IRISH RESEARCH COUNCIL
An Chomhairle um Thaighde in Éirinn

Critical transitions in financial markets

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Introduction

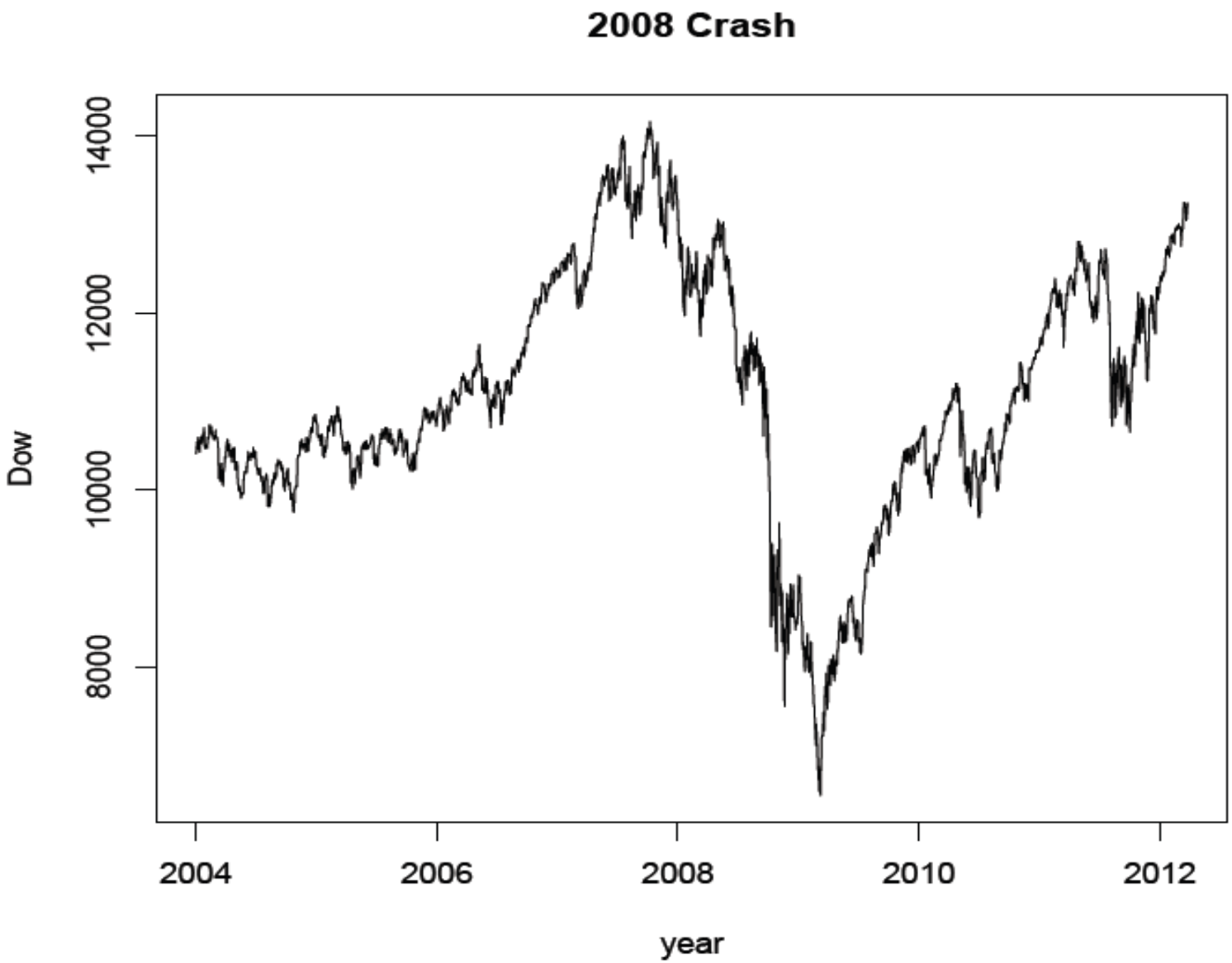
- In our examination of financial markets we are confronted with 2 stylized facts:

1. Financial markets experience prolonged phases of bullish growth followed by dramatic crashes

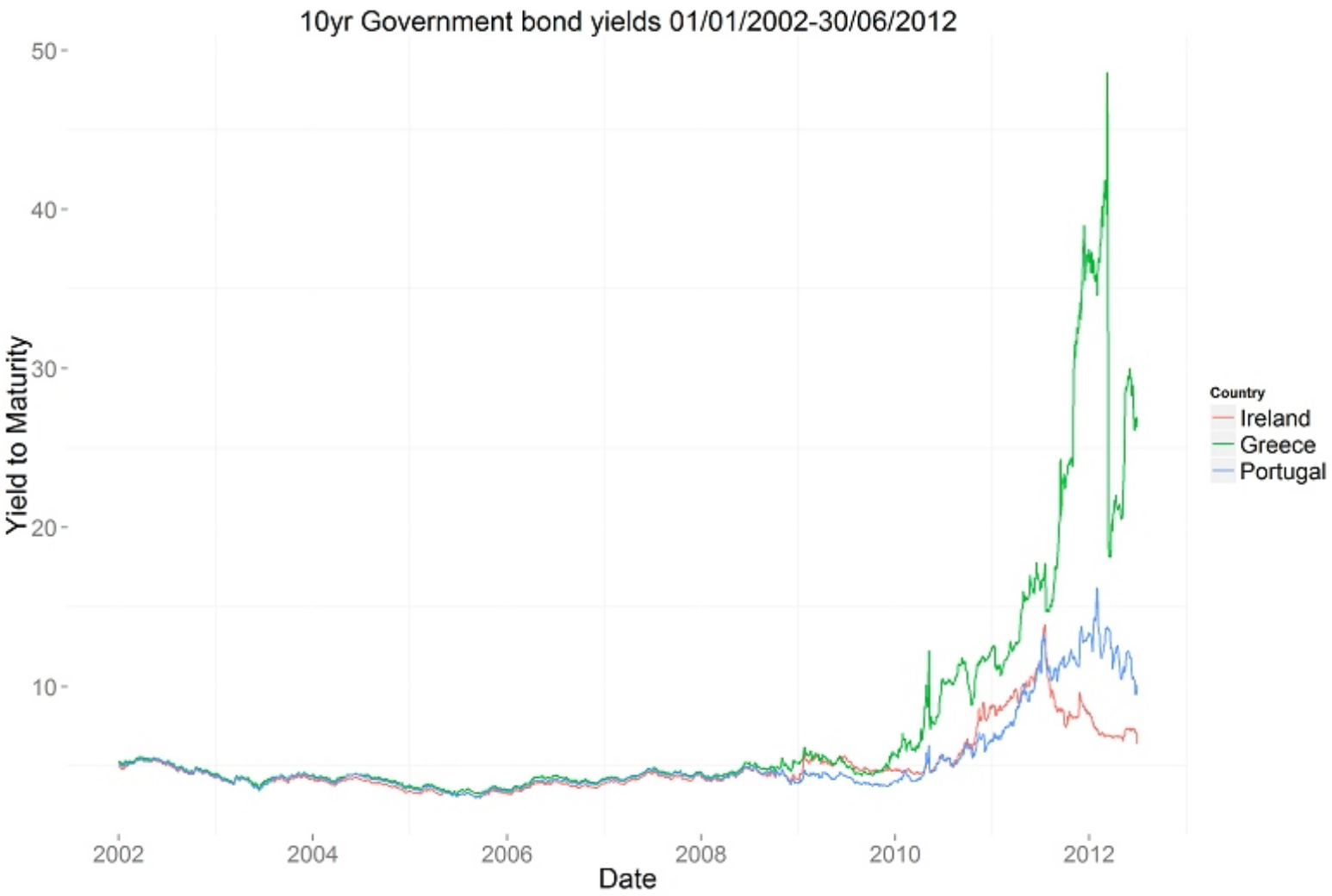
2. After a crash the market can linger in the recesionnary state for quite some time

Eg. 2008 crash and Eurozone sovereign debt crisis

2008 Crash Dow Jones industrial average



Eurozone sovereign debt crisis



Endogenous risk

- Traditional economics approach of rational agents and fully efficient markets with exogenously driven asset price movements fails to predict or explain abrupt stock market crashes.

- Danielsson and Shin (2003): Modern risk management has a blind spot in that it uses a single person "game against nature approach" which fails to take feedback loops into account and endogenous risk.

- Zigrand (2014): Endogenous risk is the risk of a systemic event where the forces that drive the build up of the event are feedback loops and cascades.

Behavioural Finance and Agent Based Models

- Agent Based Models (ABMs) with adaptive belief systems capture the stylised facts of financial markets including financial market crashes and fat tailed distributions (Hommes and Wagner 2004).

- Boundedly-rational agents who calculate and trade on the fundamental value of an asset price can switch behaviour and embark on technical trading strategies such as trend following if such strategies are seen to generate excess returns in past time periods.

- Instabilities such as temporary bubble formation and eventual asset price crashes build up as fraction following technical strategies increase.

- Key parameters such as risk aversion, intensity of strategy switching or variability of excess returns reach critical threshold or tipping point and causes system to switch abruptly between alternate steady states.

Approach

Given that financial crises and crashes appear to be caused by instabilities building from within the system, we test for evidence of such build up in financial time series at a micro and macro level.

i) Macro Level Analysis

- Examine the Sovereign bond yields of Greece, Ireland and Portugal in the lead up to the Eurozone sovereign debt crisis and ask whether "early warning signals" (EWS) were present in the case of bond market.
- In particular we test for the phenomenon called "critical slowing down" which has been shown to precede critical transitions in many real systems

ii) Micro Level Analysis

- Examine the network structure of 37 stocks in the S&P 500 for changes prior to the 2008 stock market crash which could indicate growing instabilities in the lead up to the crisis.

Objectives

We ask these questions which are in turn the objectives of the paper.

1. Are EWS were present before the crisis and are these indicators reliable enough to provide consistent warnings of impending crisis in the bond markets or financial markets in general?

2. Can these indicators provide information as to how instabilities build up within the financial system so we can use this information to develop more relevant asset price models?

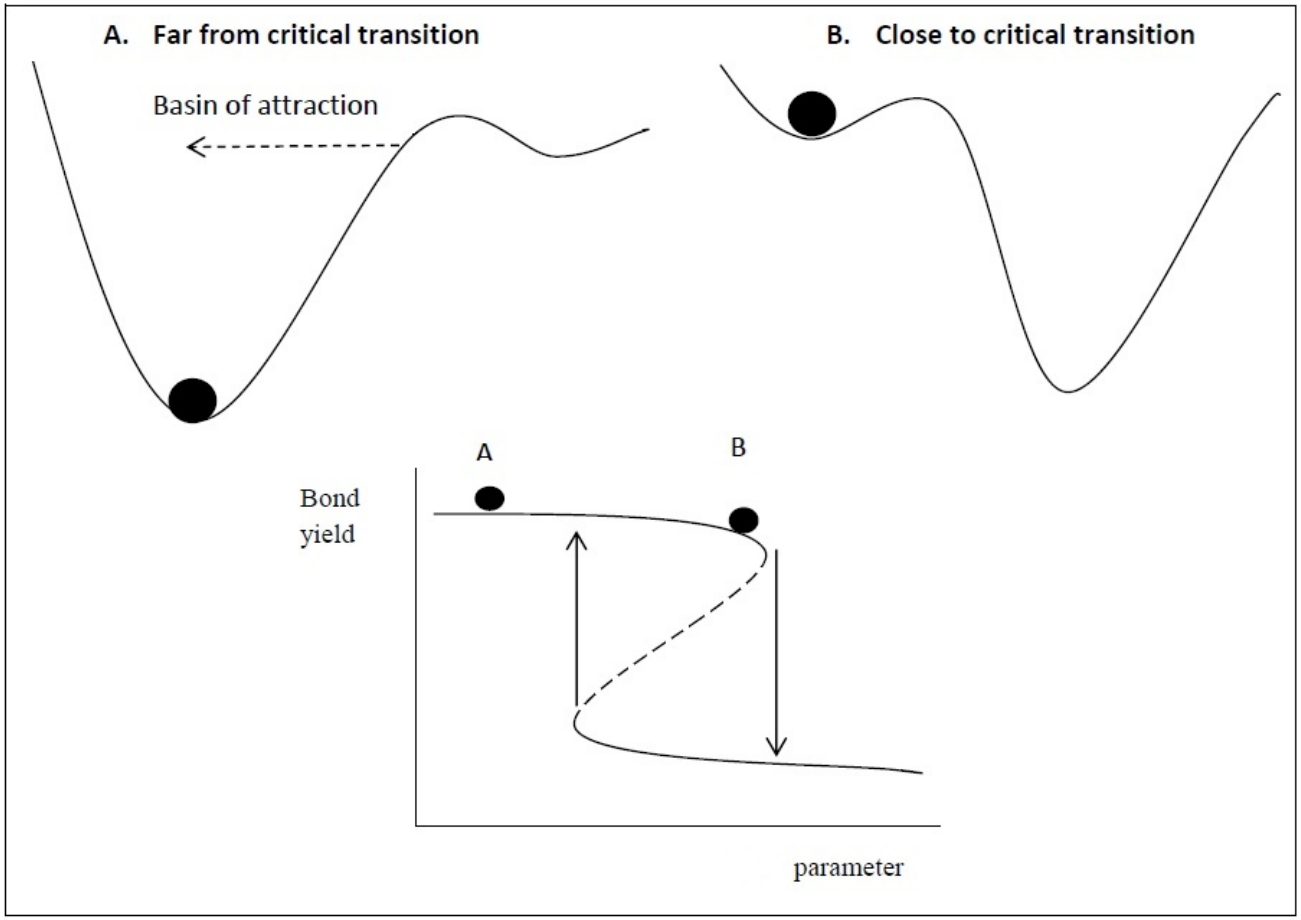
Critical transitions real world systems

- There is a huge body of literature that shows that many real world systems, such as ecosystems and climate systems, display similar behaviour to financial crises with abrupt regime shifts caused by an underlying parameter or driver of the system passing through a critical threshold.

- These “critical transitions” are amongst the range of dynamics generated by the build up of instabilities in ABMs and in simulations cause abrupt asset price crashes.

Critical transitions in financial markets

- A universal property of system approaching a critical transition is **Critical Slowing Down (CSD).**



- **CSD: Increasing Autocorrelation, Autoregression, Standard deviation, Skewness, Kurtosis.**

Methodology

- **Step 1:** The bond yield data is detrended by first log differencing to remove unit roots and secondly using a Gaussian kernel smoother to remove any remaining non stationarities, which may lead to spurious results.

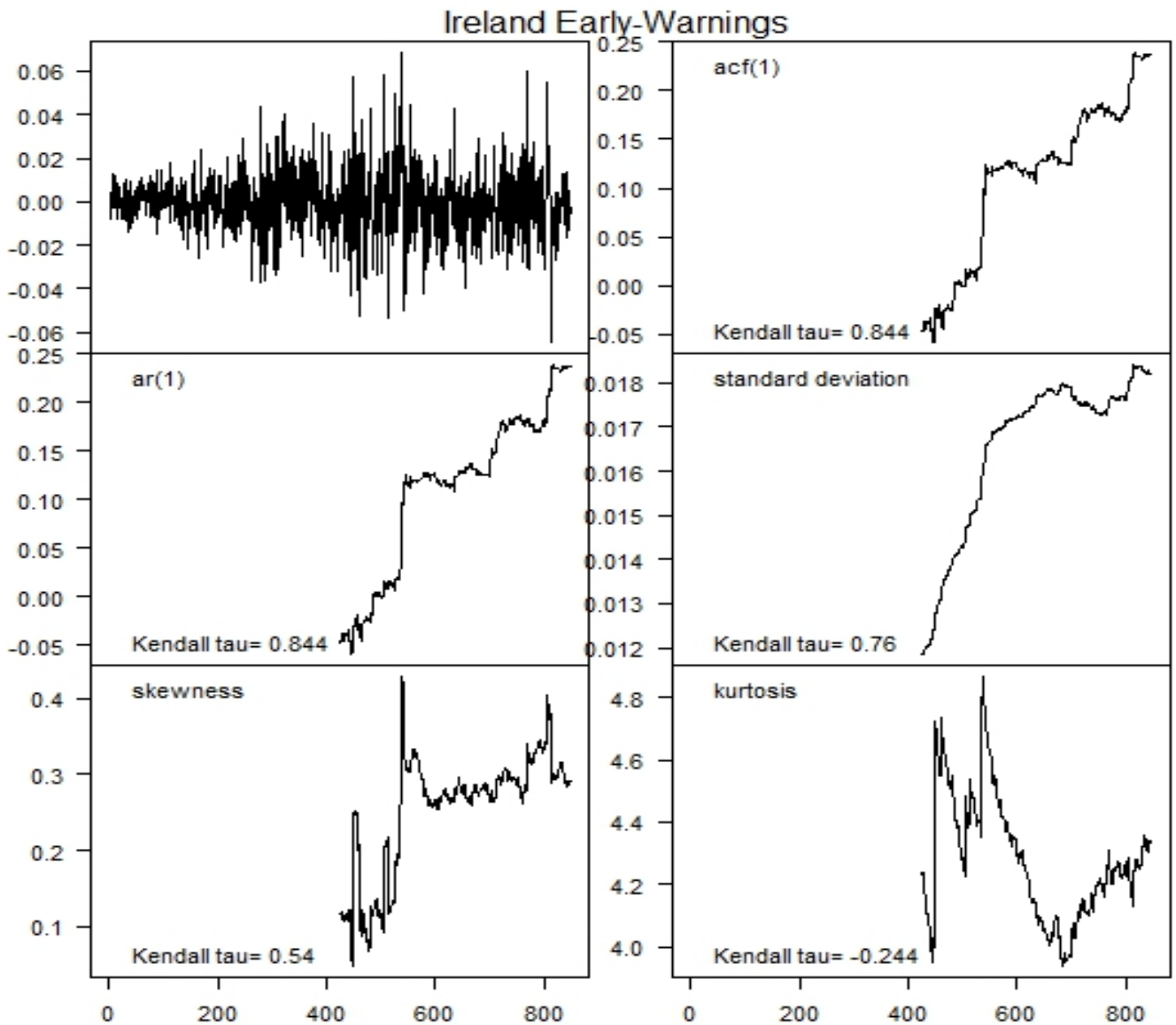
- **Step 2:** The indicators are calculated in overlapping rolling windows equal to 50% of the sample size.
  - For Greece 10 year bond yields from 01/01/2007-31/10/2009; for Ireland and Portugal from 01/01/2007-31/03/2010.

- **Step 3:** Kendall's tau correlation coefficient is used to calculate the strength of the trend in the indicators as the critical threshold is approached.
  - A continuously increasing variable would have a Kendall's tau value of 1

- **Step 4:** The significance of the trend is calculated using surrogate data methods

- **Step 5:** Sensitivity testing by varying the rolling window size and bandwidth of kernel smoother.

Results: Ireland



Significance of Indicators of Critical Slowing Down						
	Greece		Ireland		Portugal	
	Kendall's Tau	p-value	Kendall's Tau	p-value	Kendall's Tau	p-value
ACF1	0.943***	0.001	0.844***	0.008	0.796**	0.026
AR1	0.943***	0.002	0.844***	0.001	0.795**	0.032
SD	0.855***	0.007	0.76**	0.038	0.855***	0.004
Skew	0.237	0.39	0.54	0.157	0.661	0.114
Kurt	0.249	0.389	-0.244	0.646	-0.081	0.549

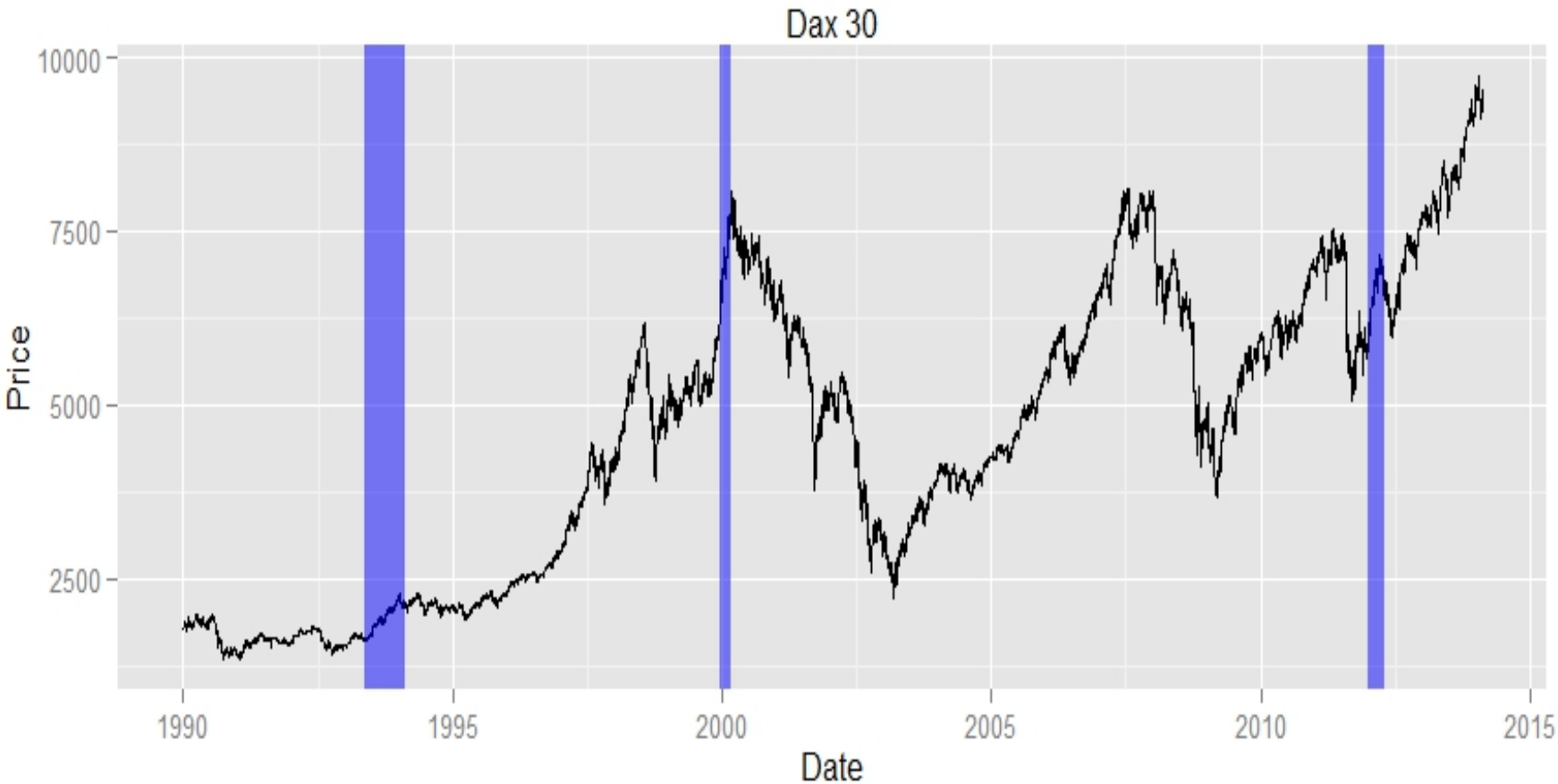
*** Indicates 10% significance, ** 5% significance and *** 1% significance**

- Sensitivity analysis carried out by varying rolling window size and sensitivity of Gaussian kernel smoother.
  - Results are robust to changes in kernel smoother and for smaller rolling window sizes with Skewness and Kurtosis becoming significant.

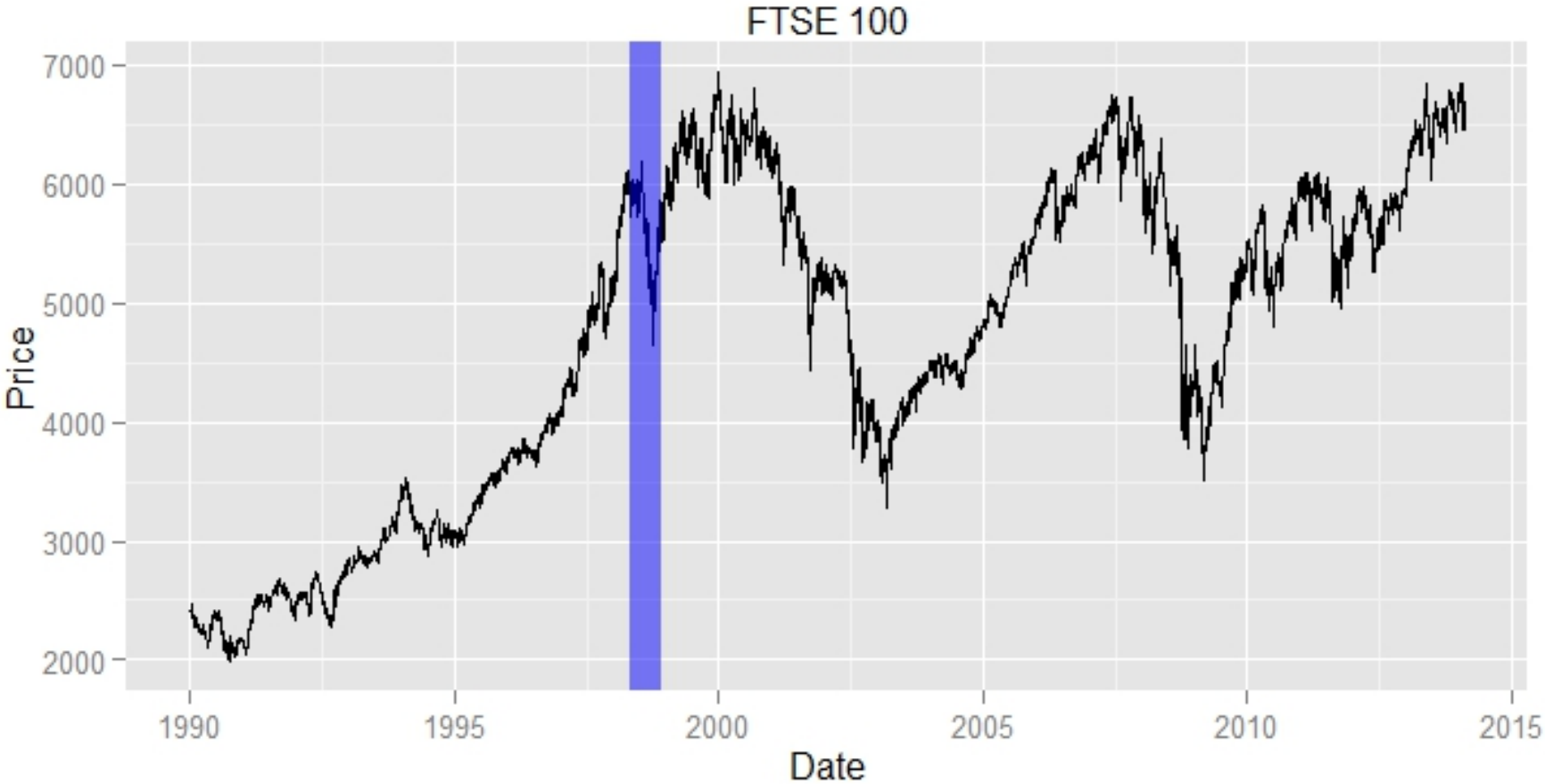
False positives in early warning signals

- Can CSD be used as a consistent early warning signal for financial crises?
- DAX 30, DOW Jones Industrial Average, Eurostoxx 50, FTSE 100, Nikkei 225, Toronto SE from 01/01/1990-12/02/2014.
- Calculate ACF1 and corresponding Kendall's tau coefficients in 400 day rolling windows.
- A positive EWS is given when a statistically significant trend in autocorrelation is registered over a 400 day window coupled with autocorrelation coefficients which are statistically different from 0.

DAX 30



- **Figure 13: Dax 30 index positive trends in autocorrelation calculated on log-returns of international stock indices. Shaded area indicates period over which both ACF1 and Kendall's are significant at a 5% level. ACF1 calculated using a 400 day window and trend evaluated using Kendall's tau over 400 days from 01/01/1990-12/02/2014.**

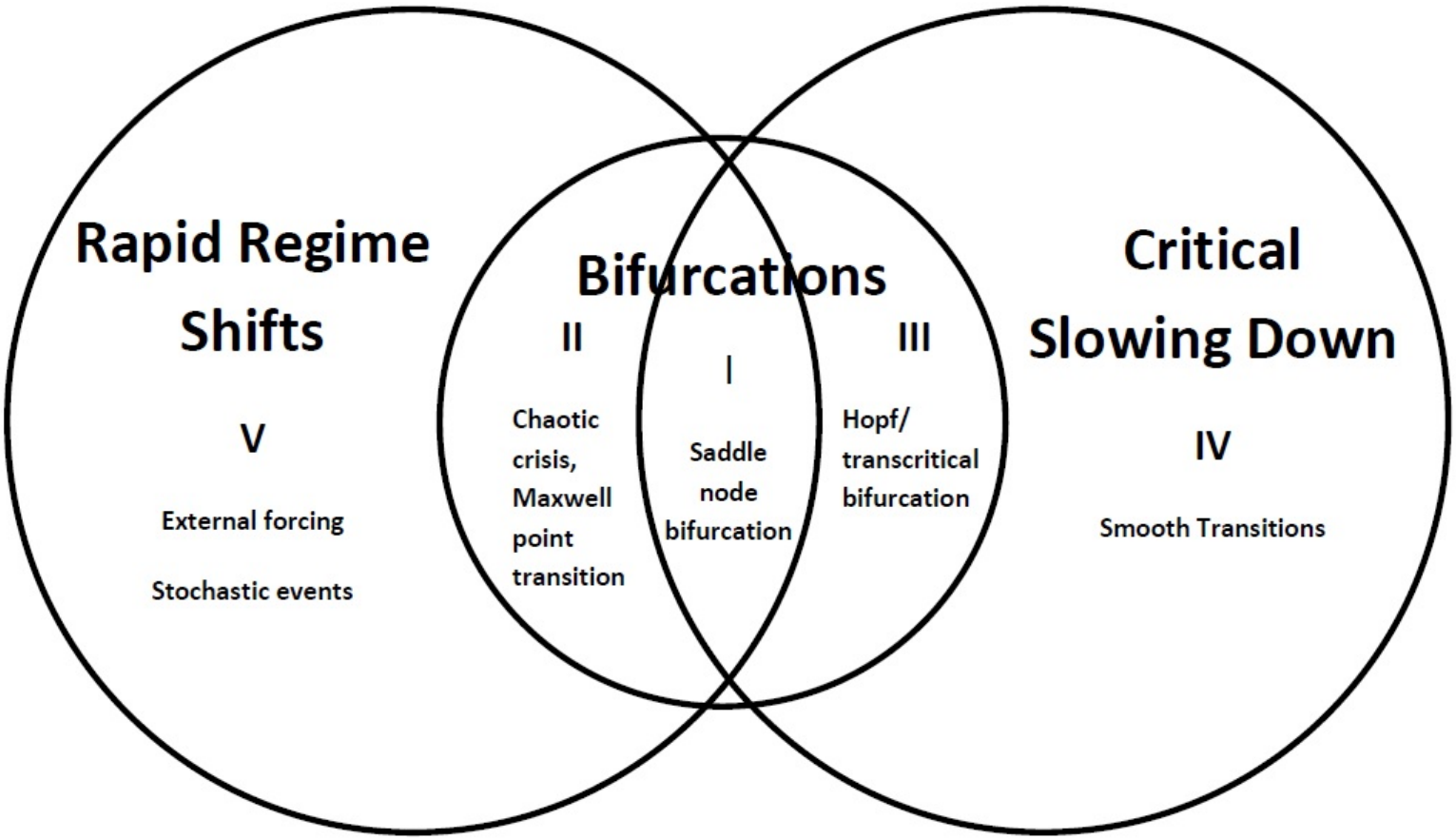


- **Figure 13: FTSE 100 index positive trends in autocorrelation calculated on log-returns of international stock indices. Shaded area indicates period over which both ACF1 and Kendall's are significant at a 5% level. ACF1 calculated using a 400 day window and trend evaluated using Kendall's tau over 400 days from 01/01/1990-12/02/2014.**

Positive Early Warning Signals				
	Start date	**Stop date**	**Succeeded by transition**	**False Positive**
Dax 30	19/05/1993	10/02/1994	✗	✓
	23/12/1999	07/03/2000	✓	✗
	02/01/2012	27/04/2012	✗	✓
Dow Jones	21/01/1995	08/03/1996	✗	✓
Eurostoxx 50	03/05/1994	21/02/1995	✗	✓
	11/05/1999	26/10/1999	✗	✓
	24/01/2012	17/04/2012	✗	✓
FTSE 100	05/05/1998	03/12/1998	✓	✓
Nikkei 225	N/A	N/A		
Toronto SE	23/10/1997	27/10/1997	✗	✓
	11/05/1999	26/10/1999	✗	✓
	24/01/2012	17/04/2012	✗	✓

Table 4: Incidence and duration of positive early warning signals in daily stock price returns of Dax 30, Dow Jones, Eurostoxx 50, FTSE 100, Nikkei 225 and Toronto SE.

Boettiger et al (2013) classification.



Results and discussion section 1

- Evidence of critical slowing down in sovereign bond markets of Portugal, Ireland and Greece prior to the Eurozone sovereign debt crisis providing a potential early warning signal for financial crises.

- Prevalence of false positive early warning signals when CSD used as leading indicator.

- Further research is needed. This includes further examination of periods where false positive early warnings are present for evidence of other types of dynamical behaviour which are known to be preceded by critical slowing down.

Micro level analysis: Changing network structure of 2008 crash

- Correlations and Co-movements between stocks reflect the degree to which changes in information set are factored into individual stock prices.

- Increasing instabilities caused for example by traders switching to trend following strategies may be detectable in changes in the network structure of the stock market.

- We examine direct causal connections between 37 different stocks from the S&P 500 operating in 8 different sectors using an information theoretic measure Partial Mutual Information at Mixed Embedding (PMIME)

  (Vlachos and Kugiumtzis, 2010), (Kugiumtzis, 2013).

PMIME

- There are numerous benefits to using PMIME over traditional correlation coefficients and linear Granger causality measure.

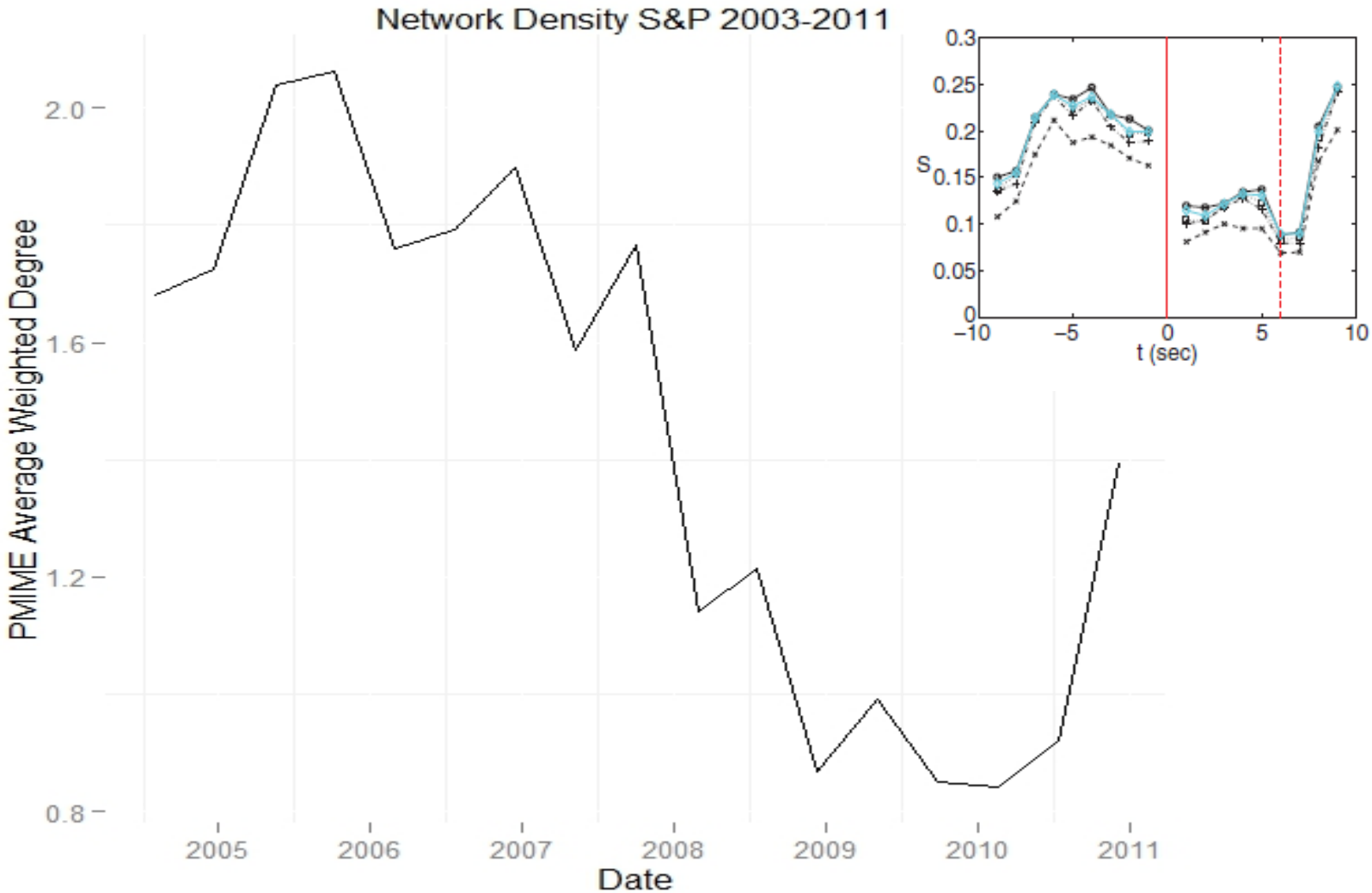
1. Mutual Information measures can detect both linear and nonlinear correlations between stocks.
2. It is a (Granger) causality measure so it can pick up which sectors react first to new information and if shock originating in one sector are transmitted to another.
3. It uses conditional mutual information(CMI) so looks only at the direct connections between the stocks in the network. Using CMI also reduces any bias introduced by Knn estimation.
4. Uses a non-uniform embedding scheme which allows use to examine relationship between a large number of stocks and multiple lagged time periods. Increasing sample size causes alternate methods to become computationally intractable.

Data and Methodology

- 5 top stocks in 8 sectors of S&P 500- 3 dropped due to insufficient observations.
- PMIME estimated between each of the individual stocks using a 400 day rolling window and 100 day step from 01/01/2003 to 31/12/2010.
- PMIME outputs a 37x37 matrix of direct causal connections significant at a 5% level with cell $(X,Y)=0$ if stocks X and Y are independent and cell $(X,Y)>0$ if stock X Granger causes stock Y.

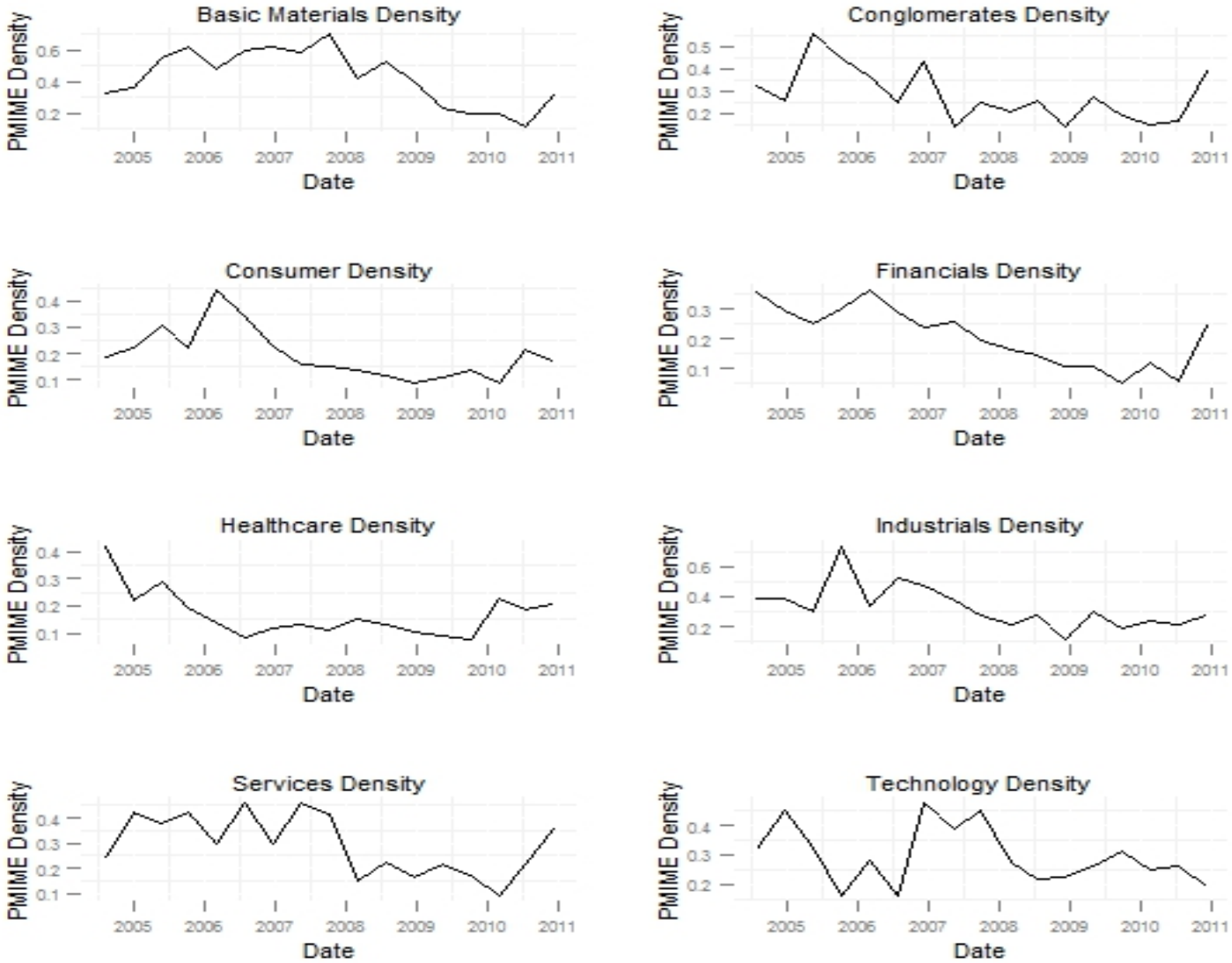
Basic Materials	Conglomerates	Consumer Goods	Financials
COP	UTX	PG	BRK
XOM	MMM	KO	WFC
CVX	CAT	PEP	JPM
SLB	DOW	MO	C
OXY	LUK		BAC
Healthcare	**Industrials**	**Services**	**Technology**
JNJ	GE	AMZN	AAPL
PFE	HON	DIS	MSFT
MRK	EMR	HD	IBM
BMY	LMT	WMT	T
AMGN		CMCSA	

Results: Network density



- **Total average weighted connection over 17 overlapping time periods from 01/01/2003-31/12/2010 using 400 day rolling window and 100 day step. Inset: connectivity of EEG time series in before during and after epileptic discharge using PMIME.**

Results: Network density per sector



- **Total average weighted outwards connection per sector normalised by the total possible number of connections per sector.**

Results and discussion section 2

- Decrease in density of the network of PMIME connections beginning in 2006
  - Larger decrease with onset of crash in early 2008

- At a sectoral level the average weighted connections from the Financial, Consumer Goods and Industrials sectors begin reduce from 2006.
  - Remaining sectors experience reduction in causal connections during the crash in 2008.

- Further research is needed to determine cause of reduction in network density prior to 2008 crash.

  I. Simulation study to determine the effect of increasing noise on magnitude of PMIME estimate.

  II. Examination of Dot Com crash and 1987 crash for evidence of similar dynamics.

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Thank you for listening

Questions comments or suggestions are welcome.

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