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# Early Warning for Financial Stress Events: A Credit-Regime Switching Approach

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# Objectives

- **Build an early warning model to predict the possibility of a financial stress event at a given upcoming time.**

- Predict the possibility of a financial stress event **at a given upcoming time** rather than **at a given upcoming period of time;**

- Examine credit's role, as a nonlinear propagator of shocks, in predicting a financial stress event;

- Investigate performance of such an early warning model.

# Motivations

- **Major findings from the analyses of the global financial crises(Allen and Carletti 2010).**

➢ Market observers did not know how to watch for signs of trouble in the financial system

⇒ an appropriate monitoring instrument may intelligently observe systemic risk and assess financial system conditions

➢ Market observers did not know how the financial system will evolve

=>conduct macro-prudential and prediction analyses, such as stress tests, early warning for a financial crisis or a financial event, etc.

# Motivation

- An early warning model is designed to predict the possibility of occurrence of financial crisis within a given period of time;

  e.g, IMF and FSB collaborate on regular early warning exercises to strengthen surveillance of economic and financial risks.

- The events qualified as financial crises for developed countries are scarce or non-existence:

  e.g. , Canada has not experienced ``twin crises’’, and has experienced four currency crises since 1945.

- These features of the sample preclude a meaning individual country-level analysis.

# Motivation

- **Despite absence of financial crisis, financial systems may still be subjected to financial stress.**

$\Rightarrow$ **Financial stress increases uncertainty in economy and could lead to financial crisis.**

- Construct an early warning model to help policy makers to take pre-emptive actions to head off a potential financial stress event or limit its effects:

➢ Christensen and Li (2014) use signal extraction approach to predict the possibility of financial stress events **within a given upcoming period of time.**

➢ Propose an approach to predict the possibility of a financial stress event **at a given future time.**

# Literature Review

- **The methodologies commonly used for financial crises**

Three varieties of financial crises are distinguished:

**currency crises, banking crises, and debt crises.**

- **The signal extraction approach**

This approach is proposed by Kaminsky, Lizondo and Reinhart (1998).

- **Logit approach**

Frankel and Rose (1996) are the first to apply Logistic model to predict financial crises.

- **Early warning for financial stress events**

Christensen and Li (2014) use a signal extraction approach to predict financial stress events for a given upcoming period of time,

**but not to predict a financial stress event at a given future time.**

# Contributions

- **Early warning for a financial stress event at a given future time**

➢ Propose a credit-regime switching EWM to predict the possibility of a financial stress event at a given future time.

➢ The signal extraction approach is modified to predict the possibility of a financial stress event at a given future time.

➢ Use a linear model as a benchmark model to assess the performance.

- **Evaluate predictive ability**

➢ **The three models are useful tools for predicting financial stress events.**

➢ **The credit-regime switching model performs better across all criteria and forecasting horizons considered.**

# A Measure of Financial Stress

- **What is financial stress?**

➢ **The definition of Financial stress**

Financial stress is characterized as an interruption to the normal functioning of the financial system(ECB, 2009).

- **Why do we care financial stress?**

**An increase in financial stress  causes a decline in economic activity by three  possible channels:**

➢ Increase in uncertainty about fundamental value of assets and behavior of other investors.

➢ Increase  in the cost to business and households of financial spending.

➢ Cause banks to tighten their credit standards.

# A Measure of Financial Stress

- **Measure financial stress by Financial Stress Index (FSI)**

➢ For Canada, Illing and Liu (2006) construct **a credit-weighted index**. The indicators come from equity, bond, foreign exchange, and banking markets;

➢ For the United States, Oet et al (2012) employs **a dynamic weighting method** that captures the changing relative importance of the different sectors of the financial system;

➢ For advanced countries, IMF (2009) constructs the FSI as **a variance-weighted average** of three sub-indices associated with the banking, securities, and foreign exchange markets.

# FSI used for Canada

**The FSI is a continuous measure including the following indicators:**

**1.** the spread between the yields on bonds issued by Canadian financial institutions and the yields on government bonds of comparable duration;

**2.** the spread between yields on Canadian nonfinancial corporate bonds and government bonds;

**3.** the inverted term spread;

**4.** the beta derived from the total return index for Canadian financial institutions;

**5.** Canadian trade-weighted dollar GARCH volatility;

**6.** TSX GARCH volatility;

**7.** the difference between Canadian and U.S. government short-term borrowing rates;

**8.** the average bid-ask spread on Canadian treasury bills;

**9.** the spread between Canadian commercial paper rates and Treasury bill rates of comparable duration.

# Model Specification

- **Defining financial stress events**

$$hfs_{j,t} = 1, \text{ if FSI}_t \geq 49.96$$
$$hfs_{j,t} = 0, \text{ otherwise}$$

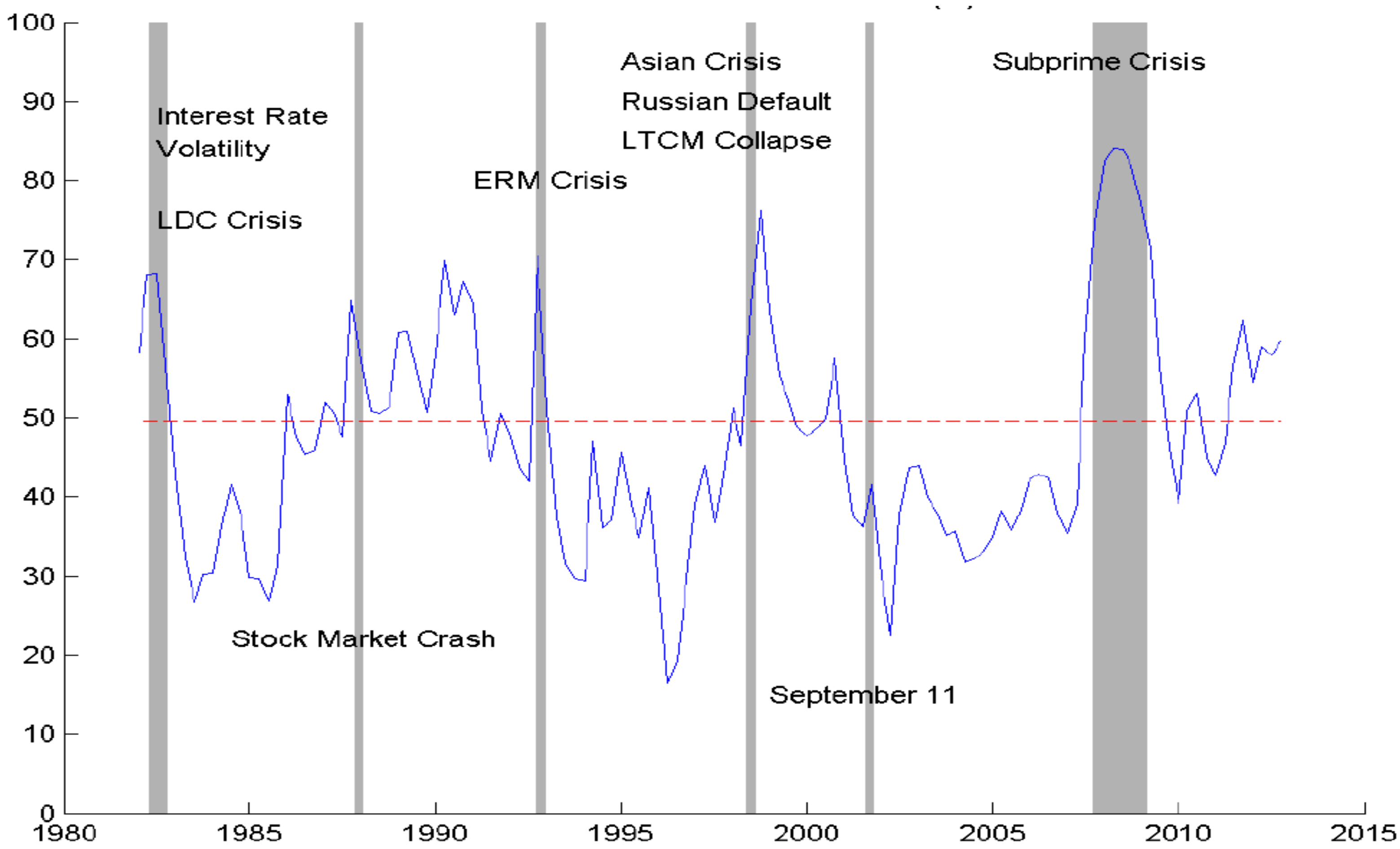
where the threshold value is chosen by the model in Li and St-Amant (2010).

- Illing and Liu (2006) use a cutoff of two standard deviation above the mean to identify financial stress events;

- Cardarelli et al. (2009) use a cutoff of one standard deviation above the mean to identify financial stress events;

- Christensen and Li (2013) use a cutoff of 1.5 standard deviation above the mean to identify financial stress events.

# FSI for Canada



# Model Specification

- **A credit-regime switching EWM**

➢ The development in the credit market may provide an early-warning indicator of financial vulnerability in the financial system (e.g.,Borio and Lowe 2002);

➢ credit markets may act as non-linear propagators of the impact of shocks to financial stress in financial system;

➢ a regime switching model is used to examine the impact of a credit condition, as a nonlinear propagator of shocks, on economy and financial system (Bernanke and Gertler (1989), Azariadis and Smith (1998), Misina and Tkacz (2008), etc).

# Model specification

- the role of credit in modeling and predicting financial stress events is captured by a threshold regression model

$$FSI_t = \alpha^1 + \beta^1 FSI_{t-k} + \gamma^1 X_{t-k} + \delta^1 z_{t-k} + [\alpha^2 + \beta^2 FSI_{t-k} + \gamma^2 X_{t-k} + \delta^2 z_{t-k}] I_{[z_{t-k} > \tau]} + \varepsilon_t$$

- capturing nonlinearity such as regime switching, asymmetry, and multiple equilibria;

- Given the information set $I_t$ at time $t$, the possibility of a financial stress event at time $t+k$ is:

$$\Pr[FSI_{t+k} \geq 49.96 \mid I_t].$$

# Model specification

- **Use the bootstrapping method to estimate the probability**

**Step1:** using the original sample to compute the unknown parameters, we obtain residual,

$$\hat{\varepsilon}_t = FSI_t - \hat{\alpha}_1 - \hat{\beta}_1 FSI_{t-k} - \hat{\gamma}_1 X_{t-k} - \hat{\delta}_1 z_{t-k} - [\hat{\alpha}_2 + \hat{\beta}_2 FSI_{t-k} + \hat{\gamma}_2 + \hat{\delta}_2 z_{t-k}] I_{[z_{t-k} > \hat{\tau}]}.$$

**Step2:** the data $\{\hat{\varepsilon}_{t'}\}_{t'=1}^{n}$ is split into $n-b-1$ overlapping blocks. $n/b$ blocks are drawn at random with replacement. Then aligning these blocks gives the bootstrapping data.

**Step3 :** use the bootstrapping sample to compute

$$FSI_i^j = \hat{\alpha}_1 + \hat{\beta}_1 FSI_{t-k} + \hat{\gamma}_1 X_{t-k} + \hat{\delta}_1 z_{t-k} + [\hat{\alpha}_2 + \hat{\beta}_2 FSI_{t-k} + \hat{\gamma}_2 + \hat{\delta}_2 z_{t-k}] I_{[z_{t-k} > \hat{\tau}]} + \varepsilon_i^*,$$

the estimation of the probability of a financial stress event

$$B^j = \frac{1}{n} \sum_{i=1}^{n} I[FSI_i^j \geq 49.96].$$

# Model specification

**Step 4:** repeat Step2-Step3 B times, the probability of a financial stress event at time t is estimated as

$$\frac{1}{B}\sum_{j=1}^{B} B^{j}.$$

- A benchmark linear EWM

$$FSI_t = \alpha^1 + \beta^1 FSI_{t-k} + \gamma^1 X_{t-k} + \varepsilon_t.$$

Use similar bootstrapping method to obtain the estimation of the probability of a financial stress event.

# Model Specification

- **Variables**

  The variables are chosen based on theoretical considerations and their availability on a quarterly basis.

  Most of these variables reported in Demirguc-Kunt and Detragiache (1998), Davis and Karim (2008), and Misina and Tkacz (2009).

➢ **Credit measures:**
Credit/GDP , Household credit, Business credit;

➢ **Asset prices:**
Stock prices (TSX), Residential real estate indices (new and existing house price indexes), Housing price/personal disposable income.

# Model Specification

- **Macroeconomic variables:**

  Real GDP growth rate, Inflation, Exchange rate, Investment/GDP Investment growth, the growth rate of money (M2++), Household disposable income.

- **Foreign variables:**

  Crude oil price, the U.S. credit growth, U.S. federal fund rate, World GDP growth, World gold price, Asset return indices for the U.S..

# Model Specification

- **Cut-off probability**

➢ If the predicted probability is above the Cut-off probability, then we send a signal of pending financial stress event . Otherwise, we keep silent.

➢ The cut-off probability minimizes the noise-to-signal ratio which is determined by using a grid search approach over the range of potential threshold values.

➢ Different models may have different cut-off probabilities.

# Model Specification

- **The criterion to choose the cut-off probability**

| | Financial stress event | No financial stress event |
|---|---|---|
| Signal issued | **A** | **B** |
| No signal issued | **C** | **D** |

The cut-off probability is the value which minimizes the noise-to-signal ratio:

$$[B/(B+D)]/[A/(A+C)]$$

# Model Specification

- **Signal extraction approach**

➢ **Individual indicators**

The indicator $j$ is denoted by $X_t^j$. The threshold for this indicator $j$ is denoted by $X_j^*$. A signal relating to indicator $j$ is denoted by $S_t^j$. If the indicator crosses the threshold, $S_t^j = 1$. Otherwise, $S_t^j = 0$.

➢ **Composite indicator**

$$I_t = \sum_{j=1}^{m} \frac{S_t^j}{w^j},$$

where $w^j$ is the noise-to-signal ratio of indicator $j$.

# Model Specification

## ➢ Probability of a financial stress event

Forecasting horizon is $k$, and the occurrence of a financial stress event at $t+k$ is expressed as $C_{t,t+k}$.

Given $I_t \in \Gamma$ at time t, the probability of the occurrence of $C_{t,t+k}$ is denoted as $\Pr[C_{t,t+k} \mid I_t \in \Gamma]$ and is estimated by :

$$\hat{\Pr}[C_{t,t+k} \mid I_t \in \Gamma] = \frac{\text{Quarters with } I_t \in \Gamma \text{ and a financial stress event at } t+k}{\text{Quarters with } I_t \in \Gamma}.$$

# Model Specification

- **Logistic model**

Let $Y_t = 1$ if $FSI_{t+k} > 49.96$, $Y_t = 0$ otherwise.

$\beta$ is estimated by the log likelihood

$$\Pr(Y_t = 1) = \frac{e^{X_t \beta}}{1 + e^{X_t \beta}}$$

$$Log_e L = \sum_{t=1}^{T} Y_t \log_e F(X_t \beta) + (1 - Y_t) \log_e (1 - F(X_t \beta))$$

# Implementation of the EW models

- **The data**

➢ Data period: 1982 Q1-2012 Q4.

➢ Data from 1982 Q1 to 2006 Q4 is used to estimate the models.

➢ Data from 2007 Q1-2012Q4 is used to evaluate out of sample performance.

➢ The explanatory variables are converted into growth rates to make all variables be stationary.

➢ Annual growth rates are considered, since it is possible that longer-run cumulative growth rates may contain more information about financial stress.

# Implementations of the EW Models

- **Predicting windows**

Choosing the length of the predicting horizon need a balance between two opposite requirements:

- the more reliably a financial stress can be anticipated, the closer the financial stress event is;
- it is desirable to have an indication of a financial stress event as early as possible in order to be able to take pre-emptive policy action;
- the predicting windows are set at: one quarter, two quarters, four quarters, eight quarters.

# Implementations of the EW Models

- **Criteria used for evaluating predictive ability:**

➢ The probability of financial stress events correctly called:

$$A/(A+C).$$

➢ The probability of false alarms in total alarms:

$$B/(A+B).$$

➢ The probability of financial stress event given an alarm:

$$A/(A+B).$$

➢ The probability of financial stress given no alarm:

$$C/(C+D).$$

➢ Noise-to-signal ratio is defined as the ratio of false signals to good signals:

$$[B/(B+D)]/[A/(A+C)].$$

# Estimation results for threshold regression models

| | k=1 | | k=2 | | k=4 | | k=8 | |
|---|---|---|---|---|---|---|---|---|
| Regime | $\leq \hat{\tau}_1$ | $> \hat{\tau}_1$ | $\leq \hat{\tau}_2$ | $> \hat{\tau}_2$ | $\leq \hat{\tau}_3$ | $> \hat{\tau}_3$ | $\leq \hat{\tau}_4$ | $> \hat{\tau}_4$ |
| Constant | 57.64 | 101.15 | 62.55 | 48.40 | 62.20 | 76.61 | 47.58 | 230.84 |
| | (6.12) | (44.09) | (5.22) | (63.49) | (2.85) | (68.46) | (3.19) | (88.99) |
| $FSI_{t-k}$ | 0.42 | 0.26 | -0.06 | -0.07 | 0.40 | -0.06 | -0.10 | 0.02 |
| | (0.16) | (0.13) | (0.17) | (0.19) | (0.14) | (0.14) | (0.40) | (0.21) |
| GDP growth $rate_{t-k}$ | -1.81 | -1.42 | -0.90 | -1.03 | 1.33 | -2.65 | -4.66 | -2.65 |
| | (1.80) | (1.14) | (1.91) | (1.72) | (1.49) | (1.35) | (3.56) | (1.67) |
| House price $growth_{t-k}$ | -2.29 | -0.58 | -1.65 | -0.39 | -1.51 | -1.84 | -4.30 | 0.09 |
| | (0.95) | (1.00) | (1.02) | (1.42) | (0.83) | (1.18) | (2.04) | (1.50) |
| Household income $growth_{t-k}$ | 0.33 | 0.82 | 0.58 | -0.91 | 1.29 | 1.35 | 0.53 | 2.08 |
| | (0.87) | (0.65) | (1.01) | (0.87) | (0.80) | (0.66) | (1.84) | (1.05) |
| $CPI_{t-k}$ | -4.21 | -0.62 | -3.74 | -0.24 | -5.94 | -0.09 | -5.30 | -0.06 |
| | (2.53) | (2.15) | (2.90) | (2.88) | (2.25) | (2.27) | (5.03) | (3.27) |
| Return on stock market $index_{t-k}$ | 0.07 | 0.00 | 0.26 | -0.16 | 0.09 | 0.03 | 0.25 | 0.02 |
| | (0.15) | (0.09) | (0.15) | (0.13) | (0.12) | (0.09) | (0.40) | (0.17) |
| Exchange $rate_{t-k}$ | 1.61 | -0.05 | 1.07 | -0.88 | -1.49 | -0.15 | 3.01 | -0.45 |
| | (0.54) | (0.36) | (0.60) | (0.51) | (0.49) | (0.40) | (1.10) | (0.73) |
| Fed fund $rate_{t-k}$ | -3.88 | 1.55 | -6.32 | 2.93 | -1.52 | -0.85 | -3.51 | -2.44 |
| | (2.35) | (0.90) | (2.41) | (1.24) | (2.03) | (0.99) | (5.04) | (1.47) |
| M2++ $growth_{t-k}$ | 0.38 | -0.25 | -0.99 | 5.11 | 1.69 | 0.21 | 0.96 | -0.13 |
| | (1.32) | (1.46) | (1.46) | (2.12) | (1.22) | (1.47) | (2.60) | (2.34) |
| Credit/$GDP_{t-k}$ | -128.42 | 18.04 | -224.55 | 91.13 | -99.67 | -4.79 | 38.89 | -78.65 |
| | (45.71) | (37.29) | (47.24) | (48.47) | (40.32) | (42.33) | (122.07) | (64.98) |
| Investment $growth_{t-k}$ | 0.67 | 0.27 | -0.49 | 0.37 | -0.12 | 0.34 | 1.28 | 0.79 |
| | (0.43) | (0.28) | (0.42) | (0.45) | (0.33) | (0.38) | (1.04) | (0.42) |
| Investment/$GDP_{t-k}$ | 359.33 | -525.38 | 704.50 | -485.40 | 48.93 | -220.86 | 6.60 | -884.48 |
| | (204.30) | (195.30) | (201.34) | (282.99) | (181.14) | (274.50) | (554.96) | (377.81) |
| Oil price $growth_{t-k}$ | 0.01 | 0.04 | 0.08 | 0.07 | -0.17 | -0.01 | 0.18 | -0.00 |
| | (0.08) | (0.03) | (0.07) | (0.05) | (0.06) | (0.04) | (0.15) | (0.06) |
| Household credit $growth_{t-k}$ | -2.13 | 1.98 | 0.94 | -0.56 | 3.28 | 0.55 | -3.91 | 2.08 |
| | (1.64) | (0.89) | (1.58) | (1.48) | (1.34) | (1.13) | (2.85) | (2.10) |
| US credit $growth_{t-k}$ | -2.00 | -0.26 | -2.06 | 0.61 | -3.05 | -0.43 | 0.33 | 0.65 |
| | (1.33) | (0.64) | (1.32) | (0.91) | (1.05) | (0.69) | (2.33) | (1.14) |
| Business credit $growth_{t-k}$ | 2.55 | 1.82 | 3.00 | 1.28 | 2.64 | 3.30 | 3.74 | 3.05 |
| | (0.48) | (0.83) | (0.51) | (1.12) | (0.42) | (0.90) | (1.51) | (1.27) |
| Gold price $growth_{t-k}$ | -0.70 | 0.16 | -0.68 | 0.17 | 0.55 | -0.39 | -0.25 | -0.65 |
| | (0.30) | (0.11) | (0.32) | (0.18) | (0.26) | (0.23) | (0.75) | (0.29) |
| House price/personal $income_{t-k}$ | -0.23 | 0.36 | -0.21 | 0.47 | -0.04 | 1.78 | 0.72 | -0.08 |
| | (0.47) | (0.66) | (0.51) | (0.89) | (0.42) | (0.23) | (0.75) | (0.29) |

# Performance of Indicators in the Signal Extraction Approach (k=1)

| Indicator | Threshold percentile | $\frac{A}{(A+C)}$ | $\frac{B}{(B+D)}$ | Noise/signal ratio | $P$[fse\|signals] | $P$[fse\|signals] $-P$[fse] |
|---|---|---|---|---|---|---|
| Real GDP growth | 0.11 | 0.26 | 0.06 | 0.23 | 0.67 | 0.35 |
| Inflation | 0.77 | 0.48 | 0.12 | 0.24 | 0.65 | 0.34 |
| Exchange rate | 0.80 | 0.26 | 0.18 | 0.68 | 0.40 | 0.09 |
| Investment/GDP | 0.86 | 0.32 | 0.04 | 0.14 | 0.77 | 0.46 |
| M2++ growth | 0.88 | 0.35 | 0.01 | 0.04 | 0.92 | 0.60 |
| Household credit growth | 0.87 | 0.39 | 0.01 | 0.04 | 0.92 | 0.61 |
| Business credit growth | 0.83 | 0.52 | 0.01 | 0.03 | 0.94 | 0.63 |
| US credit growth | 0.84 | 0.16 | 0.15 | 0.91 | 0.33 | 0.02 |
| House price/disposable income growth | 0.89 | 0.29 | 0.03 | 0.10 | 0.82 | 0.51 |
| New house price growth | 0.10 | 0.13 | 0.09 | 0.68 | 0.40 | 0.09 |
| Crude oil price growth | 0.70 | 0.32 | 0.29 | 0.91 | 0.33 | 0.02 |
| 3-quarter moving average of FSI | 0.85 | 0.48 | 0.00 | 0.03 | 1.00 | 0.69 |
| Fed fund rate | 0.64 | 0.68 | 0.22 | 0.33 | 0.58 | 0.27 |

# Performance of Indicators in the Signal Extraction Approach (k=2)

| Indicator | Threshold percentile | $\frac{A}{(A+C)}$ | $\frac{B}{(B+D)}$ | Noise/signal ratio | $P[\text{fes}\|\text{signals}]$ | $P[\text{fes}\|\text{signals}] - P[\text{fes}]$ |
|---|---|---|---|---|---|---|
| Real GDP growth | 0.14 | 0.27 | 0.10 | 0.39 | 0.53 | 0.23 |
| Inflation | 0.77 | 0.47 | 0.13 | 0.28 | 0.61 | 0.30 |
| Exchange rate | 0.74 | 0.30 | 0.25 | 0.83 | 0.35 | 0.04 |
| Investment/GDP | 0.86 | 0.33 | 0.03 | 0.09 | 0.83 | 0.53 |
| M2++ growth | 0.88 | 0.37 | 0.01 | 0.04 | 0.92 | 0.61 |
| Household credit growth | 0.86 | 0.47 | 0.00 | 0.03 | 1.00 | 0.69 |
| Business credit growth | 0.83 | 0.52 | 0.01 | 0.03 | 0.94 | 0.63 |
| US credit growth | 0.84 | 0.16 | 0.15 | 0.91 | 0.33 | 0.02 |
| House price/disposable income growth | 0.89 | 0.29 | 0.03 | 0.10 | 0.82 | 0.51 |
| New house price growth | 0.10 | 0.13 | 0.09 | 0.68 | 0.40 | 0.09 |
| Crude oil price growth | 0.70 | 0.32 | 0.29 | 0.91 | 0.33 | 0.02 |
| 3-quarter moving average of FSI | 0.85 | 0.48 | 0.00 | 0.03 | 1.00 | 0.69 |
| Fed fund rate | 0.66 | 0.63 | 0.22 | 0.35 | 0.56 | 0.25 |

# Performance of Indicators in the Signal Extraction Approach (k=4)

| Indicator | Threshold percentile | $\frac{A}{(A+C)}$ | $\frac{B}{(B+D)}$ | Noise/signal ratio | $P[\text{fes}\mid\text{signals}]$ | $P[\text{fes}\mid\text{signals}] - P[\text{fes}]$ |
|---|---|---|---|---|---|---|
| Real GDP growth | 0.15 | 0.18 | 0.16 | 0.91 | 0.31 | 0.02 |
| Inflation | 0.65 | 0.68 | 0.24 | 0.35 | 0.54 | 0.25 |
| Investment | 0.87 | 0.32 | 0.00 | 0.05 | 1.00 | 0.71 |
| M2++ growth | 0.86 | 0.39 | 0.04 | 0.11 | 0.79 | 0.49 |
| Household credit growth | 0.46 | 0.00 | 0.03 | 1.00 | 0.71 | 0.41 |
| Business credit growth | 0.80 | 0.61 | 0.04 | 0.07 | 0.85 | 0.56 |
| US credit growth | 0.81 | 0.21 | 0.16 | 0.75 | 0.35 | 0.06 |
| House price/disposable income growth | 0.88 | 0.39 | 0.01 | 0.04 | 0.92 | 0.63 |
| Crude oil price growth | 0.65 | 0.39 | 0.31 | 0.79 | 0.34 | 0.05 |
| 3-quarter moving average of FSI | 0.58 | 0.86 | 0.26 | 0.31 | 0.57 | 0.28 |
| Fed fund rate | 0.66 | 0.64 | 0.24 | 0.37 | 0.53 | 0.24 |

# Performance of Indicators in the Signal Extraction Approach (k=8)

| Indicator | Threshold percentile | $\frac{A}{(A+C)}$ | $\frac{B}{(B+D)}$ | Noise/signal ratio | $P[\text{fse}\mid\text{signals}]$ | $P[\text{fse}\mid\text{signals}] - P[\text{fse}]$ |
|---|---|---|---|---|---|---|
| Real GDP growth | 0.12 | 0.14 | 0.14 | 0.98 | 0.31 | 0.00 |
| Inflation | 0.76 | 0.50 | 0.16 | 0.31 | 0.58 | 0.28 |
| Investment/GDP | 0.87 | 0.29 | 0.02 | 0.05 | 0.89 | 0.58 |
| M2++ growth | 0.89 | 0.32 | 0.03 | 0.10 | 0.82 | 0.51 |
| Household credit growth | 0.90 | 0.32 | 0.02 | 0.05 | 0.90 | 0.60 |
| House price/ disposable income growth | 0.88 | 0.39 | 0.02 | 0.04 | 0.92 | 0.61 |
| House price growth | 0.12 | 0.14 | 0.14 | 0.98 | 0.31 | 0.00 |
| Return on stock market index | 0.50 | 0.61 | 0.41 | 0.67 | 0.40 | 0.09 |
| Crude oil price growth | 0.65 | 0.36 | 0.28 | 0.79 | 0.36 | 0.05 |
| 3-quarter moving average of FSI | 0.87 | 0.21 | 0.11 | 0.51 | 0.46 | 0.16 |
| US credit growth | 0.80 | 0.39 | 0.11 | 0.28 | 0.61 | 0.31 |
| Fed fund rate | 0.65 | 0.68 | 0.25 | 0.37 | 0.54 | 0.24 |

# Conditional Probabilities of a Financial Stress Event Associated with Compositor Indicator

| $k = 1$ | Probability | $k = 2$ | Probability | $k = 4$ | Probability | $k = 8$ | Probability |
|---|---|---|---|---|---|---|---|
| (0, 13.8] | 0.09 | (0, 4.5] | 0.06 | (0, 7.4] | 0.10 | (0, 5.4] | 0.12 |
| (13.8, 27.7] | 0.50 | (4.5, 9] | 0.18 | (7.4, 14.9] | 0.25 | (5.4, 10.8] | 0.31 |
| (27.7, 41.6] | 0.87 | (9,13.6] | 0.46 | (14.9, 22.4] | 0.33 | (10.8, 21.6] | 0.33 |
| (41.6, 55.5] | 1.00 | (13.6, 36.3] | 0.50 | (22.4, 29.9] | 0.67 | (21.6, 37.9] | 1.00 |
| (55.5, 69.4] | 1.00 | (36.3, 40.9] | 0.83 | (29.9, 37.4] | 1.00 | | |
| | | (40.9, 50.0] | 1.00 | | | | |

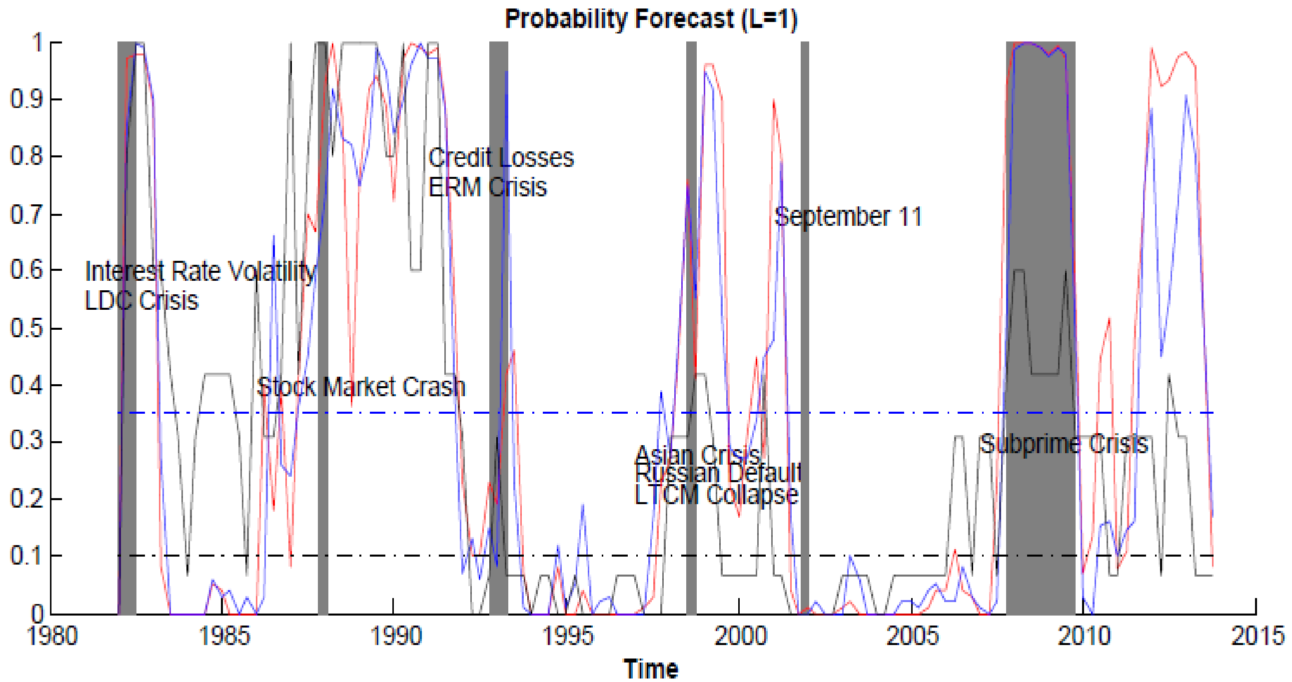
# In-Sample Predictive Ability from Alternative Models

| Model | Cut-off probability | Signal-noise ratio | Stress events correctly called | False alarms | Correctly call given alarm | Correctly call non-financial stress events |
|---|---|---|---|---|---|---|
| $k = 1$ | | | | | | |
| Linear | 0.35 | 3.79 | 0.71 | 0.45 | 0.55 | 0.90 |
| Threshold1 | 0.35 | 4.09 | 0.71 | 0.43 | 0.57 | 0.90 |
| Threshold2 | 0.35 | 3.96 | 0.79 | 0.44 | 0.56 | 0.92 |
| Threshold3 | 0.30 | 3.37 | 0.58 | 0.48 | 0.52 | 0.86 |
| Signal extraction | 0.10 | 4.99 | 0.62 | 0.38 | 0.62 | 0.88 |
| $k = 2$ | | | | | | |
| Linear | 0.35 | 3.13 | 0.71 | 0.50 | 0.50 | 0.89 |
| Threshold1 | 0.35 | 3.33 | 0.67 | 0.48 | 0.52 | 0.88 |
| Threshold2 | 0.35 | 4.17 | 0.67 | 0.43 | 0.57 | 0.89 |
| Threshold3 | 0.25 | 2.78 | 0.67 | 0.53 | 0.47 | 0.88 |
| Signal extraction | 0.20 | 3.89 | 0.54 | 0.46 | 0.54 | 0.86 |
| $k = 4$ | | | | | | |
| Linear | 0.30 | 1.69 | 0.54 | 0.65 | 0.35 | 0.82 |
| Threshold1 | 0.30 | 1.81 | 0.46 | 0.63 | 0.37 | 0.81 |
| Threshold2 | 0.25 | 1.56 | 0.46 | 0.67 | 0.33 | 0.80 |
| Threshold3 | 0.35 | 1.56 | 0.42 | 0.67 | 0.33 | 0.80 |
| Signal extraction | 0.35 | 3.13 | 0.47 | 0.53 | 0.47 | 0.75 |
| $k = 8$ | | | | | | |
| Linear | 0.10 | 0.99 | 0.75 | 0.76 | 0.24 | 0.75 |
| Threshold1 | 0.35 | 2.01 | 0.38 | 0.61 | 0.39 | 0.80 |
| Threshold2 | 0.20 | 0.93 | 0.46 | 0.77 | 0.23 | 0.75 |
| Threshold3 | 0.25 | 1.17 | 0.50 | 0.73 | 0.27 | 0.88 |
| Signal extraction | 0.35 | 3.10 | 0.48 | 0.52 | 0.48 | 0.85 |

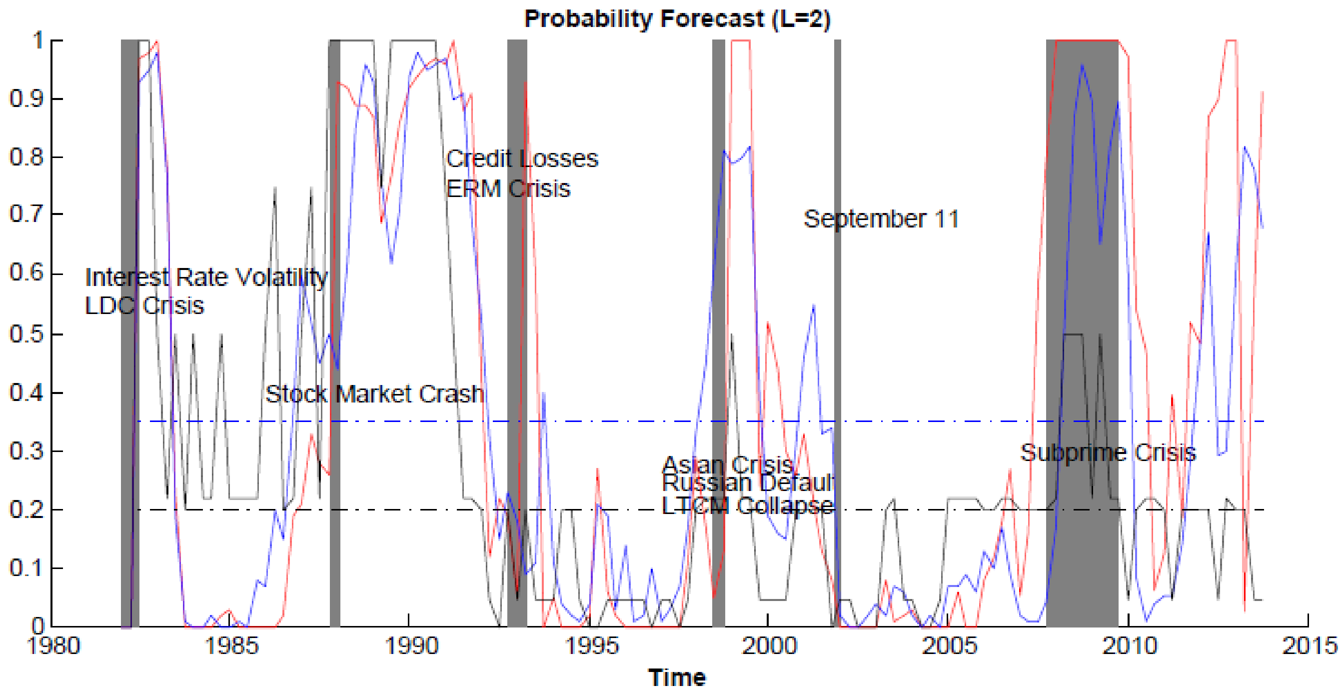
# Out-of-Sample Predictive Ability from Alternative Models

| Model | Cut-off probability | Signal-noise ratio | Stress events correctly called | False alarms | Correctly call given alarm | Correctly call non-financial stress events |
|---|---|---|---|---|---|---|
| $k=1$ | | | | | | |
| Linear | 0.35 | 2.52 | 0.84 | 0.05 | 0.95 | 0.33 |
| Threshold1 | 0.35 | Inf | 0.96 | 0.00 | 1.00 | 0.75 |
| Threshold2 | 0.35 | 2.88 | 0.96 | 0.04 | 0.96 | 0.77 |
| Threshold3 | 0.30 | Inf | 0.92 | 0.00 | 1.00 | 0.60 |
| Signal extraction | 0.10 | 8.59 | 0.78 | 0.01 | 0.99 | 0.33 |
| $k=2$ | | | | | | |
| Linear | 0.35 | 2.40 | 0.80 | 0.05 | 0.95 | 0.29 |
| Threshold1 | 0.35 | 2.76 | 0.92 | 0.04 | 0.96 | 0.50 |
| Threshold2 | 0.35 | 2.76 | 0.92 | 0.04 | 0.96 | 0.50 |
| Threshold3 | 0.25 | Inf | 0.92 | 0.04 | 1.00 | 0.60 |
| Signal extraction | 0.20 | 6.13 | 0.36 | 0.02 | 0.98 | 0.15 |
| $k=4$ | | | | | | |
| Linear | 0.30 | 1.56 | 0.52 | 0.07 | 0.93 | 0.14 |
| Threshold1 | 0.30 | 1.38 | 0.92 | 0.08 | 0.92 | 0.33 |
| Threshold2 | 0.25 | 1.38 | 0.92 | 0.08 | 0.92 | 0.33 |
| Threshold3 | 0.35 | 2.52 | 0.84 | 0.05 | 0.95 | 0.33 |
| Signal extraction | 0.35 | 0.93 | 0.23 | 0.11 | 0.89 | 0.10 |
| $k=8$ | | | | | | |
| Linear | 0.10 | 0.76 | 0.76 | 0.14 | 0.86 | 0.00 |
| Threshold1 | 0.35 | 2.88 | 0.96 | 0.04 | 0.96 | 0.67 |
| Threshold2 | 0.20 | 2.88 | 0.96 | 0.04 | 0.96 | 0.67 |
| Threshold3 | 0.25 | 1.32 | 0.88 | 0.08 | 0.92 | 0.25 |
| Signal extraction | 0.35 | 1.10 | 0.28 | 0.10 | 0.90 | 0.11 |

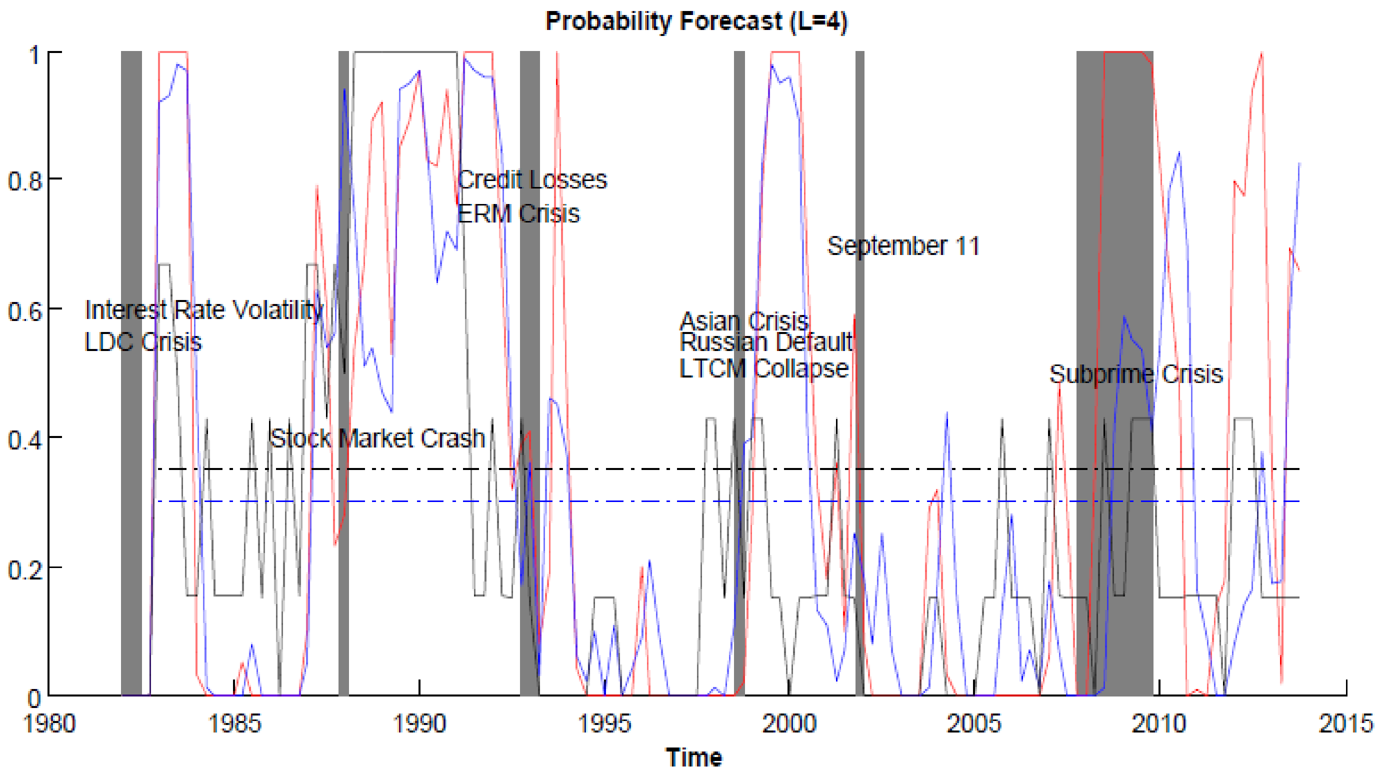
# Probability Forecasts of Financial Stress Events



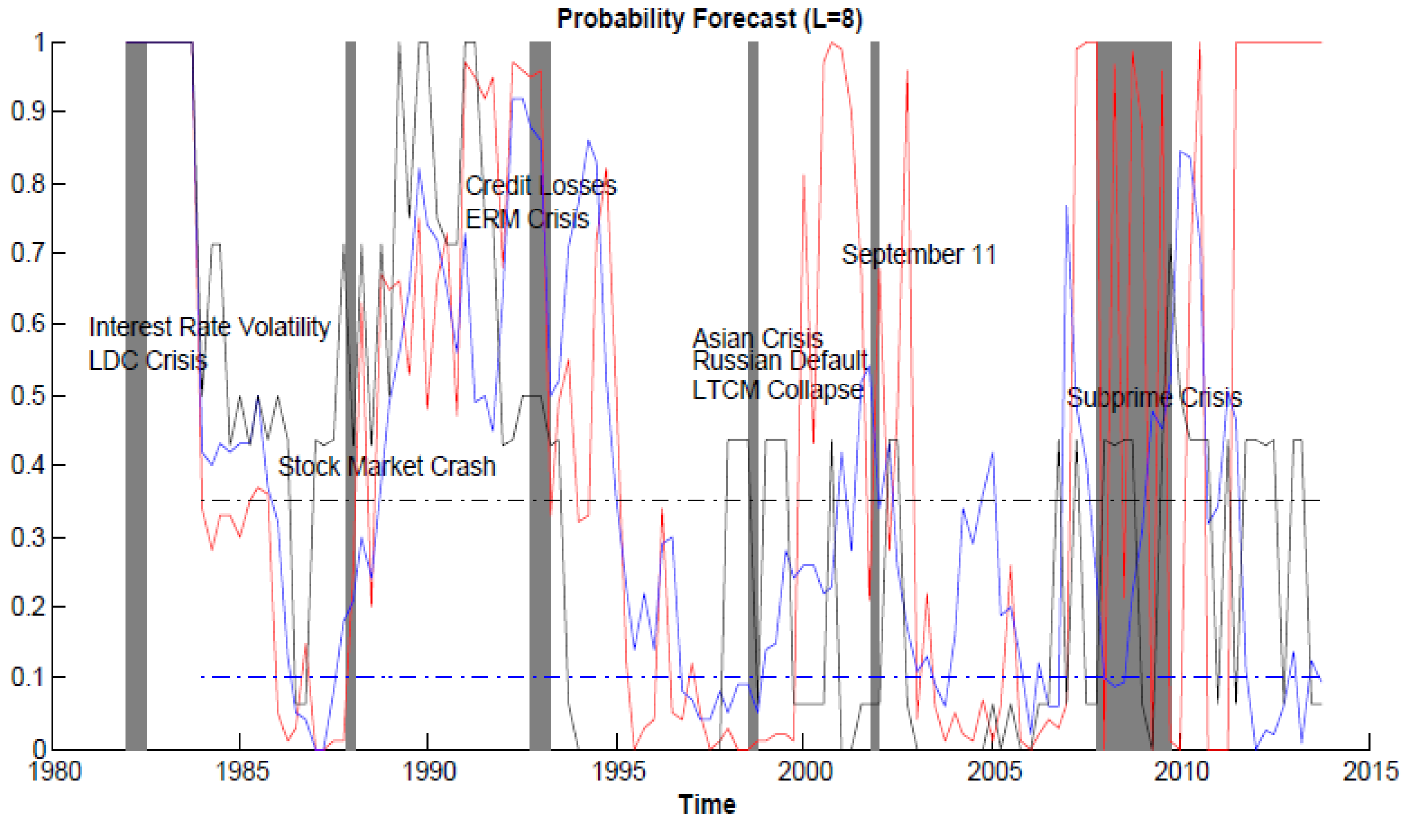
# Probability Forecasts of Financial Stress Events



# Probability Forecasts of Financial Stress Events



# Probability Forecasts of Financial Stress Events



# Conclusion and future research

- Propose a credit-regime switching approach to examine credit's role as a nonlinear propagator of shocks for predicting a financial stress event at a given future time.
- The signal extraction approach proposed by Kaminsky, Lizondo and Reinhart (1998) is modified to predict a financial stress event at a given future time.
- In-sample evaluation indicates that the three models are useful tools for predicting financial stress events at a given future time.
- Out-of-sample predictive ability of the regime-switching model has better performance than.
- In future study, we will focus on some specific markets, such as early warning for a housing pricing correction in Canada, etc.

# Model Specification

- $\{P_l\}_{l=1}^{L}$ are the series of probabilities corresponding to $\{\Gamma_l\}_{l=1}^{L}$. Let $\{R_l\}_{l=1}^{T}$ be the time series of realizations: $R_t = 1$ if a financial stress event occurs between $t$ and $t+h$, $R_t = 0$ otherwise.

We define: $Q_l(\Gamma_l) = \sum_{t=1}^{T} I(I_t^3 \in \Gamma_l)(P_l - R_t)^2$ and $Q(\{\Gamma_l\}_{l=1}^{L}) = \sum_{l=}^{L} Q_l$.

We choose $\{\Gamma_l\}_{l=1}^{L}$ which minimizes $Q(\{\Gamma_l\}_{l=1}^{L})$.

# Implementation of the EW Models

| Table 7: Logistic regression for k=1 | | | | | |
|---|---|---|---|---|---|
| Variable | Coef. | Std. Err | z | P>\|z\| | 95% conf. Interval |
| House price/Personal disposable income growth | 0.071 | 0.06 | 0.98 | 0.329 | [-0.072 0.214] |
| Investment/GDP ratio growth | 136.11 | 43.50 | 3.12 | 0.002 | [50.7 221.4] |
| Real GDP | -0.278 | 0.23 | -1.17 | 0.244 | [-0.74 0.18] |
| M2++ growth | 0.698 | 0.33 | 2.10 | 0.036 | [0.04 1.35] |
| CPI core inflation growth | -0.665 | 0.46 | -1.43 | 0.153 | [-1.57 0.25] |
| Japan asset return | 0.042 | 0.03 | 1.22 | 0.223 | [-0.03 0.11] |
| U.S. asset return | -0.176 | 0.09 | -1.99 | 0.046 | [-0.35 -0.003] |
| World gold price growth | -0.098 | 0.04 | -2.44 | 0.015 | [-0.18 -0.02] |
| Constant | -26.736 | 6.70 | -3.45 | 0.001 | [-41.9 -11.5] |
| Log likelihood=-32.23 | | | | | |

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# Implementation of the EW Models

| Table 8: Logistic regression for k=4 | | | | | |
|---|---|---|---|---|---|
| Variable | Coef. | Std. Err | z | P>\|z\| | 95% conf. Interval |
| House price/Personal disposable income growth | 0.23 | 0.12 | 1.86 | 0.06 | [-0.01 0.48] |
| Investment/GDP ratio growth | 109.59 | 50.97 | 2.15 | 0.03 | [9.67 209.51] |
| Real GDP | -0.26 | 0.30 | -0.98 | 0.33 | [-0.79 0.26] |
| M2++ growth | 0.35 | 0.34 | 1.06 | 0.29 | [-0.30 1.01] |
| CPI core inflation growth | 0.03 | 0.51 | 0.06 | 0.59 | [-0.97 1.03] |
| Japan asset return | 0.09 | 0.05 | 1.62 | 0.10 | [-0.02 0.20] |
| U.S. asset return | -0.10 | 0.11 | -0.88 | 0.38 | [-0.33 0.13] |
| World gold price growth | -0.19 | 0.08 | -2.37 | 0.02 | [-0.36 -0.03] |
| Constant | -23.10 | 9.04 | -2.55 | 0.01 | [-40.82 -5.38] |

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# Implementation of the EW Models

<table>
<tr><th colspan="6">Table 9: Logistic regression for k=8</th></tr>
<tr><td>Variable</td><td>Coef.</td><td>Std. Err</td><td>z</td><td>P>|z|</td><td>95% conf. Interval</td></tr>
<tr><td>House price/Personal disposable income growth</td><td>0.11</td><td>0.07</td><td>1.52</td><td>0.12</td><td>[-0.03 0.257]</td></tr>
<tr><td>Investment/GDP ratio growth</td><td>-23.57</td><td>36.17</td><td>-0.65</td><td>0.51</td><td>[-94.47 47.31]</td></tr>
<tr><td>Real GDP</td><td>0.04</td><td>0.18</td><td>0.26</td><td>0.79</td><td>[-0.30 0.39]</td></tr>
<tr><td>M2++ growth</td><td>0.64</td><td>0.27</td><td>2.31</td><td>0.02</td><td>[0.09 1.19]</td></tr>
<tr><td>CPI core inflation growth</td><td>0.21</td><td>0.36</td><td>0.59</td><td>0.55</td><td>[-0.49 0.93]</td></tr>
<tr><td>Japan asset return</td><td>0.06</td><td>0.03</td><td>1.67</td><td>0.09</td><td>[-0.01 0.12]</td></tr>
<tr><td>U.S. asset return</td><td>-0.07</td><td>0.07</td><td>-1.01</td><td>0.31</td><td>[-0.22 0.07]</td></tr>
<tr><td>World gold price growth</td><td>-0.08</td><td>0.04</td><td>-2.05</td><td>0.04</td><td>[-0.15 -0.00]</td></tr>
<tr><td>Constant</td><td>-2.98</td><td>5.57</td><td>-0.56</td><td>0.57</td><td>[-0.00 7.54]</td></tr>
</table>

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| | QPS | S/N | Correctly call | False alarm | Given alarm | No alarm |
|---|---|---|---|---|---|---|
| | 0.29 | 3.40 | 0.78 | 0.11 | 0.89 | 0.41 |
| | 0.17 | 6.59 | 0.94 | 0.06 | 0.94 | 0.14 |
| | 0.48 | Inf | 0.65 | 0.00 | 1.00 | 0.46 |
| | 0.27 | 2.15 | 0.57 | 0.16 | 0.83 | 0.58 |
| | | | | | | |
| | 0.28 | 3.24 | 0.78 | 0.11 | 0.89 | 0.41 |
| | 0.20 | 5.19 | 0.88 | 0.07 | 0.93 | 0.27 |
| | 0.63 | 1.51 | 0.65 | 0.21 | 0.79 | 0.60 |
| | 0.27 | 1.73 | 0.61 | 0.19 | 0.81 | 0.59 |

Table 13: Predictive Abilities of alternative models

| Model | QPS | S/N | Correctly call | False alarm | Given alarm | No alarm |
|---|---|---|---|---|---|---|
| L-four lag | 0.95 | 0.84 | 0.53 | 0.33 | 0.67 | 0.76 |
| T-four lag | 0.60 | 1.48 | 0.77 | 0.22 | 0.78 | 0.54 |
| SEA-four lag | 0.75 | 1.03 | 0.59 | 0.29 | 0.71 | 0.70 |
| Logistic-four lag | 0.71 | NA | NA | NA | NA | 0.81 |
| | | | | | | |
| L-eight lag | 1.13 | 0.52 | 0.40 | 0.44 | 0.56 | 0.86 |
| T-eight lag | 0.41 | 2.06 | 0.88 | 0.17 | 0.83 | 0.33 |
| SEA-eight lag | 0.79 | 2.06 | 0.59 | 0.17 | 0.83 | 0.58 |
| Logistic-eight lag | 0.65 | 1.61 | 0.05 | 0.20 | 0.79 | 0.70 |

Table 14: Predictive Abilities of alternative models

| Model | QPS | S/N | Correctly call | False alarm | Given alarm | No alarm |
|---|---|---|---|---|---|---|
| L-twelve lag | 0.92 | 0.91 | 0.39 | 0.31 | 0.69 | 0.72 |
| T-twelve lag | 0.18 | 6.20 | 0.89 | 0.06 | 0.94 | 0.24 |
| SEA-twelve lag | 0.91 | 1.10 | 0.47 | 0.27 | 0.73 | 0.69 |
| Logistic-twelve lag | 0.71 | 0.04 | 1.85E-07 | 0.91 | 0.09 | 0.70 |

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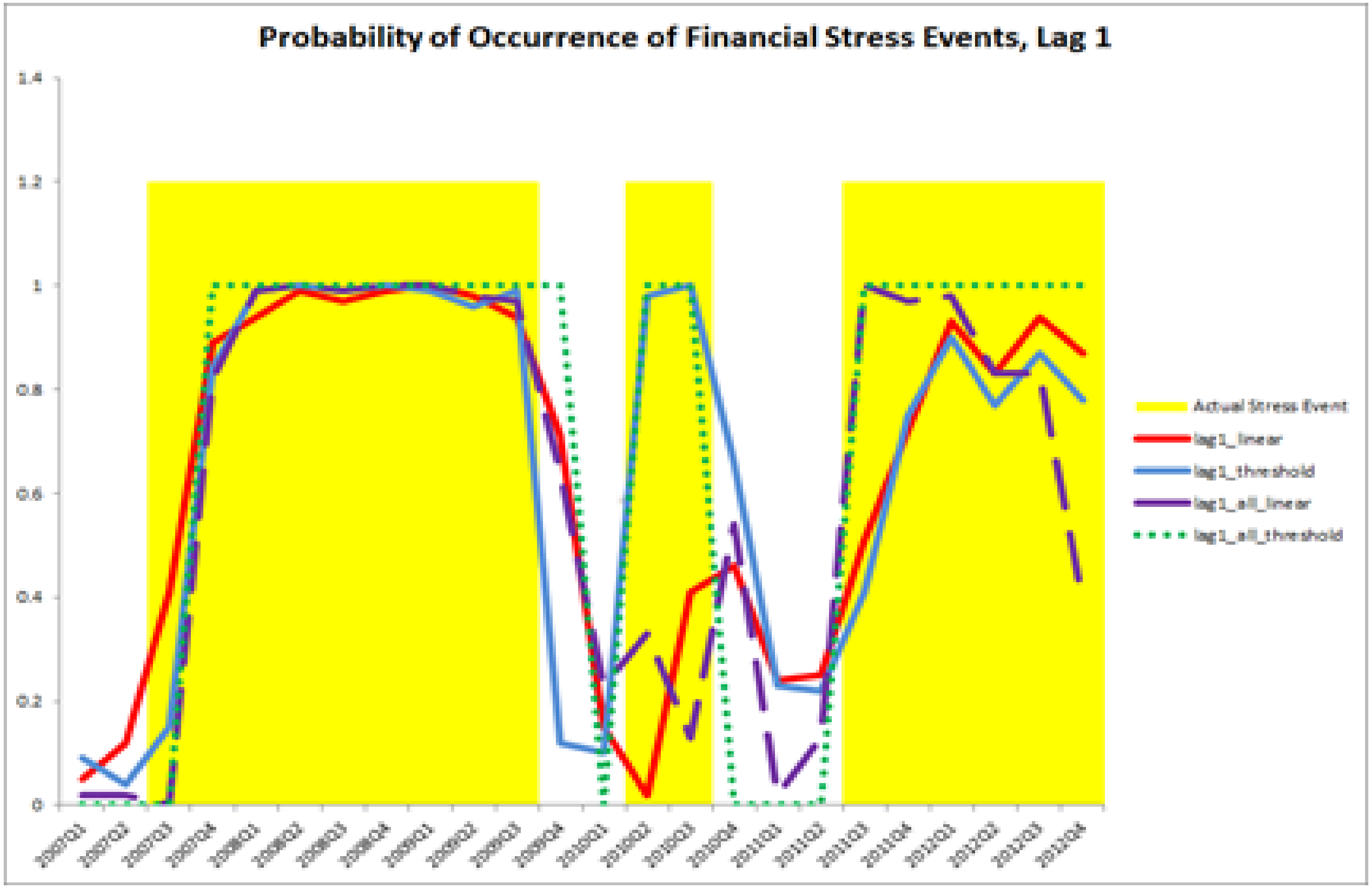

Probability of Occurrence of Financial Stress Events, Lag 1
1.4
1.2
1
0.8
0.6
0.4
0.2
0
2007Q1
2007Q2
2007Q3
2007Q4
2008Q1
2008Q2
2008Q3
2008Q4
2009Q1
2009Q2
2009Q3
2009Q4
2010Q1
2010Q2
2010Q3
2010Q4
2011Q1
2011Q2
2011Q3
2011Q4
2012Q1
2012Q2
2012Q3
2012Q4
Actual Stress Event
lag1_linear
lag1_threshold
lag1_all_linear
lag1_all_threshold


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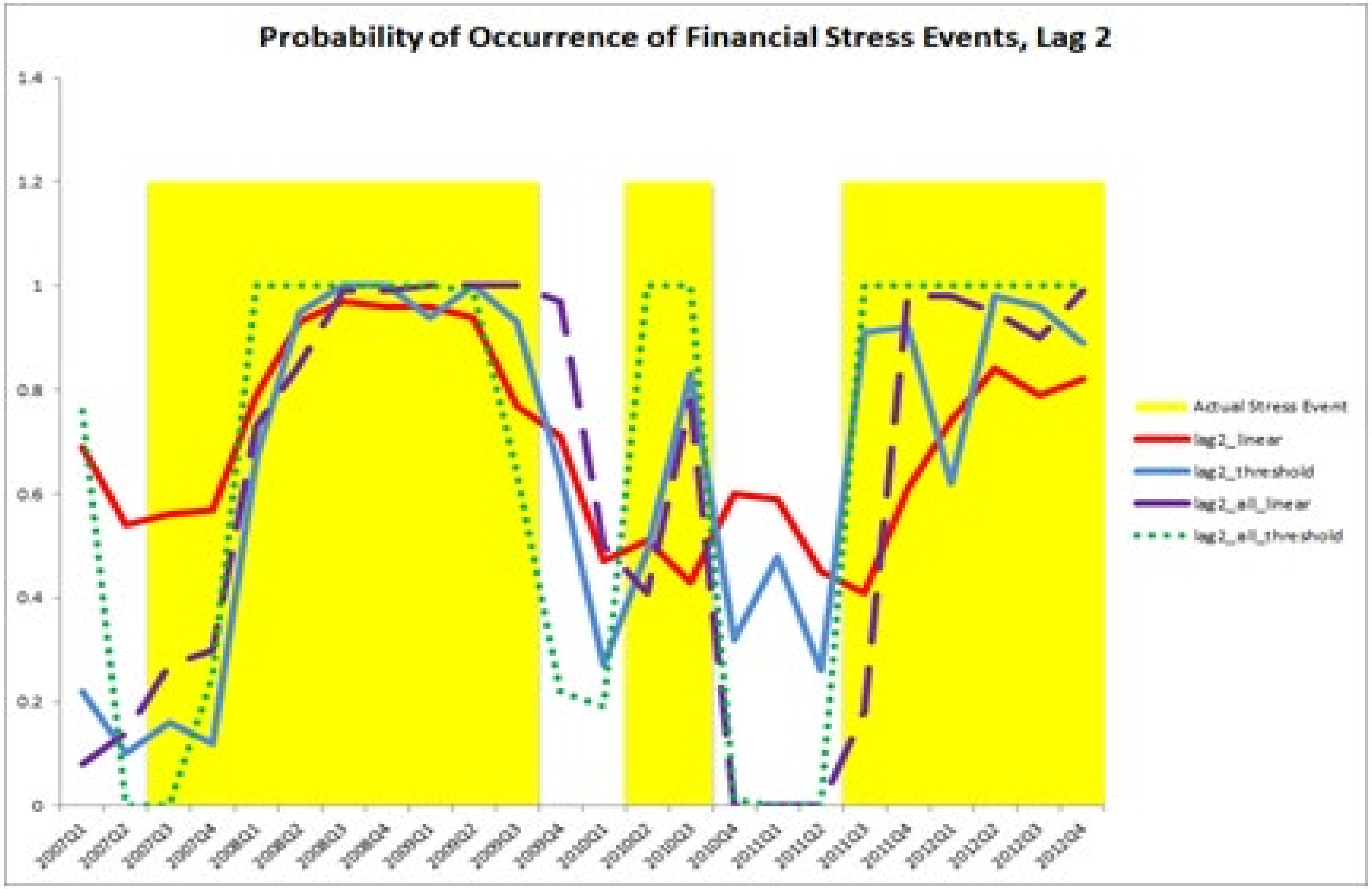
Probability of Occurrence of Financial Stress Events, Lag 2
Actual Stress Event
lag2_linear
lag2_threshold
lag2_all_linear
lag2_all_threshold

38