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# Early Warning System of Government Debt Crises

Christian Dreger and Konstantin A. Kholodilin

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#### IMPRESSUM

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# Early Warning System of Government Debt Crises<sup>1</sup>

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**Abstract.** The European debt crisis has revealed serious deficiencies and risks on a proper functioning of the monetary union. Against this backdrop, early warning systems are of crucial importance. In this study that focuses on euro area member states, the robustness of early warning systems to predict crises of government debt is evaluated. Robustness is captured via several dimensions, such as the chronology of past crises, econometric methods, and the selection of indicators in forecast combinations. The chosen approach is shown to be crucial for the results. Therefore, the construction of early warning systems should be based on a wide set of variables and methods in order to be able to draw reliable conclusions.

**Keywords:** Sovereign debt crises, multiple bubbles, signal approach, logit, panel data model.

**JEL:** C23, C25, H63

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## 1 Introduction

Although the acute phase of the European debt crisis has overcome for the time being, the crisis has revealed serious deficiencies and risks on a proper functioning of the monetary union. While some progress has been made to strengthen policy instruments, the euro area institutions still show huge deficits. The responses to the crisis, especially those of the ECB, have bought additional time but did not solve the underlying problems. Government debt is still at high levels. Bailout expectations continue to weaken market based fiscal discipline. Against this backdrop, early warning systems are of crucial importance. In fact, the timely detection of imbalances can ensure preemptive policy responses. For instance, the EU Commission (2011) constructed a scoreboard based on 14 headline and 25 auxiliary indicators. If robust signals can be extracted, measures for the correction of unsustainable public debt levels could be undertaken well in advance, for instance, through a restructuring of government debt. For profound policy advice, the signals should be reliable, as false alarms can imply losses in economic wealth. For robustness, different approaches are used to uncover the most relevant variables for the early detection of imbalances.

The paper is structured as follows. The next section discusses alternative methods to identify periods of excessive government debt. Section 3 presents the forecasting methods used in the analysis. Construction principles for early warning systems are derived in section 4. Finally, section 5 concludes.

## 2 Periods of excessive government debt

The first step to construct an early warning system is to derive a chronology for the periods of excessive government debt. Three approaches are employed to identify the debt crises, based on the government debt to GDP ratio: 1) explosive roots tests of Phillips et al. (2015); 2) the approach used by Dreger and Reimers (2013); and 3) a policy approach.

The first method determines multiple debt crises based on the explosive root tests of the debt-to-GDP ratio. Against the null hypothesis of a random walk the alternative of an explosive behavior is tested. The test is based on the rolling regression model:

$$(1) \quad \Delta y_t = \hat{\alpha}_{r_1, r_2} + \hat{\beta}_{r_1, r_2} y_{t-1} + \sum_{i=1}^k \hat{\varphi}_{r_1, r_2}^i \Delta y_{t-i} + \hat{\varepsilon}_t,$$

where  $y_t$  is the variable to be tested for explosive roots;  $k$  is the lag order;  $\alpha$ ,  $\beta$ , and  $\varphi$  are parameters to be estimated; and  $\varepsilon_t$  is the disturbance term. The sample of this rolling-window regression starts from the  $r_1^{\text{th}}$  fraction and ends at the  $r_2^{\text{th}}$  fraction of the total sample ( $T$ ), where  $r_2 = r_1 + r_w$  and  $r_w > 0$  is the (fractional) window size of the regression. Based on this regression, an augmented Dickey-Fuller (ADF) test is conducted on a forward expanding sample sequence. The window size,  $r_w$ , expands recursively from  $r_0$  to 1; where  $r_0$  is the smallest and 1 is the largest window width fraction, which corresponds to the total sample size. The starting point  $r_1$  of the sample sequence is fixed at 0. The end of each sample ( $r_2$ ) equals  $r_w$ , and changes from  $r_0$  to 1. The test of Phillips et al. (2015) is then the supremum value of this ADF statistic sequence:

$$(2) \quad SADF(r_0) = \sup_{r_2 \in [r_0, 1]} ADF_0^{r_2},$$

where  $ADF_0^{r_2}$  is the ADF statistic for a sample running from 0 to  $r_2$ . The asymptotical critical values for this test have been tabulated by Phillips et al. (2015) by Monte Carlo simulations.

A big advantage of the Phillips et al. (2015) test is that it can detect multiple bubbles. In contrast, the tests suggested by Phillips et al. (2011) and Homm and Breitung (2012) are restricted to single bubbles. In the analysis, the multiple bubbles test is carried out for each country's government debt-to-GDP ratio. Three chronologies are obtained depending on the  $p$ -value of the test, i.e., 0.8, 0.9, and 0.95.

The second approach is based on the budget constraint of the government in continuous time, see Greiner and Fincke (2009)<sup>2</sup>. By definition, the change of public debt ( $\Delta D$ ) is equal to the difference of government expenditures ( $G$ ) and government revenues ( $E$ ) plus the interest which is paid on public debt ( $iD$ )

$$(3) \quad \Delta D = G - E + iD$$

Dividing the relationship by nominal GDP ( $Y$ ) one obtains the public balance to GDP ratio, i.e.

$$(4) \quad \frac{\Delta D}{Y} = \frac{G}{Y} - \frac{E}{Y} + i \frac{D}{Y} = g - e + i \cdot d = p + i \cdot d.$$

Differentiating the debt-to-GDP ratio with respect to time and rearranging yields

$$(5) \quad \frac{\partial(D/Y)}{dt} = p + (i - y)d$$

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<sup>2</sup> The following condition can be also obtained from a model specified in discrete time, see Blanchard (2000).

where  $p$  is the primary deficit to GDP ratio,  $y$  the growth rate of nominal output and  $d$  the debt-to-GDP ratio. If  $p=0$  the debt to GDP ratio will not increase, if the interest rate is below nominal output growth. If the interest rate exceeds this bound, a primary surplus ( $p<0$ ) is required to stabilize debt-to-GDP ratio. This condition is captured by a dummy variable. It is set to unity, if the primary surplus is less than the product of the debt ratio and the difference between the interest rate and nominal output growth, and zero otherwise, i.e.

$$(6) \quad \begin{aligned} Z_t &= 1 && \text{if } -p_t < (i_t - y_t)d_t \\ Z_t &= 0 && \text{otherwise} \end{aligned}$$

By multiplying the debt ratio with the dummy variable, the periods of sustainable and non-sustainable government debt to GDP ratio can be distinguished. Note that sustainability is achieved if the debt ratio does not increase. To match this condition, governments will eventually react to obtain a sufficient primary surplus.

Finally, institutional arrangements are considered to determine the threshold value (naïve chronology). For the debt-to-GDP ratio, 60 percent (Maastricht criterion) and 90 percent are used. Debt will be harmful for the economic development, if debt ratio exceeds these bounds.

### 3 Forecasting methods

The second step to construct an early warning system is to implement models to explain the chronology. To assess the quality of forecasts, the Cramer (1999) measure is used:

$$(7) \quad CM = E(\widehat{F}_t | C_t = 1) - E(\widehat{F}_t | C_t = 0)$$

where  $C_t$  is the binary crisis variable, such that  $C_t=1$ , if there occurs a crisis in period  $t$ , and  $C_t=0$ , otherwise.  $\hat{F}_t$  are the model-derived probabilities of crisis. Thus, the first term on the right-hand side is the conditional average of  $\hat{F}_t$  for  $C_t=1$ , while the second term is the conditional average of  $\hat{F}_t$  in normal times ( $C_t=0$ ). Unlike many other forecast accuracy measures, such as quadratic probability scores, the Cramer measure heavily penalizes the incorrect predictions, and as each proportion is taken within the subsample, the statistic is not unduly influenced by the larger size of the group of the more frequent outcomes. The measure varies between  $-1$ , when the model-derived probabilities are perfectly negatively correlated with the binary crisis variable, and  $+1$ , when the model-derived probabilities perfectly coincide with the binary variable. The larger the statistic in the  $[-1, +1]$  interval, the more reliable the forecast.

The detection of crises is based on signal and logit models. The signal approach has been proposed by Kaminsky et al. (1998) and Reinhart and Kaminsky (1999). It looks for indicators that allow the best prediction of past crises. To extract a signal for a crisis the predictors should deviate from a normal behavior in advance. Every time an indicator exceeds a certain threshold value, it is interpreted as a warning signal that a crisis may take place in the next periods. The thresholds are determined separately for each predictor variable. To obtain the threshold, the values of the predictor are ordered and then a grid search is conducted for the values between the first and the ninth deciles. The value that gives the highest Cramer measure is chosen as the optimal threshold. Thresholds are also considered for lags of the predictor. This approach was already applied in the sovereign debt context by Knedlik and von Schweinitz (2012) as well as El-Shagi et al. (2013), who constructed an early warning system based on the signal ap-

proach in order to forecast the excessive public debt in the European Monetary Union countries.

Logit models are widely used to detect and predict economic recessions, currency crises, and speculative movements in financial markets. They determine the sign and significance of the impact of the relevant predictors. As debt crises are infrequent events, the logit model is more adequate compared to the probit approach, as stressed in Kumar et al. (2003). The logit regression can be formulated as:

$$(8) \quad Pr(R_{it} = 1 / X_{it}) = F(X_{it}\beta + \varepsilon_{it}) \quad , \quad i = 1, \dots, N \quad , \quad t = 1, \dots, T$$

where  $Pr(\bullet)$  is the conditional probability of a crisis for the reference chronology;  $X_{it}$  is a predictor variable;  $F(\bullet)$  is the logistic cumulative probability function;  $\varepsilon_{it}$  is the disturbance term;  $N$  the number of countries; and  $T$  is the number of time periods. The logit model is investigated for panel data. Fixed effects are accounted for by subtracting from all the variables their within-group means. Then, the pooled logit estimation is applied to the demeaned data.

Logit models are specified for each predictor separately. They include a constant and the lags of the predictor up to a maximum of 4 periods. The smallest model includes a constant and the contemporaneous value of the predictor, while the largest model includes the constant and all the four lags of the predictor. The model specification with the highest Cramer measure is chosen for the predictor under consideration.

In addition, the performance for forecast combinations is evaluated. In fact, the predictive power of combinations often exceeds that of the individual forecasts, since structural breaks may cancel out in the aggregate. To test whether some pre-selection of individual forecasts might be advisable, a

combination of all models is compared to a combination of the best models. The latter are based on the out-of-sample performance of the individual predictors and includes only the best predictors with a Cramer measure exceeding 0.1.

#### **4 Constructing early warning systems**

Early warning systems to detect future crises developments in government debt are calibrated for 12 members of the euro area (EA12): Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, and Spain. New member states are excluded, as a sufficient time span of data is not available. The total sample runs from 1991q1 and 2015q4. The estimation subsample is 1991q1-2010q4, and the forecast subsample is 2011q1-2015q4.

The set of potential predictors includes 54 variables plus the logarithms of the positively valued variables. Thus, the total number of predictors is 83. The variables are obtained at the quarterly frequency and reported by the OECD and Bloomberg databases, see Table 1 for the details.

*-Table 1 about here-*

By applying the different methodologies mentioned above, historical chronologies for excessive government debt can be derived (Figure 1). Generally, the crises cannot be uniquely identified, as the respective periods only partially overlap. For instance, while a crisis is indicated for Germany after the unification, the evidence is missed by the naïve chronologies. The correlation of the chronologies obtained by the various approaches is positive,

although far below unity (Table 2). The lack of robustness of the chronology is a serious obstacle for the appropriate construction of early warning systems. As a rule, sound policy advice should be based on different specifications of the chronology.

*Figure 1 and Table 2 about here*-Nonetheless, some construction principles for early warning systems can be derived. In the following, the (0,1) chronologies are explained by different indicators capturing various aspects of the economy. The model parameters are estimated in a recursive manner with an increasing length of the window. Out-of-sample forecasts are derived to reproduce the actual situation where the forecaster is in. For the sake of brevity, the in-sample and out-of-sample results for individual indicators are shown only for Phillips et al. (2015) 90% chronology (Table 3 and Table 4 respectively). Moreover, we report the predictive accuracy of the forecast combinations and a one quarter forecasting horizon (Table 5)<sup>3</sup>.

-Table 3 and Table 4 about here-

-Table 5 about here-

The forecasting performance of the different methods is not overwhelmingly large, as shown by low values of the Cramer statistic. Usually, the values do not exceed 0.3. The chronologies constructed by Dreger and Reimers (2013) and the naïve approach can be explained by a slightly higher precision, compared to the chronology favored by the explosive root approach. A pre-selection of individual indicators is recommended in most cases. For instance, the forecasting accuracy could be doubled in case of the Dreger and Reimers (2013) chronology. A general dominance of the logit or the signal approach is not detected. Furthermore, the most successful variables

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<sup>3</sup> Further results for individual variables and different forecasting horizons are available from the authors upon request.

in the forecasting combination refer to asset prices, industrial production, GDP growth, consumption expenditure, interest rate spreads, and certain confidence indicators. External balances, international reserves and labor market variables are of minor relevance. However, a focus on fiscal and financial variables is hardly sufficient to detect a crisis development in government debt. Overall, a wide set of variables should be monitored to identify debt crises in the future. Our conclusions are, thus, in line with the findings of Knedlik and von Schweinitz (2012), who state that most indicators are helpful in signaling the public debt crises.

## **5 Conclusions**

The European debt crisis has revealed serious deficiencies and risks on a proper functioning of the monetary union. Against this backdrop, early warning systems are of crucial importance. In this study that focuses on euro area member states, the robustness of early warning systems is discussed to indicate crises of government debt. Robustness is captured via several dimensions, such as the chronology of past crises, econometric methods and the selection of indicators in forecast combinations. The crises chronology is developed by different methods. Furthermore, we distinguish between the signal and discrete-choice approach. Drawing on a large set of indicators, a horse race exercise is conducted for each predictor. In addition, a forecast combination is employed using different weighting schemes of the individual methods to find the most appropriate set of predictors for the early detection of imbalances.

The chosen approach is shown to be crucial for the results. Therefore, the construction of early warning systems should be based on a wide set of variables and methods to extract reliable conclusions.

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**Table 1: Data and sources**

Code	Description	Definition	Measurement unit
RGDP_annual_lev	Gross domestic product - expenditure approach	VOBARSA: National currency, volume estimates, OECD reference year, annual levels, seasonally adjusted	Euro, Millions, 2010
P_GDP	Gross domestic product - expenditure approach	DOBSA: Deflator, OECD reference year, seasonally adjusted	Index, 2010
GDP_vol	Gross domestic product - expenditure approach	VIXOBSA: Volume index, OECD reference year, seasonally adjusted	Index, 2010
D4RGDP	Gross domestic product - expenditure approach	GYSA: Growth rate compared to the same quarter of previous year, seasonally adjusted	Percentage
DRGDP	Gross domestic product - expenditure approach	GPSA: Growth rate compared to previous quarter, seasonally adjusted	Percentage
P_Cons	Final consumption expenditure	DNBSA: Deflator, national base/reference year, seasonally adjusted	Index, 2010
X_annual_lev	Gross domestic product - expenditure approach	CARSA: National currency, current prices, annual levels, seasonally adjusted	Euro, Millions
RX_annual_lev	Gross domestic product - expenditure approach	VOBARSA: National currency, volume estimates, OECD reference year, annual levels, seasonally adjusted	Euro, Millions, 2010
P_X	Gross domestic product - expenditure approach	DOBSA: Deflator, OECD reference year, seasonally adjusted	Index, 2010
X_vol	Gross domestic product - expenditure approach	VIXOBSA: Volume index, OECD reference year, seasonally adjusted	Index, 2010
D4RX	Gross domestic product - expenditure approach	GYSA: Growth rate compared to the same quarter of previous year, seasonally adjusted	Percentage
DRX	Gross domestic product - expenditure approach	GPSA: Growth rate compared to previous quarter, seasonally adjusted	Percentage
M_annual_lev	Gross domestic product - expenditure approach	CARSA: National currency, current prices, annual levels, seasonally adjusted	Euro, Millions
RM_annual_lev	Gross domestic product - expenditure approach	VOBARSA: National currency, volume estimates, OECD reference year, annual levels, seasonally adjusted	Euro, Millions, 2010
P_M	Gross domestic product - expenditure approach	DOBSA: Deflator, OECD reference year, seasonally adjusted	Index, 2010
M_vol	Gross domestic product - expenditure approach	VIXOBSA: Volume index, OECD reference year, seasonally adjusted	Index, 2010
D4RM	Gross domestic product - expenditure approach	GYSA: Growth rate compared to the same quarter of previous year, seasonally adjusted	Percentage

Code	Description	Definition	Measurement unit
DRM	Gross domestic product - expenditure approach	GPSA: Growth rate compared to previous quarter, seasonally adjusted	Percentage
P_FCE	Private final consumption expenditure	DOBSA: Deflator, OECD reference year, seasonally adjusted	Index, 2010
RGFCF	Gross fixed capital formation	VOBARSA: National currency, volume estimates, OECD reference year, annual levels, seasonally adjusted	Euro, Millions, 2010
LTIR	Long-term interest rates, Per cent per annum		Percentage
STIR	Short-term interest rates, Per cent per annum		Percentage
CPI	Relative consumer price indices		Index, 2010=100
P_Share	Share Prices > All shares/broad > Total > Total		Index, 2010=100
Ex_rate	Currency Conversions > US\$ exchange rate > Spot, end of period > USD:national currency		Euro
RHPI	Real house price		Index, 2010=100
HPI	Nominal house price indices, s.a.		Index, 2010=100
Rent	Rent prices, s.a.		Index, 2010=100
P2R	Price to rent ratio		Index, 2010=100
P2Y	Price to income ratio		Index, 2010=100
BONDSIR	Long-term interest rate on government bonds	Percentage	
BONDS10Y	Long-term Government bond yields, 10-year	Yield	
GDPYOY	Real GDP	Chained 2010 Prices YoY %, SWDA	
GDPQoQ	Real GDP	Chained 2010 Prices QoQ %, SWDA	
CONSYOY	Final Consumption Expenditure	Chained 2010 Prices YoY %, SWDA	
GFCFYOY	GFCF	Chained 2010 Prices YoY %, SWDA	
GOVCONS	General Government Final Consumption Ex-	Chained 2010 Prices, SWDA	Euro, Millions

Code	Description	Definition	Measurement unit
	penditure		
GOVCONSYOY	General Government Final Consumption Expenditure	Chained 2010 Prices YoY %, SWDA	
EXPYOY	Exports of Goods and Services	Chained 2010 Prices YoY %, SWDA	
IMPYOY	Imports of Goods and Services	Chained 2010 Prices YoY %, SWDA	
CPIYOY	CPI	YoY %, NSA	
CPIMOM	CPI	MoM %, NSA	
PPI	PPI (excl. construction)	2010=100, NSA	
PPIYOY	PPI (excl. construction)	YoY %, NSA	
PPIMOM	PPI (excl. construction)	MoM %, NSA	
PROD	Industrial production (Volume)	2010=100, SWDA	Index
PRODYOY	Industrial production (Volume)	YoY %, SWDA	
PRODMOM	Industrial Production (Volume)	MoM %, SWDA	
ESI	European Commission Economic Sentiment Indicator	Index, SA, Long-term average = 100	
CONFINDEX	European Commission Consumer Confidence Indicator	SA, % Balance/Diffusion Index	Index
CABALANCE	Current Account Balance	% of GDP	
TRADEBALANCE	Trade Balance	Nominal Value, NSA	Euro, Billions
FORRES	Total International Reserves	Value, NSA	Euro, Millions
Spread	LTIR minus STIR	own calculations	

**Table 2. Correlation between alternative debt crises chronologies**

Chronology	Phillips et al. (2015) 90%	Phillips et al. (2015) 95%	Dreger and Reimers (2013)	Naive 60%	Naive 90%
Phillips et al. (2015) 80%	0.785	0.625	0.106	0.089	0.139
Phillips et al. (2015) 90%		0.795	0.105	0.127	0.167
Phillips et al. (2015) 95%			0.254	0.185	0.219
Dreger and Reimers (2013)				0.227	0.276
Naive 60%					0.513

**Table 3: In-sample forecast accuracy of signal and logit approaches with respect to the Phillips et al. (2015) 90% chronology**

Variable	Signal approach					Logit approach				
	Lag_0	Lag_1	Lag_2	Lag_3	Lag_4	Lag_0	Lag_1	Lag_2	Lag_3	Lag_4
RGDP_annual_lev.demeaned	-0.025	-0.028	-0.010	-0.004	0.015	0.009	0.047	0.047	0.058	0.068
P_GDP.demeaned	0.005	0.011	0.021	0.027	0.032	0.002	0.023	0.064	0.093	0.115
GDP_vol.demeaned	0.000	0.000	0.000	0.005	0.005	0.054	0.074	0.074	0.089	0.111
D4RGDP.demeaned	-0.022	-0.037	-0.064	-0.073	-0.064	0.013	0.027	0.047	0.067	0.083
DRGDP.demeaned	-0.104	-0.116	-0.122	-0.092	-0.088	0.001	0.002	0.008	0.019	0.031
P_Cons.demeaned	0.110	0.122	0.122	0.110	0.122	0.009	0.046	0.099	0.153	0.232
X_annual_lev.demeaned	-0.038	-0.040	-0.022	-0.016	-0.010	0.001	0.039	0.042	0.045	0.047
RX_annual_lev.demeaned	0.011	0.008	0.015	0.033	0.027	0.002	0.041	0.046	0.048	0.049
P_X.demeaned	0.086	0.108	0.084	0.105	0.150	0.010	0.011	0.011	0.014	0.021
X_vol.demeaned	0.000	0.000	0.000	0.000	0.000	0.006	0.022	0.030	0.030	0.030
D4RX.demeaned	0.045	-0.012	-0.061	-0.082	-0.128	0.000	0.019	0.031	0.047	0.072
DRX.demeaned	0.018	0.018	0.006	0.024	-0.028	0.002	0.002	0.004	0.007	0.020
M_annual_lev.demeaned	-0.013	0.021	0.063	0.069	0.063	0.004	0.026	0.027	0.028	0.032
RM_annual_lev.demeaned	0.011	0.021	0.027	0.033	0.051	0.012	0.036	0.038	0.038	0.040
P_M.demeaned	-0.055	-0.028	-0.012	0.009	0.031	0.030	0.033	0.033	0.039	0.050
M_vol.demeaned	0.000	0.000	0.000	0.000	0.000	0.005	0.022	0.023	0.023	0.026
D4RM.demeaned	0.006	-0.021	-0.067	-0.091	-0.119	0.001	0.015	0.028	0.052	0.080
DRM.demeaned	0.020	0.039	0.027	0.015	-0.043	0.001	0.001	0.001	0.004	0.018
P_FCE.demeaned	0.000	0.005	0.011	0.016	0.021	0.001	0.008	0.021	0.040	0.080
RGFCF.demeaned	0.021	0.003	0.000	0.018	0.037	0.003	0.013	0.017	0.027	0.042
LTIR.demeaned	-0.076	-0.099	-0.120	-0.099	-0.046	0.033	0.056	0.060	0.062	0.063
STIR.demeaned	0.000	0.000	0.000	0.000	0.000	0.140	0.147	0.152	0.154	0.155
CPI.demeaned	0.122	0.131	0.161	0.168	0.174	0.006	0.019	0.035	0.047	0.052

Variable	Signal approach					Logit approach				
	Lag_0	Lag_1	Lag_2	Lag_3	Lag_4	Lag_0	Lag_1	Lag_2	Lag_3	Lag_4
P_Share.demeaned	-0.274	-0.321	-0.338	-0.328	-0.290	0.086	0.101	0.106	0.107	0.107
Ex_rate.demeaned	-0.089	-0.069	-0.024	0.031	0.098	0.004	0.004	0.008	0.019	0.027
RHPI.demeaned	-0.157	-0.144	-0.155	-0.142	-0.144	0.012	0.024	0.030	0.037	0.045
HPI.demeaned	-0.141	-0.147	-0.040	-0.116	-0.080	0.004	0.025	0.034	0.047	0.062
Rent.demeaned	0.038	0.035	0.042	0.048	0.042	0.011	0.036	0.044	0.054	0.066
P2R.demeaned	-0.128	-0.134	-0.122	-0.118	-0.128	0.022	0.024	0.024	0.024	0.024
P2Y.demeaned	-0.055	-0.029	-0.025	-0.021	-0.017	0.016	0.018	0.019	0.022	0.030
BONDSIR.demeaned	0.010	0.000	0.000	0.000	0.000	0.067	0.090	0.093	0.094	0.094
BONDS10Y.demeaned	-0.317	-0.329	-0.293	-0.258	-0.150	0.120	0.136	0.159	0.167	0.170
GDPYOY.demeaned	-0.152	-0.136	-0.136	-0.136	-0.136	0.020	0.047	0.058	0.071	0.095
GDPQoQ.demeaned	-0.136	-0.152	-0.152	-0.273	-0.273	0.000	0.007	0.020	0.035	0.047
CONSYOY.demeaned	0.010	0.040	0.152	0.278	0.121	0.001	0.008	0.018	0.023	0.023
GFCFYOY.demeaned	-0.288	-0.091	-0.106	-0.121	-0.121	0.055	0.134	0.167	0.193	0.241
GOVCONS.demeaned	0.000	0.019	0.019	0.019	0.038	0.100	0.151	0.203	0.275	0.293
GOVCONSYOY.demeaned	-0.048	0.273	0.125	0.125	-0.007	0.000	0.005	0.009	0.009	0.012
EXPYOY.demeaned	-0.101	-0.212	-0.197	-0.106	-0.106	0.013	0.045	0.058	0.074	0.130
IMPYOY.demeaned	-0.035	-0.020	-0.131	-0.242	-0.258	0.027	0.074	0.090	0.134	0.237
CPIYOY.demeaned	-0.319	-0.309	-0.237	-0.280	-0.298	0.162	0.176	0.196	0.228	0.249
CPIMOM.demeaned	-0.170	-0.143	-0.184	-0.197	-0.215	0.009	0.030	0.040	0.050	0.063
PPI.demeaned	-0.127	-0.116	-0.106	-0.095	-0.090	0.007	0.007	0.007	0.007	0.009
PPIYOY.demeaned	-0.097	-0.165	-0.168	-0.138	-0.158	0.002	0.009	0.021	0.036	0.045
PPIMOM.demeaned	-0.122	-0.161	-0.117	-0.131	-0.151	0.000	0.002	0.002	0.006	0.012
PROD.demeaned	-0.010	-0.010	-0.010	-0.010	0.016	0.017	0.033	0.059	0.069	0.068
PRODYOY.demeaned	-0.189	-0.230	-0.272	-0.272	-0.308	0.111	0.129	0.140	0.153	0.179
PRODMOM.demeaned	0.144	0.111	0.077	0.167	0.059	0.012	0.021	0.021	0.041	0.041
ESI.demeaned	-0.143	-0.166	-0.172	-0.172	-0.176	0.009	0.019	0.033	0.049	0.063

Variable	Signal approach					Logit approach				
	Lag_0	Lag_1	Lag_2	Lag_3	Lag_4	Lag_0	Lag_1	Lag_2	Lag_3	Lag_4
CONFINDEX.demeaned	-0.082	-0.105	-0.111	-0.114	-0.121	0.037	0.054	0.078	0.099	0.118
CABALANCE.demeaned	0.074	0.083	0.083	0.091	0.099	0.029	0.035	0.035	0.038	0.038
TRADEBALANCE.demeaned	0.203	0.203	0.234	0.223	0.143	0.078	0.082	0.082	0.082	0.090
FORRES.demeaned	-0.002	-0.007	-0.017	-0.026	-0.030	0.062	0.065	0.065	0.065	0.065
Spread.demeaned	0.166	0.184	0.171	0.157	0.100	0.088	0.091	0.094	0.095	0.095
LRGDP_annual_lev.demeaned	-0.095	-0.089	-0.095	-0.077	-0.046	0.001	0.002	0.004	0.011	0.023
LP_GDP.demeaned	0.005	0.011	0.021	0.027	0.037	0.005	0.032	0.077	0.109	0.131
LGDP_vol.demeaned	0.000	0.000	0.000	0.000	0.005	0.060	0.080	0.081	0.098	0.122
LP_Cons.demeaned	0.110	0.122	0.122	0.122	0.134	0.004	0.048	0.106	0.162	0.241
LX_annual_lev.demeaned	-0.025	-0.053	-0.059	-0.065	-0.031	0.000	0.005	0.005	0.006	0.008
LRX_annual_lev.demeaned	-0.086	-0.101	-0.144	-0.101	-0.080	0.001	0.005	0.005	0.006	0.007
LP_X.demeaned	0.091	0.108	0.118	0.094	0.140	0.014	0.014	0.014	0.017	0.024
LX_vol.demeaned	0.000	0.000	0.000	0.000	0.000	0.000	0.016	0.025	0.025	0.025
LM_annual_lev.demeaned	0.023	-0.004	-0.022	-0.028	-0.010	0.002	0.003	0.003	0.005	0.009
LRM_annual_lev.demeaned	0.023	0.021	0.027	0.021	0.018	0.005	0.005	0.005	0.006	0.009
LP_M.demeaned	-0.055	-0.028	-0.012	0.009	0.031	0.036	0.038	0.038	0.044	0.053
LM_vol.demeaned	0.000	0.000	0.000	0.000	0.000	0.001	0.019	0.020	0.020	0.022
LP_FCE.demeaned	0.000	0.011	0.011	0.011	0.016	0.003	0.013	0.028	0.047	0.088
LRGFCF.demeaned	-0.051	-0.021	0.016	0.052	0.089	0.003	0.007	0.009	0.020	0.032
LCPI.demeaned	0.128	0.137	0.167	0.174	0.180	0.006	0.018	0.033	0.044	0.049
LP_Share.demeaned	-0.195	-0.227	-0.227	-0.214	-0.207	0.054	0.071	0.077	0.078	0.079
LEx_rate.demeaned	-0.089	-0.052	-0.001	0.040	0.098	0.003	0.003	0.007	0.017	0.024
LRHPI.demeaned	-0.157	-0.153	-0.159	-0.173	-0.175	0.009	0.017	0.021	0.027	0.032
LHPI.demeaned	-0.181	-0.187	-0.179	-0.189	-0.199	0.003	0.015	0.021	0.029	0.041
LRent.demeaned	0.054	0.076	0.067	0.086	0.093	0.017	0.038	0.044	0.054	0.065
LP2R.demeaned	-0.104	-0.114	-0.120	-0.130	-0.144	0.020	0.020	0.021	0.021	0.022

Variable	Signal approach					Logit approach				
	Lag_0	Lag_1	Lag_2	Lag_3	Lag_4	Lag_0	Lag_1	Lag_2	Lag_3	Lag_4
LP2Y.demeaned	-0.020	-0.020	-0.007	-0.003	0.006	0.009	0.009	0.010	0.011	0.015
LBONDSIR.demeaned	0.010	0.000	0.000	0.000	0.000	0.052	0.070	0.076	0.077	0.077
LBONDS10Y.demeaned	-0.281	-0.281	-0.246	-0.210	-0.102	0.096	0.108	0.127	0.131	0.137
LGOVCONS.demeaned	0.000	0.019	0.019	0.038	0.058	0.095	0.148	0.201	0.277	0.297
LPPI.demeaned	-0.147	-0.136	-0.125	-0.115	-0.110	0.008	0.008	0.008	0.008	0.010
LPROD.demeaned	0.016	0.016	0.016	0.016	0.016	0.005	0.015	0.033	0.038	0.038
LESI.demeaned	-0.146	-0.166	-0.176	-0.172	-0.176	0.007	0.015	0.030	0.044	0.059
LFORRES.demeaned	-0.022	-0.026	-0.034	-0.035	-0.037	0.017	0.027	0.036	0.040	0.045

**Table 4: Out-of-sample forecast accuracy of signal and logit approaches with respect to the Phillips et al. (2015) 90% chronology**

Variable	Signal approach					Logit approach				
	Lag_0	Lag_1	Lag_2	Lag_3	Lag_4	Lag_0	Lag_1	Lag_2	Lag_3	Lag_4
RGDP_annual_lev.demeaned	0.003	0.007	0.059	0.101	0.116	0.032	0.036	0.036	0.042	0.042
P_GDP.demeaned	0.000	0.000	0.000	0.000	0.000	0.004	0.015	0.025	0.032	0.041
GDP_vol.demeaned	0.000	0.000	0.000	0.000	0.000	0.022	0.023	0.024	0.025	0.026
D4RGDP.demeaned	0.064	0.046	0.022	-0.016	-0.037	0.005	0.017	0.032	0.046	0.052
DRGDP.demeaned	0.026	0.033	-0.013	-0.012	-0.012	0.000	0.000	0.004	0.011	0.021
P_Cons.demeaned	0.000	0.000	0.000	0.000	0.000	-0.049	0.028	0.109	0.187	0.271
X_annual_lev.demeaned	-0.007	-0.021	-0.032	-0.032	-0.025	0.000	0.014	0.017	0.016	0.013
RX_annual_lev.demeaned	0.101	0.094	0.056	-0.017	-0.037	0.000	0.012	0.015	0.015	0.012
P_X.demeaned	0.000	0.000	0.000	0.000	0.011	0.006	0.006	0.006	0.006	0.004
X_vol.demeaned	0.000	0.000	0.000	0.000	0.000	0.003	0.007	0.009	0.008	0.008
D4RX.demeaned	0.015	0.033	0.002	-0.039	-0.043	-0.001	-0.003	0.001	0.002	0.001
DRX.demeaned	0.008	0.029	0.016	0.013	0.013	0.002	0.002	0.001	0.001	-0.003
M_annual_lev.demeaned	-0.121	-0.058	-0.037	0.020	0.016	0.001	0.012	0.013	0.013	0.011
RM_annual_lev.demeaned	-0.008	0.003	-0.070	-0.077	-0.059	0.004	0.015	0.016	0.016	0.015
P_M.demeaned	0.000	0.000	0.000	0.000	0.000	0.018	0.017	0.017	0.017	0.017
M_vol.demeaned	0.000	0.000	0.000	0.000	0.000	0.002	0.007	0.008	0.008	0.008
D4RM.demeaned	0.036	0.016	-0.029	-0.060	-0.061	0.001	0.005	0.017	0.030	0.040
DRM.demeaned	-0.026	-0.008	-0.029	-0.036	-0.011	-0.001	-0.001	0.000	0.003	0.009
P_FCE.demeaned	0.000	0.000	0.000	0.000	0.000	0.006	0.020	0.031	0.042	0.051

Variable	Signal approach					Logit approach				
	Lag_0	Lag_1	Lag_2	Lag_3	Lag_4	Lag_0	Lag_1	Lag_2	Lag_3	Lag_4
RGFCF.demeaned	0.058	0.065	0.051	0.048	0.044	0.004	0.006	0.006	0.010	0.013
LTIR.demeaned	0.159	0.174	0.200	0.185	0.185	-0.081	-0.106	-0.115	-0.123	-0.120
STIR.demeaned	0.000	0.000	0.000	0.000	0.000	0.097	0.103	0.107	0.109	0.110
CPI.demeaned	0.141	0.155	0.159	0.163	0.177	0.013	0.016	0.021	0.024	0.029
P_Share.demeaned	-0.047	-0.036	-0.039	-0.029	-0.018	-0.024	-0.022	-0.021	-0.021	-0.021
Ex_rate.demeaned	-0.009	0.003	-0.075	-0.110	-0.106	-0.002	-0.002	-0.004	-0.008	-0.010
RHPI.demeaned	-0.211	-0.211	-0.222	-0.211	-0.233	0.031	0.048	0.056	0.066	0.073
HPI.demeaned	-0.378	-0.356	-0.278	-0.356	-0.333	0.016	0.045	0.055	0.068	0.076
Rent.demeaned	0.000	0.000	0.000	0.000	0.000	0.006	0.018	0.021	0.023	0.025
P2R.demeaned	-0.178	-0.178	-0.167	-0.167	-0.167	0.055	0.053	0.053	0.053	0.054
P2Y.demeaned	0.009	0.026	0.057	0.074	0.091	0.017	0.022	0.026	0.030	0.037
BONDSIR.demeaned	0.111	0.122	0.133	0.122	0.122	-0.090	-0.105	-0.111	-0.115	-0.111
BONDS10Y.demeaned	0.000	0.000	0.000	0.000	0.000	-0.073	-0.070	-0.048	-0.041	-0.038
GDPYOY.demeaned	-0.050	-0.100	-0.100	-0.100	-0.100	-0.019	-0.021	-0.027	-0.035	-0.062
GDPQoQ.demeaned	0.050	0.000	0.000	-0.050	-0.050	0.000	-0.004	-0.011	-0.016	-0.020
CONSYOY.demeaned	0.000	0.000	0.000	0.000	0.050	-0.005	-0.006	0.000	0.006	-0.002
GFCFYOY.demeaned	-0.050	0.000	0.000	0.000	0.000	-0.015	-0.024	-0.027	-0.043	-0.088
GOVCONS.demeaned	0.000	0.000	0.000	0.000	0.000	0.029	0.018	0.012	-0.004	-0.014
GOVCONSOY.demeaned	-0.150	-0.150	-0.150	-0.150	-0.150	0.001	-0.002	0.007	0.010	-0.003
EXPYOY.demeaned	-0.050	0.000	0.050	-0.100	-0.100	-0.017	-0.033	-0.032	-0.046	-0.101
IMPYOY.demeaned	0.000	-0.050	0.000	0.050	0.050	-0.014	-0.028	-0.040	-0.078	-0.163
CPIYOY.demeaned	-0.059	-0.025	-0.113	-0.044	-0.084	-0.039	-0.040	-0.034	-0.026	-0.006
CPIMOM.demeaned	-0.157	-0.172	-0.157	-0.190	-0.114	-0.007	-0.023	-0.028	-0.030	-0.027
PPI.demeaned	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	-0.003
PPIYOY.demeaned	0.050	0.049	-0.045	-0.101	-0.121	-0.005	-0.006	-0.013	-0.023	-0.029
PPIMOM.demeaned	0.096	0.160	0.076	0.057	0.130	-0.002	-0.006	-0.006	-0.013	-0.021

Variable	Signal approach					Logit approach				
	Lag_0	Lag_1	Lag_2	Lag_3	Lag_4	Lag_0	Lag_1	Lag_2	Lag_3	Lag_4
PROD.demeaned	0.085	0.050	0.070	0.089	0.064	-0.026	-0.019	-0.010	-0.002	-0.003
PRODYOY.demeaned	0.092	-0.004	-0.063	-0.140	-0.162	0.009	0.016	0.025	0.039	0.062
PRODMOM.demeaned	-0.128	-0.138	-0.147	-0.201	-0.147	-0.009	-0.021	-0.021	-0.058	-0.056
ESI.demeaned	0.039	0.025	0.005	-0.016	-0.049	0.005	0.014	0.027	0.039	0.049
CONFINDEX.demeaned	0.131	0.117	0.070	0.001	-0.016	-0.004	0.012	0.031	0.049	0.062
CABALANCE.demeaned	0.348	0.348	0.348	0.348	0.228	0.052	0.061	0.059	0.054	0.054
TRADEBALANCE.demeaned	0.151	0.193	0.196	0.227	0.207	0.217	0.228	0.237	0.239	0.218
FORRES.demeaned	0.198	0.187	0.176	0.166	0.155	0.013	0.016	0.018	0.018	0.018
Spread.demeaned	0.112	0.054	0.044	0.017	0.021	0.183	0.197	0.210	0.220	0.226
LRGDP_annual_lev.demeaned	-0.091	-0.070	-0.049	-0.021	0.007	-0.003	-0.003	-0.004	-0.001	0.005
LP_GDP.demeaned	0.000	0.000	0.000	0.000	0.000	0.005	0.016	0.026	0.032	0.042
LGDP_vol.demeaned	0.000	0.000	0.000	0.000	0.000	0.026	0.026	0.026	0.028	0.029
LP_Cons.demeaned	0.000	0.000	0.000	0.000	0.000	-0.029	0.044	0.120	0.191	0.267
LX_annual_lev.demeaned	0.000	0.000	0.000	0.000	0.003	0.001	0.006	0.006	0.005	0.003
LRX_annual_lev.demeaned	0.024	0.017	0.024	0.055	0.034	-0.003	0.000	0.001	0.000	-0.001
LP_X.demeaned	0.000	0.000	0.000	0.000	0.011	0.007	0.007	0.007	0.007	0.005
LX_vol.demeaned	0.000	0.000	0.000	0.000	0.000	0.002	0.007	0.010	0.010	0.009
LM_annual_lev.demeaned	0.014	0.007	0.000	0.000	0.000	-0.004	-0.003	-0.004	-0.004	-0.003
LRM_annual_lev.demeaned	-0.081	-0.084	-0.028	-0.013	0.008	0.001	0.001	0.001	0.001	0.003
LP_M.demeaned	0.000	0.000	0.000	0.000	0.000	0.020	0.019	0.019	0.019	0.018
LM_vol.demeaned	0.000	0.000	0.000	0.000	0.000	0.002	0.007	0.008	0.008	0.008
LP_FCE.demeaned	0.000	0.000	0.000	0.000	0.000	0.010	0.024	0.034	0.043	0.052
LRGFCF.demeaned	-0.103	-0.132	-0.135	-0.118	-0.094	0.004	0.008	0.006	0.010	0.017
LCPI.demeaned	0.152	0.166	0.170	0.173	0.198	0.013	0.016	0.022	0.025	0.029
LP_Share.demeaned	0.022	0.030	0.033	0.033	0.046	-0.027	-0.028	-0.026	-0.026	-0.027
LEx_rate.demeaned	-0.006	0.004	-0.020	-0.117	-0.120	-0.001	-0.002	-0.003	-0.007	-0.009

Variable	Signal approach					Logit approach				
	Lag_0	Lag_1	Lag_2	Lag_3	Lag_4	Lag_0	Lag_1	Lag_2	Lag_3	Lag_4
LRHPI.demeaned	-0.233	-0.222	-0.211	-0.200	-0.189	0.022	0.038	0.045	0.054	0.062
LHPI.demeaned	-0.222	-0.178	-0.167	-0.156	-0.178	0.009	0.030	0.039	0.049	0.058
LRent.demeaned	0.000	0.000	0.000	0.000	0.000	0.012	0.020	0.022	0.023	0.025
LP2R.demeaned	-0.133	-0.144	-0.178	-0.178	-0.178	0.048	0.045	0.046	0.046	0.049
LP2Y.demeaned	0.043	0.046	0.049	0.066	0.083	0.011	0.013	0.014	0.017	0.022
LBONDSIR.demeaned	0.089	0.100	0.100	0.100	0.100	-0.188	-0.200	-0.214	-0.219	-0.215
LBONDS10Y.demeaned	0.000	0.000	0.000	0.000	0.000	-0.099	-0.095	-0.064	-0.054	-0.051
LGOVCONS.demeaned	0.000	0.000	0.000	0.000	0.000	0.041	0.027	0.021	0.004	-0.008
LPPI.demeaned	0.000	0.000	0.000	0.000	0.000	0.002	0.001	0.001	0.001	-0.002
LPROD.demeaned	-0.014	-0.049	0.010	0.064	0.064	-0.021	-0.013	-0.003	0.004	0.003
LESI.demeaned	0.039	0.025	0.005	-0.016	-0.049	0.004	0.013	0.026	0.037	0.047
LFORRES.demeaned	0.064	0.032	0.021	0.011	0.000	0.025	0.027	0.033	0.037	0.039

**Table 5: Out-of-sample forecast accuracy of model combinations****Signal approach**

Chronology	Variables included	
	all	only best
Phillips et al. (2015) 80%	0.109	0.186
Phillips et al. (2015) 90%	0.113	0.152
Phillips et al. (2015) 95%	0.110	0.185
Dreger and Reimers (2013)	0.172	0.336
Naive 60%	0.057	0.107
Naive 90%	0.082	0.290

**Logit model**

Chronology	Variables included	
	all	only best
Phillips et al. (2015) 80%	0.051	0.196
Phillips et al. (2015) 90%	0.068	0.247
Phillips et al. (2015) 95%	0.069	0.240
Dreger and Reimers (2013)	0.099	0.199
Naive 60%	0.047	0.158
Naive 90%	0.025	0.221

**Figure 1: Alternative debt crises chronologies**

