-distribution. The Quadratic Probability Score measures the squared distance between the 'probability of crisis' (S) as determined by the random model respectively the 'signals approach' at a certain point of time (t) and the Dummy variable (D), which records realisations of currency crises. D has a value of one during the 24 months respectively two years of the signalling window in the run up to a currency crisis and zero in other periods. Hence, this coefficient of determination lies between zero and two, with zero corresponding to a perfect congruence between forecasting model and the actual realisations of currency crises.

(11) $$QPS = 1/T \cdot \sum_{t=1}^{T} 2 \cdot (S_t - D_t)^2$$

Tab. 6: Naive Forecast versus 'Signals Approach': QPS

	QPS-Score		
	Whole Period	*Tranquil Times*	*Crises Times*
Naive Forecast (generated with a beta-distribution)			
monthly	0.3363	0.2548	1.1272
annual	0.3117	0.2101	1.0807
'Signals Approach' with Moldova and Belarus			
monthly	0.2145	0.1377	0.9252
annual	0.2433	0.1409	1.0183
'Signals Approach' without Moldova and Belarus			
monthly	0.1934	0.1224	1.0014
annual	0.2070	0.1262	0.9663

Source: own calculations

The above table demonstrates a noteworthy advantage of the 'signals approach' compared with the previously presented naive forecast. Thus, the model based on beta-distributed random variables shows scores of more than 0.31 for the whole sample period, indicating a rather high explanatory power due to the realistic distribution function. Nonetheless, the coefficient of determination of the 'signals approach' ranges better between 0.19 and 0.24.[13] The decision on whether to include or to exclude from the analysis Moldova and Belarus as non-market economies is not made simpler considering the QPS-score. Although values for the reduced country sample are partly better, this cannot be considered as significant. With lower Noise-to-Signal-Ratios of the composite indices in the enlarged country sample, it seems valid to concentrate on the country sample including Moldova and Belarus.

It might be too early to draw ultimate conclusions, since a test of the statistical significance of the results is lacking. Still, indications are that the 'signals approach' is more effective than naive forecasting models. At the same time, admittedly no detailed information on the occurrence and - in contrast to logit- and probit-models - on precise probabilities of crises can be derived from the 'signals approach'. However, the 'signals approach' allows the establishment of a ranking of potentially vulnerable economies and, therewith, might give a reasonably clear picture of the risk of currency crises.

4.4 Risk Potential

As mentioned before, the composite index may prove useful in the creation of a ranking of vulnerability to currency crises. Since not only current signals but also past signals can carry information about a country's risk potential, a geometrically weighted approach is implemented, ensuring that recent developments influence the ranking more than past ones.[14]

(12) $$Z_t = \sum_{i=1}^{24} S_{t+1-i} / i$$

[13] The same conclusions can be drawn, if the QPS scores are calculated based on crises and crises-free times.

[14] Following the 'signals approach' and its signalling window, the ranking is based on the past 24 signals.

From the analysed crises, three crisis periods were taken to illustrate the ranking approach: July 1998 prior to the Russian financial crisis, July 2001 due to the economic instability in Poland and July 2002 for a current analysis.

Tab. 7: Risk Ranking: July 1998

Country	Z_t	*Currency Crisis*
Russian Federation	1.5654	August 1998
Moldova	1.4565	September 1998
Ukraine	1.3316	September 1998
Belarus	1.1817	December 1998
Poland	1.1546	
Czech Republic	0.9326	
Slovak Republic	0.8913	
Hungary	0.8830	
Estonia	0.8474	
Romania	0.7228	
Albania	0.7086	
Slovenia	0.5647	
Bulgaria	0.5597	
Lithuania	0.4735	
Latvia	0.3881	
Note: calculation of Noise-to-Signal-Ratio was based on the enlarged country sample.		

Source: own calculations

The results displayed are self-explanatory regarding the Russian financial crisis in 1998 and enlightening with respect to the Polish case throughout 2001, which had a clear lead in the risk ranking - compared with other transition economies - owing to economic reasons explained in chapter 4.2.[15]

[15] See Tab. A1 in the appendix for these results.

Tab. 8: Risk Ranking: July 2002

Country	Z_t
Hungary	1.1553
Albania	1.0454
Moldova	0.9015
Czech Republic	0.8363
Poland	0.8064
Belarus	0.7994
Estonia	0.4233
Slovenia	0.4001
Lithuania	0.3132
Latvia	0.3032
Russia	0.2940
Ukraine	0.2893
Bulgaria	0.2442
Slovak Republic	0.2428
Romania	0.2358
Note: calculation of Noise-to-Signal-Ratio was based on the enlarged country sample.	

Source: own calculations

Looking at the July 2002 values allows for an assessment even of the current vulnerability, since in the past the 'signals approach' was successful in predicting currency crises.[16] Apart from the tiny Albanian and Moldavian economies, the three largest and most influential new EU-member states and future participants in the EMS/EMU (Hungary, Czech Republic, and Poland) show the highest risks. Though the values are lower than in the run-up to former currency crises and e.g. for Poland even lower than in the past, a certain pressure on the currencies in the near future cannot be excluded.

4.5 Country-Specific Conditional Probabilities

Calculating the monthly conditional probability of crisis is yet another method of assessing the risk potential of a country. The distributions both of the composite index and the realisations of currency crises are known. Based on these considerations, it is possible to determine the conditional probability of crisis P(C|S) for the composite index, i.e. to estimate the probability that a currency crisis will occur provided that the monthly composite index has exceeded certain threshold values. Once again, the calculations are based on an enlarged country sample including Moldova and Belarus and on a reduced sample. The annual composite indicator is not used to determine conditional probabilities, as monthly available data is more promising and the results more stable. The conditional probability of crisis is defined as:

$$P(C \mid I_l \le S_t < I_u) = \frac{\sum No.\ \ of\ \ Months\ \ for\ \ I_l \le S_t < I_u \mid C}{\sum No.\ \ of\ \ Months\ \ for\ \ I_l \le S_t < I_u} \tag{13}$$

[16] The risk ranking is partly based on past signals, thus, limiting its predictive power. However, since the first 14 months of the signalling window influence the risk ranking value imperceptibly, predictions - albeit limited -can be stated.

Thus, the conditional probability of crisis is calculated as the ratio between (1) the sum of months, in which the monthly composite indicator S_t is higher than or at the lower threshold value I_l and lower than the upper threshold I_u with a currency crisis following in the following 24 months and (2) the same sum of months without the precondition of a currency crisis.

To illustrate this approach one might consider the monthly composite index which reaches values of between 0.0 and 0.1 once during the signalling window of 24 months in the run-up to a currency crisis, while reaching values in the same interval 156 times in the overall sample period between 01/1992 and 12/2001. Therefore, the probability of crisis is 0.6 percent, when the composite index shows values of between 0.0 and 0.1. In the interval between 0.5 and 0.6 currency crises followed in 19 out of 24 cases, and in five cases no currency crises occurred, indicating a conditional probability of crisis of 79.2 percent. The subsequent table displays the conditional probability.

Tab. 9: Conditional Probability of Crisis: Composite Index

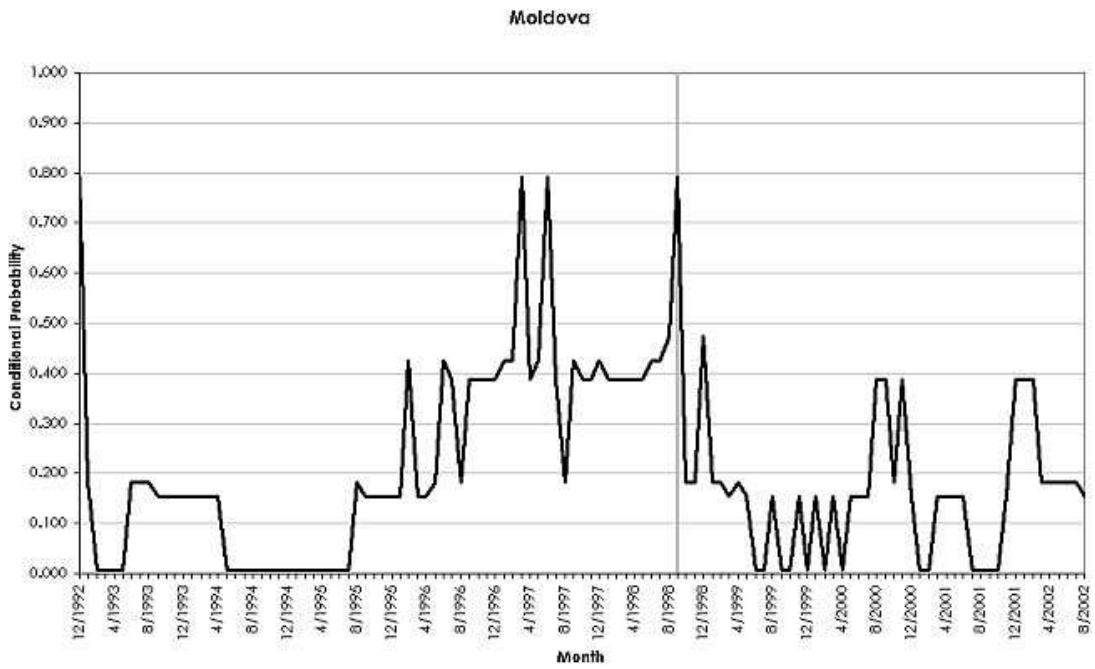
$I_l \leq S_t < I_u$	$P(C_{t,t+23}\|S_t)$
$0.0 \leq S_t < 0.1$	0.006
$0.1 \leq S_t < 0.2$	0.155
$0.2 \leq S_t < 0.3$	0.182
$0.3 \leq S_t < 0.4$	0.389
$0.4 \leq S_t < 0.5$	0.426
$0.5 \leq S_t < 0.6$	0.792
$0.6 \leq S_t < 0.7$	0.474
$0.7 \leq S_t < 0.8$	1.000
$0.8 \leq S_t < 0.9$	0.000
$0.9 \leq S_t \leq 1.0$	0.000
Note: country sample including Moldova and Belarus	

Source: own calculations

Due to a more continuous increase in the conditional probability of crisis and more stable results, the enlarged country sample was preferred to the reduced country sample. Based on these calculations the previously determined time series on the country-specific composite index can be transformed into conditional probabilities, as displayed in the figure below.[17]

[17] Figures on countries other than Moldova are available at http://www.ekonomia.de; data on Poland can be found in the appendix.

Fig. 3: Conditional Probability of Crisis: Moldova



Note: The shaded line depicts the month, in which the currency crisis occurred.

Source: own illustration

4.6 Composite Sub-Indices

One can gain further information by varying the formation of the composite index. Balance-of-Payment crises are usually categorised into three main theoretical classifications. Based on these considerations one might form monthly composite sub-indices, each with a theory-related set of variables.

Tab. 10: Composite Sub-Indices: Model-Oriented Theoretical Classification

	First-Generation	*Second-Generation*	*Third-Generation*
Real Interest Rate	+	-	+
Short-Term Debt	-	+	+
M2/Foreign Reserves	+	-	-
Domestic-Foreign Real Interest Rate Differential	+	-	+
Export Growth	+	+	-
Domestic Credit pro GDP Growth	+	+	+
Foreign Reserves	+	-	-
Banking Deposits Growth	-	+	+
Lending-to-Deposit Rate Differential	-	-	+
Real Exchange Rate	+	-	-
Output Growth	-	+	-
Import Growth	+	+	-
M2 Multiplier	+	-	+

Source: own illustration

The monthly composite sub-indices based on first-, second- and third-generation models of the theory of currency crises are formed following the same procedure as for the general composite index.

In accordance with the calculations and estimation methods of the general composite index the Noise-to-Signal-Ratio of the composite sub-indices is minimised and, thus, determined. The subsequent table depicts the Noise-to-Signal-Ratio in single crisis countries, classified according to composite sub-indices based on first-, second- and third-generation approaches, and on the general composite index.

Tab. 11: Monthly Composite Sub-Indices: Noise-to-Signal-Ratio

	Noise-to-Signal-Ratio			
	First-Generation	*Second-Generation*	*Third-Generation*	*Composite Index*
All countries	0.2305	0.5408	0.2239	0.2154
Belarus	0.2105	2.4180	1.7684	0.2947
Bulgaria	0.6353	1.1294	0.3765	0.4235
Czech Republic	0.7857	0.5714	towards infinity	0.8000
Moldova	0.1084	0.1239	0.0964	0.1157
Romania	0.0842	0.3904	0.0000	0.0000
Russian Federation	0.0480	0.4945	0.3014	0.1099
Ukraine	0.4235	0.2080	0.0941	0.2118

Note: the threshold value of the composite index was held constant for the whole country sample.

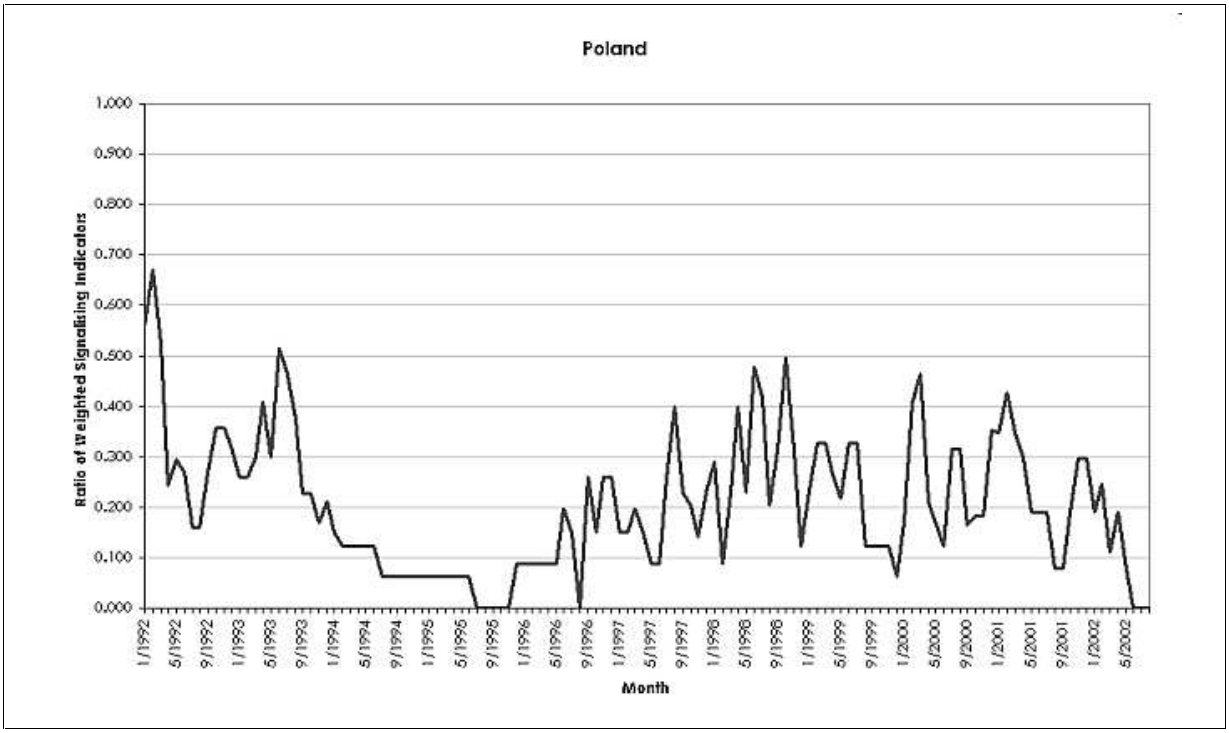
Source: own calculations

Given the country-specific Noise-to-Signal-Ratio based on first-, second- and third-generation models, special features of single crises emerge. Thus, conclusions about the theoretical background of certain crises can be drawn by comparing the model-specific NSR to the Noise-to-Signal-Ratio of the general composite index. Such a procedure produces specialised information, which would be lost in the general composite index due to aggregation.

In the case of Belarus, the Czech Republic, Moldova, Romania, and the Russian Federation the Noise-to-Signal-Ratio displays particularly good scores in connection with the index based on first-generation models. With regard to the second-generation models, solely the Czech Republic and the Ukraine reveal a higher score, while in Bulgaria, Moldova, Romania, and the Ukraine the highest values were calculated for the index based on third-generation models. On the basis of this summary, conclusions - albeit limited - can be drawn *ex-post* on the causes of currency crises: for instance, the case of the Czech Republic as an exemplar for cost-benefit considerations regarding the retention of the exchange rate goal versus the economic adjustment difficulties connected with a floating of the exchange rate. Yet another prominent example would be the crisis in the Russian Federation, which should be viewed, based on this empirical analysis, as a prototype of a first-generation-crisis, i.e. an inadequate fiscal and monetary policy. However, despite the potential for structured *ex-post* analyses, the relevance as an early warning system should also not be underestimated. For this, it is essential to continue the composite sub-indices based on first-, second- and third-generation models into the present, as it was done here. In the case of an increase in the risk potential, the availability of three different composite indices makes a structuring of political instruments possible.

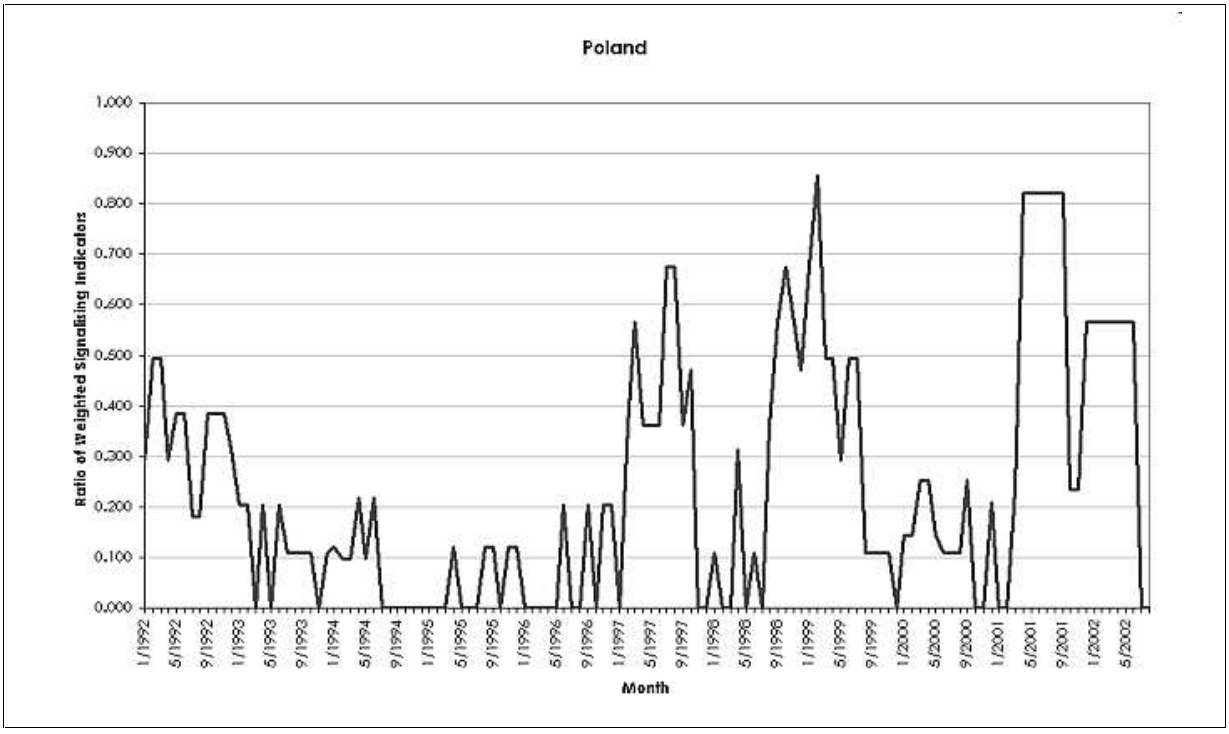
One promising application is the Polish economy in the course of 2001, as it is generally agreed that the vulnerability to a currency crisis was very high. In the following three figures monthly composite sub-indices based on first-, second- and third-generation models are shown for Poland up to August 2002.

Fig. 4: Composite Index According to First-Generation: Poland



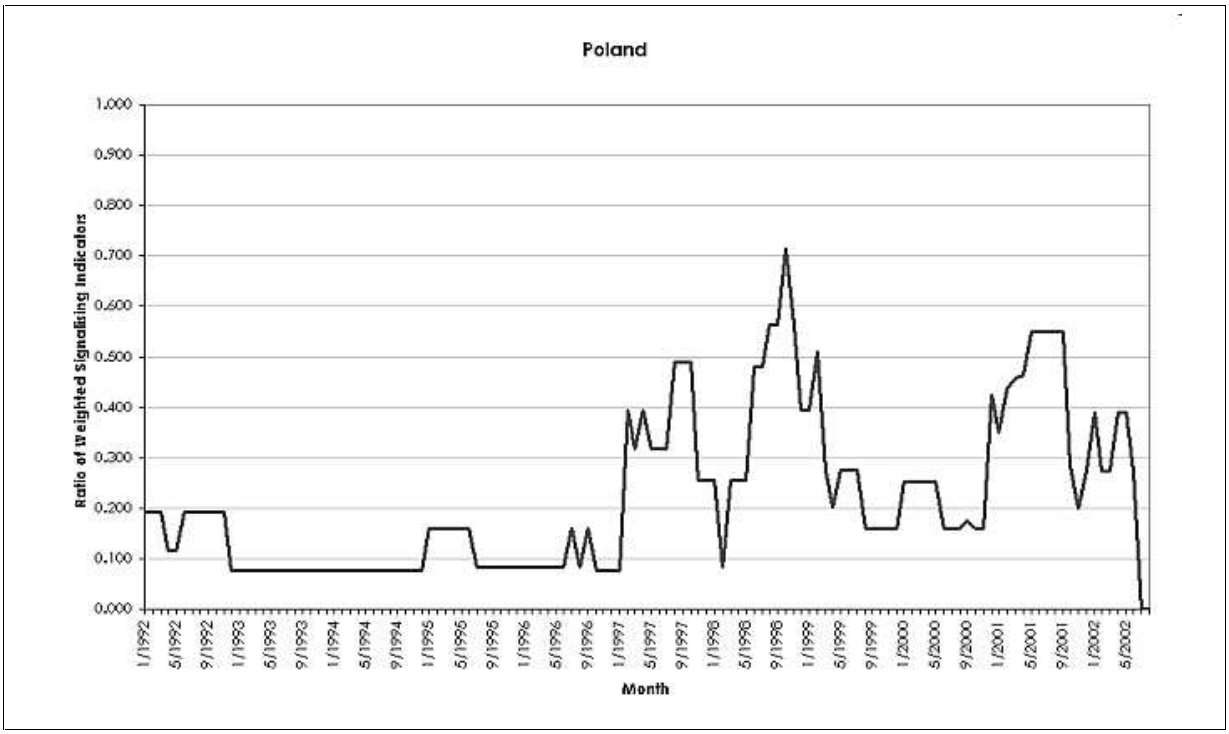
Source: own illustration

Fig. 5: Composite Index According to Second-Generation: Poland



Source: own illustration

Fig. 6: Composite Index According to Third-Generation: Poland



Source: own illustration

Irrespective of the massive and long-lasting increase in the risk potential apparent in all three sub-indices, in particular the sub-index based on the second-generation models makes clear that weaknesses in economic fundamentals existed, which might have been caused by a lack (1) of coordination between various policy fields and (2) of a mutual agreement on economic issues, primarily in balancing external and domestic concerns.

The Quadratic Probability Score has already been presented as another goodness-of-fit coefficient for composite indices. This score can also be applied to the composite sub-indices.

Tab. 12: Monthly Composite Sub-Indices: QPS

	Noise-to-Signal-Ratio		
	First-Generation	*Second-Generation*	*Third-Generation*
Bulgaria	0.3609	0.5247	0.3951
Moldova	0.2543	0.2503	0.2712
Romania	0.2365	0.3057	0.1986
Russian Federation	0.2066	0.3047	0.2213
Czech Republic	0.4293	0.3070	0.4211
Ukraine	0.3858	0.1924	0.2468
Belarus	0.2810	0.7061	0.3822
Note: the QPS-score of the naive forecast was 0.3363.			

Source: own calculations

Those values underlined depict the best Quadratic Probability Score respectively. Except for Bulgaria, the scores are also higher than the QPS-value which was calculated based on a naive forecast model. Once again, this cannot be viewed as statistically significant. However, it clear the causes of crises makes. Essentially, the results of the analysis of Noise-to-Signal-Ratios are confirmed.

Altogether, one can draw the conclusion that the breakdown of the general composite index into three separate monthly indices according to the underlying model-generations might be appropriate to avoid information losses due to the aggregation of data. Moreover, this *modus operandi* is suited to a more exact assessment of the increase in the vulnerability to a currency crisis.

5 Conclusion

The results of this study show that the 'signals approach' is useful both for assessing a country's current risk potential and for a structured *ex-post* analysis. The latter can be carried out concentrating, first, on the performance of single indicators and, second, on separate sub-indices based on theoretical considerations revealing weaknesses in specific policy areas. Single factors appropriate for such an analysis are, *inter alia*, 'Short-Term Debt', 'M2 pro Foreign Reserves', various interest rate related variables and 'Real Exchange Rate'. Altogether, various statistical approaches demonstrate also the usefulness of the modified 'signals approach' as a method of assessing the vulnerability to a currency crisis. For instance, even though the indicators were calculated based on a sample of crises countries, which does not include Poland, the composite index, the risk ranking and the conditional probabilities of currency crises show a high risk for this economy throughout the year 2001 and into mid-2002. Currently (11/2002) this is additionally the case in the future EMU-members Hungary and the Czech Republic. Even for non-market economies such as Moldova and Belarus, statistically viable results can be obtained. In spite of this, one cannot realistically expect to derive detailed information on the precise occurrence and impacts of crises from this study.

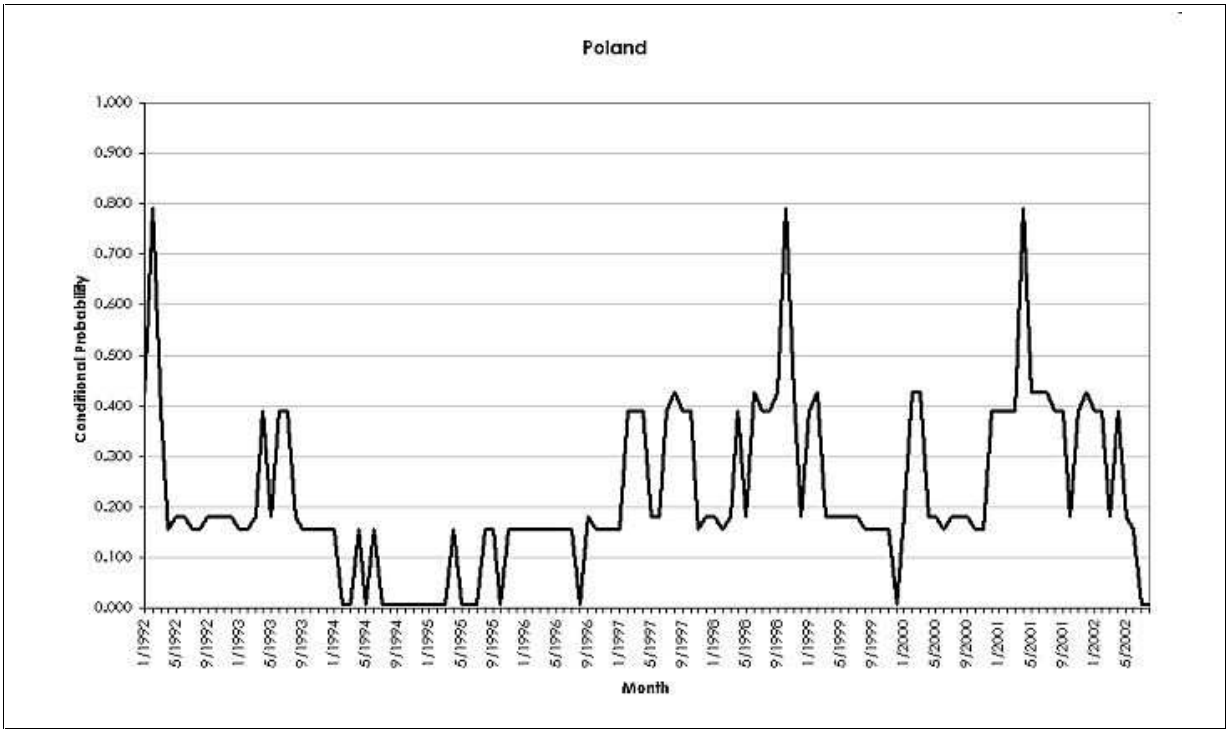
6 Appendix

Tab. A1: Risk Ranking: July 2001

Country	Z_t
Poland	1.3905
Bulgaria	0.8046
Slovenia	0.6947
Lithuania	0.6658
Hungary	0.6533
Czech Republic	0.6093
Estonia	0.5816
Latvia	0.5585
Albania	0.5246
Moldova	0.4848
Slovak Republic	0.4499
Belarus	0.4446
Romania	0.2985
Ukraine	0.2829
Russia	0.2629
Note: calculation of Noise-to-Signal-Ratio was based on the enlarged country sample.	

Source: own calculations

Fig. A1: Conditional Probability of Crisis: Poland



Source: own illustration

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