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The European Financial Market Stress Index

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ABSTRACT: This research constructs and develops a financial stress index based on European financial markets. The integration of numerous sovereign states has created difficulty identifying stress in any one single financial component, but incorporating twenty-three headline European stress indicators across equities, bonds and currencies, in terms of both spreads and levels offer substantial explanatory benefits. The incorporation of a logistical framework specifically analysing the levels, volatility and co-movement of the included standardised series enables the creation of an index that adequately represents financial market stress in European. Using periods of pre-defined crisis in a logistic regression framework also aids the development of the index. The results provide evidence that the European-specific sovereign crises from 2010 to present, with particular emphasis on the mid-2011 period, have significantly over-shadowed any event that the financially-integrated Europe has previously experienced.

Keywords: European financial crisis; financial market stress indicator; liquidity; stock markets.
JEL Classifications: G01; G15

1. Introduction

The role of crises and stress measurement has become a widely investigated topic, particularly since the international financial market chaos of 2007 to 2009 and the European-specific sovereign debt problems from 2010 to present. There exists a large gap in literature based on the measurement of European-specific financial market stress, a metric measured in numerous other nations such as the United States and Japan. This research attempts to construct a financial stress index based on differing elements of European financial markets in a manner that allows for the comparison of periods of crises.

Given the large financial market fragmentation prior to the birth of the Euro as a trading currency in 1999, a reduced period of investigation and reduced availability of financial products available, there has been significant difficulty creating a measure comparable to that already available in the United States, Great Britain and Japan. In recent years, the range of European financial products has expanded dramatically (futures markets, options, CDS, bond spreads, etc.), thus offering readily available measures of financial risk that before these product's creation would not have been easily identifiable. These markets can provide vital information based on the present and future expectations of European market participants, information that can greatly benefit the decision-making process of European policy-makers. In the United States, monitoring country-wide financial markets is less problematic when compared to Europe, as it is one country, with similar demographics among its population. Europe is based on the conglomeration of numerous extremely different populations that share a currency, but no set single financial market and experience differing speeds of financial integration between member states. This fact alone has created significant difficulty in creating generally agreed upon metrics of European-wide financial stress levels.

The stress index described in this paper builds on the recently developed United States-orientated methodology created by Carlson et al. (2012). Every different financial market metric cannot simply be bonded together and be relied upon as an accurate measure. Numerous issues based on correlations and weighting of the indexed constituents remain, but the methodology described in this research, succeeds in reducing these issues substantially. Twenty-three of the most common metrics of European financial market stress are included in this index, designed specifically to capture market stress across the three spate dimensions of market risk, liquidity and investor uncertainty.

Similarly to the work of Nelson and Perli (2005), the index is based on three sub-indices developed on the levels of the constituent series, the change in volatility and the co-movement of the selected variables. The levels offer evidence of the drastic movement in the series, thus monitor direct market perceptions of stress based on the investment product's price. The volatility of the index increases based on the aggregation of market stresses and the co-movement of the selected series is found to increase dramatically during periods of crises (Nelson and Perli, 2005).

The index uses simple intuition to denote a period as being 'in crisis'. The actions of the European Central Bank (ECB) to ease the effects of crisis in European markets are used to denote specific crisis periods, with the timeframe investigated since 1999 being segregated to denoted the period as being either 'in crisis' or 'not in crisis' based on the ECB's actions. Quite simply, a 'crisis period' that is European-specific is denoted as the period immediately before and after an ECB market intervention (interest rate cut, quantitative easing, etc.). The methodology used in this index creates a stress metric that is based on the previous experiences of European financial markets. The variables are then placed into a logistic regression framework, with the resulting coefficients being used to create a European financial market stress index. Through the use of these processes, the index generated through this research can be interpreted as 'identifying the degree to which conditions in European markets are similar at present, to those that existed when ECB policy makers saw fit to intervene'. This can offer significant information based on the strength of stress levels in European financial markets as crisis can be compared like-for-like given the structure and methodologies used.

Of course, significant issues had to be considered during the creation of this index. The variables selected to create the index are based on fundamental research and investigation into the theory and movement of the selected indices during a crisis period. The weightings of the variables were also compared and analysed. Numerous models to determine adequate weights were compared and analysed, but the logistical framework was found to be the most theoretically compatible methodology due to its adaptable and self-learning methodology. The relative youth of financial integrated European markets also creates difficulties. The dynamic nature of the model enables the comparison of crises, but one must note that the issues that Europe has undergone since 1999 have been among the most complex and damaging throughout 20th and 21st century finance. As the model develops throughout time, it consumes more information, thus its accuracy will improve.

The paper is organised as follows: Section 2 presents the previous literature aiding the selection of the underlying indices. Section 3 presents the development of the individual components and methodologies used in the creation of the European stress index, while section 4 compares the index to other international measures. Section 5 analyses the index as a tool to aid policy-makers while section 6 concludes.

2. Previous Literature

As in Nelson and Perli (2005), Grimaldi (2010) and Carlson et al. (2012), the index constructed in this paper to measure European financial market stress levels is devised based on three underlying indices that describe the aggregate characteristics of twenty-three underlying variables. In a similar manner to Carlson, Lewis and Nelson (2012), the data is standardised and aggregated built on the results of a logistic regression framework and based on the intuition that crisis in Europe is defined based on the actions of the ECB. This methodology proved to be the most parsimonious after extensive testing. There are few financial stress indices available based explicitly on European financial market behaviour, but there have been attempts to devise crisis indicators. Grimaldi (2010) built a European specific stress index that was found to adequately extract information from financial market noise. This was also denoted as the first attempt to build an explicitly European index.

There have been recent attempts to focus on a financial stress index for Greece by Louzis and Vouldis (2011). Their model uses a multivariate GARCH methodology to incorporate time-varying correlations between markets. The authors find that their index is capable of providing a precise periodization of crises and is necessary to adequately guide policy-makers decision-making. Hollo et al. (2012) attempt to create a composite indicator of systemic stress in European markets by applying basic portfolio theory to five sub-indices based on a total of fifteen individual stress measures. They then use a threshold VAR model to investigate the levels of stress that depresses real economic activity.

There have also been numerous indices built to represent conditions in other international jurisdictions, but Europe poses a particular challenge based on the relative youth of its financial markets and recent introduction of new financial markets. The United States Federal Reserve banks of St. Louis, Kansas and Cleveland remain the pioneers of the stress index. Though explicitly modelled on United States conditions, numerous facets of their approaches are considered in the creation of this model. The Cleveland Financial Stress Index (CFSI) proved to be the metric of most benefit in the creation of this model. It was developed by Oet et al. (2011) with the aim of providing a continuous signal of financial stress and broad coverage of the areas that are found to indicate stress. They use a dynamic weighting methodology to capture changes in the relative importance of the sectors for credit, foreign exchange, equity and interbank markets. The resulting index is found to parsimoniously represent the trends and dynamics of numerous United States stress indicating variables.

Illing and Liu (2003) developed an index of financial stress for Canada using a combination of factor analysis, econometric benchmarking and GARCH techniques on survey respondents that they had compiled. The authors show significant differences between the measures of financial crises suggested by the literature and the undertaken survey results. Kaminsky and Reinhart (2001) investigated the co-movement of asset stress levels across thirty-five countries to find that developed countries show more distinctive evidence of co-movement in comparison to their developing counterparties. Equity markets are also the most correlated investment product that they investigate.

Other areas of related previous research include the transmission mechanisms of stress in financial markets, as defined by Balakarishnan, Danninger, Eledag and Tytell (2009) in an IMF working paper. The authors find through the use of a new stress index based on emerging economies that there is a strong positive correlation between the transmission of stress and the depth of financial interlinkages between the countries investigated. Advanced economies possess significant threats to emerging economies through stress transmission, despite the current account and fiscal balance defences they may possess, but this may potentially dampen the effects on the real economy. Some of the informational benefits are also adapted from the Federal Reserve Bank of Cleveland's Financial Stress Index which was developed by Bianco, Oet and Ong (2012). The segregation of the index into averages based on the crisis denoted levels represents an intuitive method of scaling the index based on previous events, offering policy-makers a quick and easily developed metric to aid decision-making. 'Learning' based on previous experience, even in the short history of the euro as a currency, offer substantial crisis measurement and identification benefits. This model has the dynamic benefit of being adaptable to a changing financial environment and analysing the current situation based on the memory of what has happened in the past.

3. Development of the European Financial Market Stress Index (EFMSI)

The international financial crisis of 2007 to 2009 and the European sovereign debt problems of 2010 to present have resulted in a renewed focus on financial stability. In order to promote stability in a dynamic financial system, policymakers must continually monitor financial markets to identify the risks that threaten stability, both at present and in the future. An important first step is the development of tools that can monitor the condition of broad financial sectors while simultaneously providing insight into the factors that are adversely affecting these markets.

The European Financial Market Stress Index (EFMSI) is developed based on the methodology used in previous United States studies such as Bianco, Oet and Ong (2012) while developing The Cleveland Financial Stress Index and Carlson, Lewis and Nelson (2012) who adopted the co-movement and volatility of the included variables in their model. This model is based on a combination of the techniques used by both these methodologies. Some of the underlying European-specific components were also selected based on the previous work and findings of Grimaldi (2010).

3.1. Construction of the EFMSI and variable selection

There have been numerous international efforts to create an effective index of financial market stress in international markets, but to date, there have been no European-specific versions released. To promote financial stability and openness in the Eurozone, supervisors and market participants must have the ability to monitor systemic risk and possess the ability to assess its level at a given point in time, a facet which an adequate EFMSI can promote.

Like other international indices that measure aggregate movements in financial markets, the EFMSI takes components that quantify individual aspects of the system and combines them into a

single value. The indicator is specifically designed using daily data reflecting twenty-three components (based on the credit markets, equity markets, foreign exchange markets and interbank markets) that are based on the measurement of market liquidity, market risk spreads and investor uncertainty. The included components are listed in table A1 in appendix. The overall financial system is complex and comprises numerous individual markets of varying size and significance. The included sectors were chosen because they encompass major European markets, and observing them from an overview standpoint shows the expansive coverage that they provide of the whole European financial system. Stress in any of the investigated areas can freely transfer from one constituent to the next. It must be noted that unlike other countries that offer FSI, the EFMSI attempts to overview the financial conditions of numerous European countries. There is also no long-term European-specific bond available, thus for this reason, the German 10 year bund is accepted as the benchmark representative for all over long-term European-sovereign bonds to be compared.

The individual series included are all expected to respond to financial stress. To make the series comparable, each individual component is standardised and to reduce noise, the daily data is smoothed using a five-day moving average. The series itself is then averaged based on the individual components included, but the use of a dynamic weighting system it discussed in section four. Based on previous papers based on United States FSI attempts, the logistic regression methodology introduced by Carlson, Lewis and Nelson (2012) proved most appropriate.

During the construction of the EFMSI, the underlying series are selected in an attempt to represent the most parsimonious portrait of market fragility and dysfunction, which are deemed to be directly associated with oncoming, or indeed, the presence of financial market stress. Seven of the EFMSI components are spreads. These spreads are designed to represent gaps in yields, prices of rate differentials for different financial instruments, both of which contain information about the market-perceived risk associated with those instruments. Some of the included components are in the form of ratios and contain specific information about the stability of financial conditions in European markets. The combined information about the included sectors is more important for the detection of systemic risk, than that of the information available from any individual market. Numerous factors can affect spreads in individual markets over time, and many of them are not related to systemic stress. Further, when spreads change because of non-systemic, stress-related events in one market, the changes are not necessarily correlated with the spreads in other markets. Therefore, observing the financial conditions in a number of markets allows for the potential identification of a common causation factor.

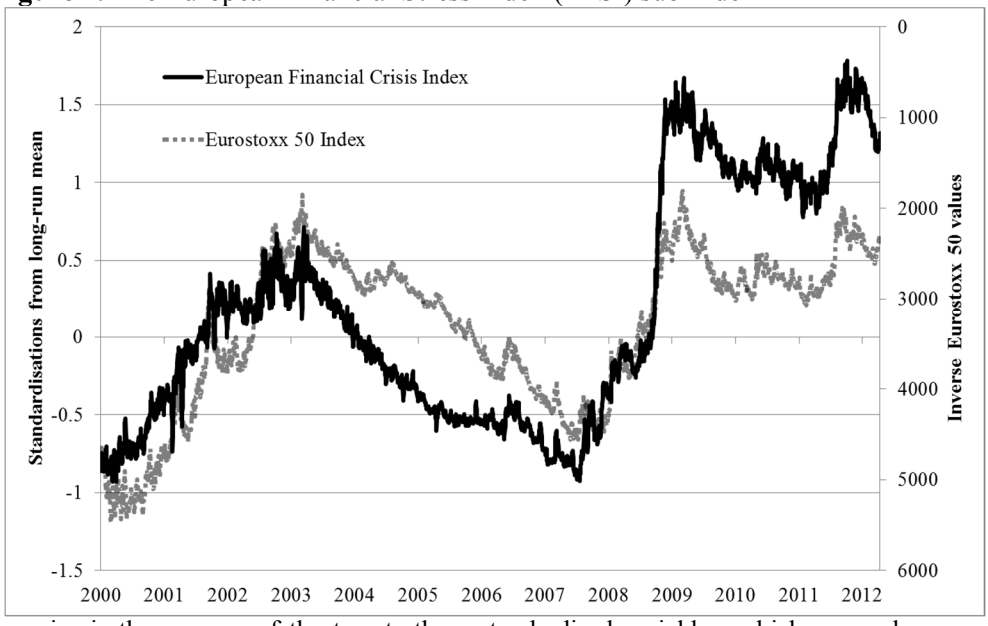
The EFMSI is designed to track stress in European financial markets on a continuous basis. This allows banking supervisors and analysts to monitor stressful episodes as they are developing. Such early detection is very important because when significant stress occurs in multiple markets, overall financial stress is quickly amplified. Section five discusses potential methodologies, similar to those used in the creation of the Federal Reserve of Cleveland's' Financial Stress Index, that allow for the ranking of current stress index levels into demographics that aid the identification process of oncoming financial market stress. The differences that are present across numerous differing financial stress indices are based on the style and components that are included and the particular emphasis that is placed on different aspects of the included financial markets. One of the main advantages of the EFMSI is that it is available on a daily basis and is based on specifically-dynamic spreads that react based on investor perceptions of both present and future market conditions.

3.2. Sub-indices of the EFMSI

This paper replicates the methodology of Carlson, Lewis and Nelson (2012) in their United States orientated FSI. The authors first focus on the creation of three sub-indices of the stress index, on which the logistic regression methodology could then be implemented. This generates weights that denote the behaviour of markets during previous episodes of denoted crisis. This allows for the comparison of European-specific crisis through the inclusion of behavioural dynamics. The first sub-index is based on the levels of the included series, based simply on an un-weighted average of the twenty-three individual standardised components of the index and is plotted in figure 1. The series are standardised such that each value is the number of standard deviations that the series is away from its long-run mean. The series appears to have reacted substantially to numerous periods of crises that are defined post-hoc, thus adding significant strength to the selection criteria used to identify significant variables. The most recent periods or crisis are also adequately portrayed, particularly the international equity collapse from 2007 to 2009 followed by the European-specific sovereign debt crisis of 2010 to

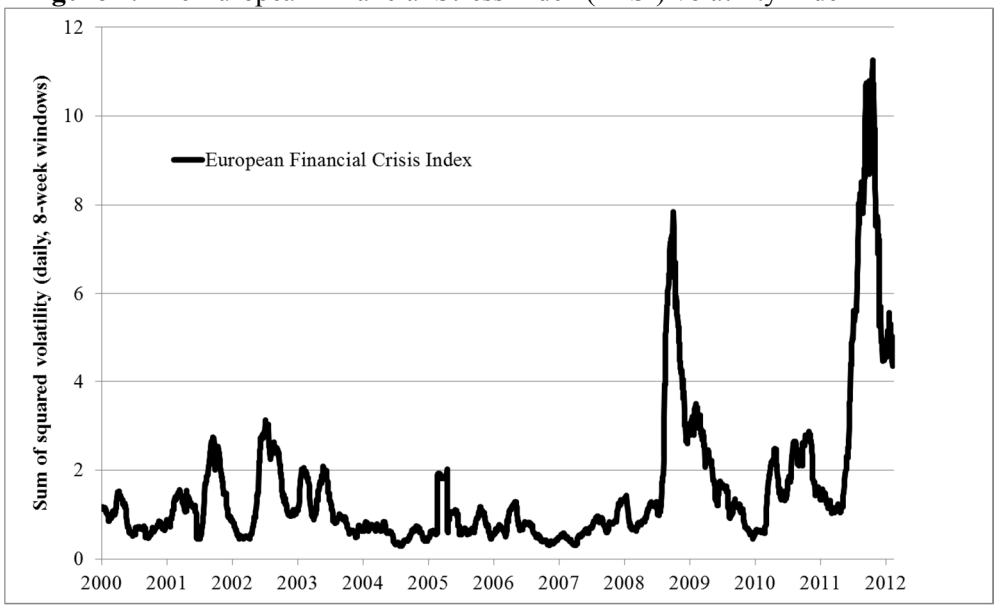
present. As shown in figure 1, despite the use of only five equity-specific variables in the creation of this stress index, the series is highly negatively correlated (-0.687) with the Eurostoxx 50 index. The correlations of the stress indicator with periods of pandemic international and US-specific stress origination offers support for the accurate selection of component series in this index's creation; as it is deemed to accurately represent international stress issues.

Figure 1. The European Financial Stress Index (EFSI) sub-index



Note: This series is the average of the twenty-three standardised variables, which are each expressed as the number of standard deviations they are from their own long-run means. The inverse of the Eurostoxx 50 Index is located on the right-hand axis. It has been inverted to match the indicator which increases as it adapts to the presence of crisis in the underlying series used in its creation. Though the trends remain similar between the two series, the index is by design capable of measuring the depth of a crisis.

Figure 2. The European Financial Stress Index (EFSI) volatility-index



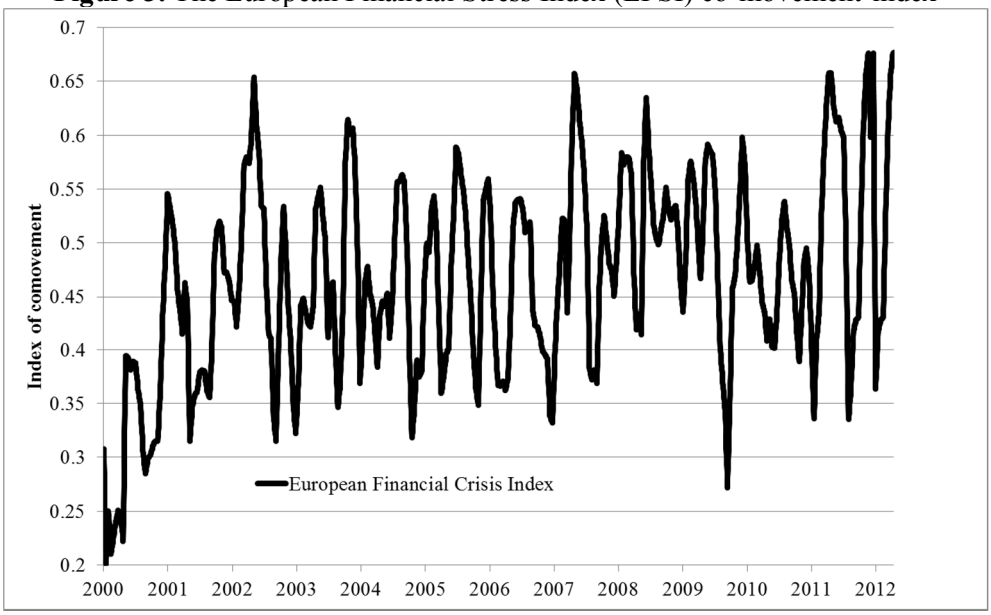
Note: The volatility series is the sum of squared changes over an 8-week rolling window and is designed to represent changes in the level of volatility in the twenty-three underlying financial market variables.

The volatility of the underlying series is also deemed to be an influential component of the EFMSI as there is a high positive correlation between volatility and market stress levels. During the onset of a crisis, the price of risky and indeed illiquid assets fall, which is picked up in the components

of the indicator measuring risk and liquidity spreads. Kritzman et al. (2010) also find that these spreads and the prices of risk assets remain especially sensitive to news as a crisis develops. The second sub-index is based on the average of the twenty-three series volatility levels, focusing specifically on the sum of squared daily changes over an eight-week rolling window, which was similarly used by Carlson et al. (2012). This measure of realised volatility allows us to access changes in asset price volatility that may not be as forward-looking as changes in implied volatility exercises, but offers the ability to look further back in time than options-based metrics may allow. The series is portrayed in figure 2, in which the recent major crises are efficiently portrayed, dwarfing any other crises event since the establishment of the euro.

Finally, during financial stress episodes, asset prices tend to move together more as market correlations tend to one. The third sub-index component investigates the time-varying level of co-movement among the investigated series. To capture the changing co-movement, we follow the previous work of Nelson and Perli (2005) and Carlson et al. (2012) and calculate the first principal component of the changes in the twenty-three variables over six-month rolling windows. Thus, the co-movement index represents the percentage of the total variation that is explained by the first principal component in each window of investigation. The higher the value of this measure, the more of the changes in the underlying index can be explained by a single common factor, which again is indicative of strong stress among the investigated series. The co-movement sub-index is plotted in figure 3.

Figure 3. The European Financial Stress Index (EFSI) co-movement-index



Note: The co-movement series looks at the percentage of changes in the twenty-three series that can be explained by a single common factor over a six month rolling window using Principal Component Analysis (PCA).

The index itself shows that the peak for co-movement between European variables occurred in late 2011 and early 2012. This is related to heightening fear in European markets about the financial health of some individual sovereign states. There were also sharp reactions in 2007 during the height of the international financial market crisis. These events appear to be less of an outlier than that represented in the other associated sub-indices.

3.3. Historical stress episodes

To combine the three sub-indices into a single index, we must consider how they behaved in previous historical stress episodes. To determine what constituted a stress event, we start by identifying interventions by the European Central Bank (ECB) and the major periods of international financial crisis that may have presented sources of systemic risk to the Eurozone, thus having negative consequences for European-specific economic activity. The types of intervention that qualify are broad, and include the interest rate changes and the opening of funding channels to aid distressed sovereign states. Also included, are the main headline United States and international orientated events, along with the headline actions and key dates of specific ECB and IMF interventions during

the European-specific sovereign debt crisis. In this period, the main interventions are included as a stress-influenced event. The complete list of crisis dates and main interventions are listed in table A2 in appendix.

This paper considers the stress periods to be that of two months and is based specifically on the month preceding the event to that month after an ECB market operation. This time frame is designed to capture the majority of the period in which the stress built to a level that resulted in either policy-maker reaction or indeed a financial-failure event, as well as the period following the action that includes of the market reaction. A sensitivity analysis was conducted, but despite testing on horizons up to six months prior and post, the two month window was deemed to contain the same informational benefits. Periods outside those denoted as 'in crises' as identified using this methodology are deemed as 'normal' or 'not in crisis'. The twenty-three underlying series are available from June 1999, but given the rolling-window structure of the models, there is a complete dataset available from March 2000 until April 2012.

3.4. Logistic regression models and EFMSI construction

To look at how the sub-indices behaved in the stress periods, we use a logistic regression framework and regress a stress episode indicator on our three sub-indexes, levels (Lev), changes in volatility (Vol) and co-movements (Com), as described in previous sections. The regression takes the form:

$$p_{logit} = P(\beta_0 + \beta_{Lev}Lev + \beta_{Vol}Vol + \beta_{Com}Com) \qquad (1)$$

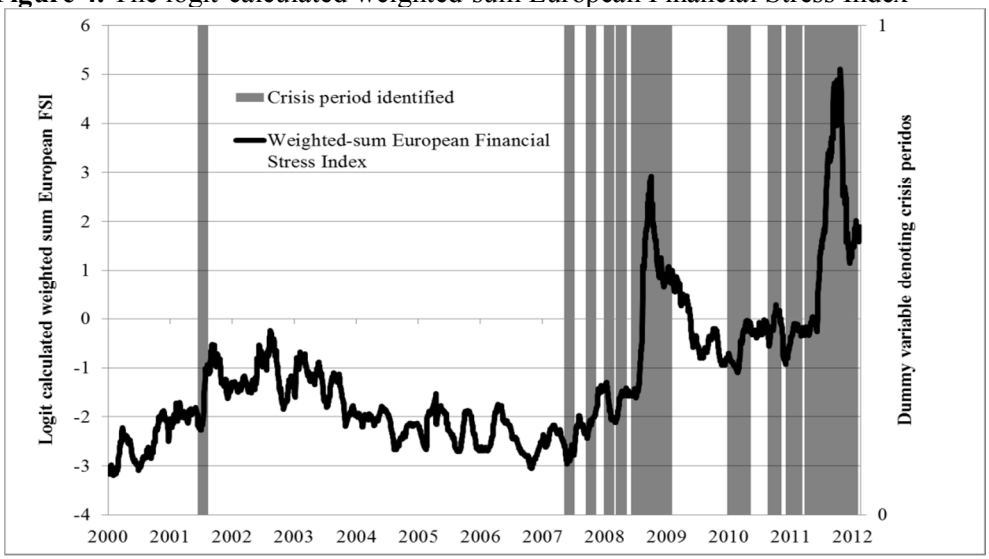
The results appear in table 1. Higher levels of all three components of the sub-indices are indicative of stress periods. It is notable, that despite the common spikes across each of the three sub-indices in financial crisis periods, each remains statistically and economically important in helping us to define an overall index of financial stress. This index is shown in figure 4. The shaded grey regions are representative of the crisis periods denoted based on the ECB actions listed in table A2 in appendix.

Table 1. Logistic regression model estimation results

	Estimate	Standard Error	z value	Prob(> |z|)
Intercept	-4.385129	0.2942463	-14.90	<0.000
Lev	2.565286	0.2291153	11.20	<0.000
Vol	0.454471	0.0480431	9.46	<0.000
Com	2.924471	0.5880836	4.97	<0.000

Note: The above table represents the results of the logistic regression model used to estimate the weighted-sum and probabilistic models used in the figures below. Lev represents the level sub-index, Vol is the volatility sub-index and Com is the co-movement sub-index.

Figure 4. The logit-calculated weighted-sum European Financial Stress Index



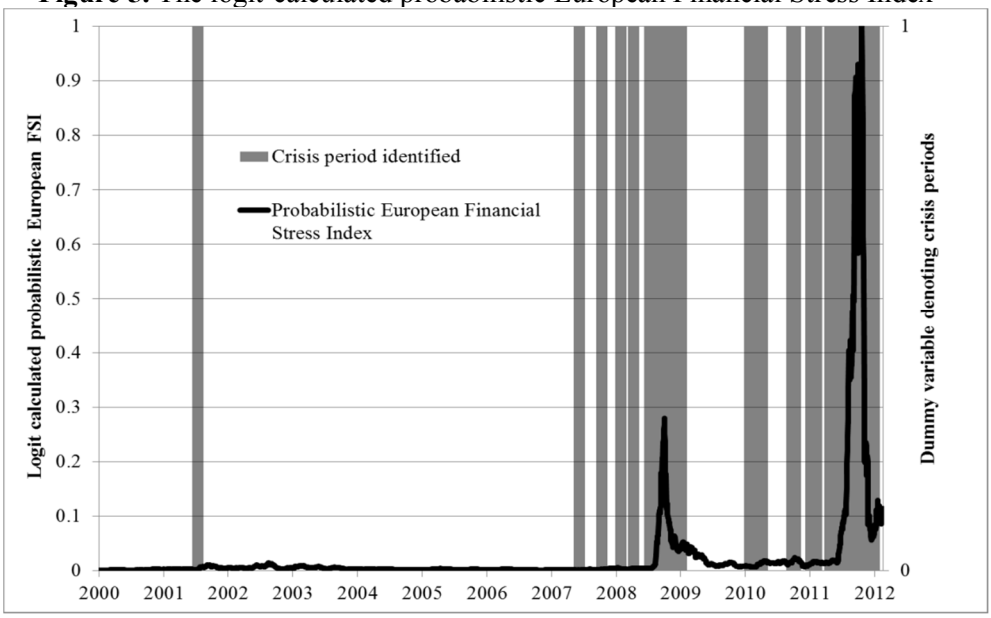
Note: The above figure represents the logit calculated weighted-sum European FSI. The grey regions represent the periods of crisis as identified by the imposed dummy variables that are described in table A2 in appendix.

As we use a logistic framework to derive the coefficients, it is also natural to express the financial index as a probability of being in a period of stress, which is shown in figure 5 and is estimated as:

$$p_{prob} = \frac{e^{(\beta_0 + p_{logit})}}{1 + e^{(\beta_0 + p_{logit})}} \qquad (2)$$

It must be made clear, that the sense in which this index is expressing a probability is limited to the context of identifying current market conditions. The statistic in figure 5 is based on probability that European financial markets are currently experiencing conditions identical to those identified in periods of extreme financial stress. The ECB and internal central banks would have data in real-time frequency, thus would be in a much stronger position to advise on Europe's current position. This index should be thought of as a statistical measure of the similarity between current European conditions and those that have prevailed already at a time of crisis.

Figure 5. The logit-calculated probabilistic European Financial Stress Index



Note: The above figure represents the logit calculated probabilistic European FSI. The grey regions represent the periods of crisis as identified by the imposed dummy variables that are described in table A2 in appendix. It is accurate to describe the black line as the probability that Europe is in full-crisis as determined by the included financial markets.

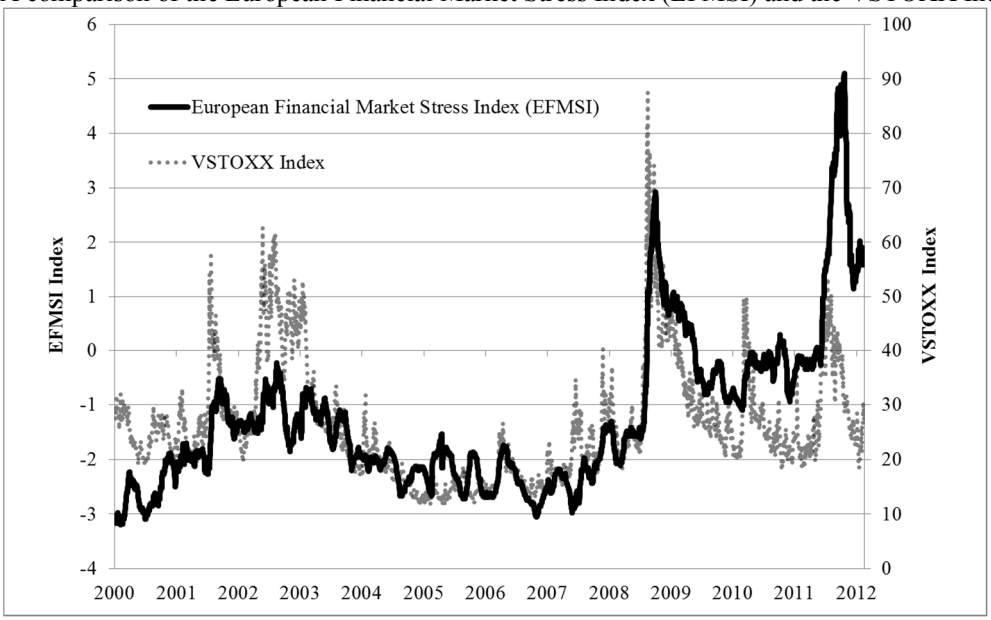
4. Comparison of the EFMSI to other stress metrics and some underlying issues

European financial market stress has primarily been identified through equity indices, currency and exotic derivative values since establishment. The creation of exotic products in European markets such as futures, options, swaps and swaptions all possess significant explanatory power towards the future expectations of investors for European markets. The EFSMI aims at using the underlying trends of these components on which to base the logistical framework and crisis identifying methodology. In figure 1, we saw that the EFMSI adequately represented the trends of the benchmark Eurostoxx 50 (with a correlation of -0.68).We must now ask, how has the EFMSI compared to other metrics of European financial market stress and indeed what additional informational benefits does it add?

One of the major European financial market stress metrics has been identified as the VSTOXX index, which is based on Eurostoxx 50 real-time options prices and is designed specifically to reflect the market expectations of near to long-term expectations of volatility, by measuring the square root of the implied variance across all options of a given time to expiry. The index used in this comparison is based on the average of all timespans for which the VSTOXX is available. This comparison is viewed in figure 6. When comparing the indices, there is a positive correlation (+0.55); with the trends of both taking the same direction, but one obvious benefit of the EFMSI is the depth, or comparability of crises that isn't included in the VSTOXX index. The initial stages of crisis appear to shock the market, leading to large reactions, but after time die out as the markets expectations adapt.

Alternatively, the EFMSI compares the depth of the crisis in its memory ('learning process'), thus ranking and scaling the events with one another, providing more conclusive evidence and informational benefits than the available market metrics. In further investigations, the EFMSI had a correlation of +0.22 with the EUR/USD and a correlation of -0.63 with the Datastream European bank index, which was used to denote the European banking collapse since 2007.

Figure 6. A comparison of the European Financial Market Stress Index (EFMSI) and the VSTOXX Index



Note: The above figure compares the EFMSI calculated in this paper with the VSTOXX Index which is a measure of option implied expectations of future volatility in European equity markets.

The updating of the EFMSI also represented issues based on the youth of the markets selected, thus providing a very short investigation window. If there had been minimal crisis since 1999, the EFMSI would be portrayed as a highly volatile index with minimal information outside the scope of 'market noise'. The historical elements attached to the methodology will change over time as new information arrives. The longer the time sample for which the model is based, the more confidence we can have in this methodology.

It must also be noted that there are also some issues associated with the relative simplicity associated with the denotion of crises periods. There have been issues of spectacular short-term deviations in trading 'normality' such as the 'flash crash[1]' that are not included in this methodology. Though United States-specific in origin, this trading anomaly had a substantial impact on European markets, along with other similar events. Further research is needed on this area, but this indicator seems fit to agree with Carlson, Lewis and Nelson (2012) on their defining methodology of when the markets are 'in crises'.

5. Predicting Future Stress and the Use of the EFMSI as a Policy Tool

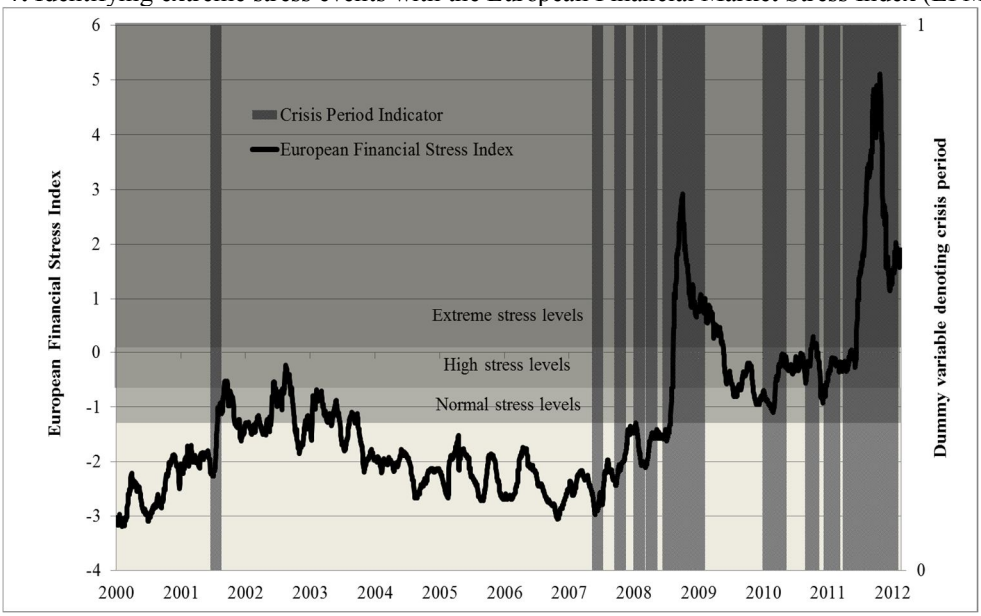
Though the stress index created in this paper primarily represents the strength of stress levels in Europe given previous experiences, it is possible to segregate the previously denoted crisis events to identify boundaries, that when breached, represent comparable stress levels of previous events. Possessing a measure of stress in financial markets and techniques enabling early identification of difficulties can significantly enhance policymakers' ability to take action to alleviate oncoming difficulties. This index offers a comparison of market identified stress which is comparable to previous crisis events, where a single event wreaked havoc in international financial markets, or indeed, when the ECB or took specific action due to the identification or presence of a crisis. Specifically

[1] The Flash Crash which occurred on May 6th 2010, was a United States stock market crash in which the Dow Jones International Average plunged 1,000 points (about 9%) only to recover the losses within minutes. Numerous government reports have identified a large sale of S&P 500 contracts and high-frequency traders (including algorithm traders) as the cause for the spiral, combined with increased negative sentiment.

investigating the average of the standard deviation of the stress index in periods denoted as crisis events and those otherwise seen as normality, it is possible to segregate the present values of the index to denote present European conditions. One caveat is that this methodology is subject to rapid change based on the presence of extreme outlier events and further market events that are identified as being in crisis. The index itself is therefore dynamic, based on additional crisis events and prolonged periods in extreme-stress and non-stress regions that also manipulate the resulting boundary calculations.

In figure 7, we can see the segregation of the index. In periods denoted as 'in crisis' in the calculation of the stress index, the indicator was an average of 0.03 standard deviations from the mean. Anything above this level is therefore representative of an extreme stress event and is denoted in dark grey. We can see that the international crisis environment of 2008 breached this threshold along with the sovereign debt crisis of 2011 and 2012 in Europe. The indicator appears to be accurately representing periods of crisis and adapting the same events as extremely stressful on financial markets.

Figure 7. Identifying extreme stress events with the European Financial Market Stress Index (EFMSI)



Note: The above figure represents the segregated average standard deviations from the mean level of stress during the identified periods of crisis in Europe. The shaded horizontal regions represent the identified strength of the stress levels. The vertical shaded regions represent the identified crisis periods.

The lower bands are based on the average standard deviations away from mean stress levels as denoted though the methodology. In the sample from 2000-2012, for periods denoted as not being in crisis, the indicator is 1.23 standard deviations below the mean, therefore anything below this level is viewed as not creating financial market stress. Based on the results, European financial markets have not witnessed a period of relative calm since Q2 2008, and most interestingly, have not witnessed levels of stress not denoted as extreme since Q2 2011. This corresponds directly to the on-going sovereign debt problems in Europe. The IMF interventions of both Greece and Ireland are clearly represented by spikes in the index in May and November 2010 respectively. The levels between extreme events and non-stress are simply averaged to create two further regions denoting high stress levels and normal stress levels. Segregation in this manner represents a comparable level of current stress in European financial markets based on previously experienced crises.

6. Conclusions

This paper constructs and develops a financial stress index based on European financial markets. This is achieved through the incorporation of twenty-three European financial metrics across equities, bonds and currencies. A logistic regression framework is used to adapt and identify crisis-denoted periods, identified specifically as a month before and after European Central Bank (ECB) market intervention. The index is found to adapt based on previous experience, thus possessing 'learning' characteristics.

The developed stress index compares well with international and European-specific measures widely associated with crisis identification. The structure of the European stress index enables the identification of crisis behaviour within the included components. The addition of rule based crisis thresholds and the immediate availability of crisis signals provide desirable characteristics supporting use of the European stress index by policymakers for crisis identification.

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APPENDIX

Table A1: *Individual components comprising the European stress indicator*

Component	Description	Measurement Aim	Notes
1	Spread between ECB financing rate and the yield on 3 month EURIBOR	Liquidity	This component acts as a measure of liquidity between the ECB offered rate and the quoted short term benchmark interbank euro lending rates. An increase in this spread is indicative of reduced credit facilities for the European banking sector along with higher perceived risk.
2	Short-term liquidity: Spread between EONIA and 1 month EURIBOR	Liquidity	This spread acts as a barometer of short term liquidity as the spread indicates the perceived risk of interbank lending. In affluent periods, the spread will be minimal when the overnight rate is close to the official policy rates.
3	Medium-term liquidity: Spread between EONIA and 3 month EURIBOR	Liquidity	This spread acts as a barometer of medium term liquidity as the spread indicates the perceived risk of interbank lending.
4	Currency crisis: ratio of current price relative to previous 365 day peak for EUR/USD, EUR/CHF, EUR/JPY and EUR/GBP*	Liquidity	A trade-weighted Euro denominated basket is created and analysed to measure flights from the euro to other main international currencies. This signals increased demand for liquidity from the European financial system.
5	Interbank liquidity spread: spread between 3 month LIBOR and 3 month EURIBOR	Liquidity	This spread reflects the perception of counterparty risk in interbank lending by measuring the risk premium associated with lending to commercial banks. The spread increases when either market liquidity is scarce or when counterparty default risk increases, either of which are associated with increasing financial stress.
6	Interbank cost of borrowing: spread between 3 month LIBOR and 10 year German BUND**	Liquidity	This spread is similar to the above interbank liquidity spread and can be used as a measure of counterparty risk. The interbank cost of borrowing measures the difference between the three month LIBOR and the benchmark German bund.
7	Spread between yields of AAA European Corporate Bonds and 10 year German BUND	Risk Spread	This spread is indicative of high-end corporate risk as when the likelihood of losses increases, firms have reduced ability to easily financing debt and may be less likely to obtain liquidity. High-end corporates are included due to the use of high grade credit agency denoted ratings.
8	Spread between yields of BBB European Corporate Bonds and 10 year German BUND	Risk Spread	This spread is indicative of medium corporate risk as when the likelihood of losses increases, firms have reduced ability to easily financing debt and may be less likely to obtain liquidity. Medium risk corporates are included due to the use of credit agency denoted ratings at the point of segregation between investment and junk grade status.
9	Spread between yields of high yielding European Corporate Bonds and 10 year German BUND	Risk Spread	This spread is indicative of long-term corporate risk on the most high-yielding European corporates, indicative of added sovereign comparative stress in the most risky corporates.
10	Spread between yields of 10 year+ (long-term) European Corporate Bonds and 10 year German BUND	Risk Spread	This spread is indicative of long-term corporate risk as when the likelihood of losses increases, firms have reduced ability to easily financing debt and may be less likely to obtain liquidity.
11	Spread between 3 month EURIBOR and 3 month US Treasury-bill	Risk Spread	This spread is indicative of the covered interest spread and specifically contains information about uncertainty in government bond markets between Europe and the United States. A widening spread displays investor aversion to hold a government's debt.
12	Spread between 3 month EONIA futures and 3 month EURIBOR	Risk Spread	This spread captures the short-term risk premium on financial companies' debt and a widening spread signals increases in the underlying risk of financial companies' operations.

Notes: The data for the above set of stress indicator components was taken from Bloomberg and Thompson Reuters Datastream. *A trade-weighted methodology is applied to averaging the basket of main European trading counterparties. **The German 10 year Bund is seen as representative of the benchmark European-wide bond and is used based on the absence of a suitable European-wide candidate.

Table A1: *Individual components comprising the European stress indicator (continued)*

Component	Description	Measurement Aim	Notes
13	Spread between average European sovereign 10 year yield and benchmarked-German 10 year BUND	Risk Spread	This spread focuses specifically on the sovereign element of the European bond market and uses an average of the main European countries over the benchmark German 10 year bund. This component is designed to uncover risk specifically generated by investor perceptions of the financial health of the European system of sovereign states.
14	Spread between 3 month EURIBOR and German 10 year BUND	Investor Uncertainty	This spread represents the European-specific yield curve and is a useful predictor of economic recessions and real economic activity. The slope captures the combination of long-term uncertainty and short-term liquidity needed at the outset of, and during, recessionary times.
15	Equity crash index: ratio of current price of the Eurostoxx relative to previous 365 day peak	Investor Uncertainty	In a similar manner to the Cleveland Federal Reserve Financial Stress Index, the present value of the Eurostoxx is used as the ratio of its previous 365 day peak to capture the extent to which values have dropped in the previous year. This contains information on expectations about the future conditions of European equity markets.
16	German 10 year BUND implied volatility	Investor Uncertainty	This indicator measures the implied variance of the European-benchmark German ten year bund and is deemed as representative of headline European bond-volatility.
17	VSTOXX Eurostoxx volatility index	Investor Uncertainty	The VSTOXX index is based on the EUROSTOXX 50 real-time option prices. It is designed to represent the market expectations of near-term up to long-term volatility by measuring the square root of implied variance across all options of a given time of expiration.
18	Ratio of Eurostoxx financials index relative to Eurostoxx index relative to the ratio of the spot values of each, relative to their previous 365 day highs	Investor Uncertainty	This component is representative of the financial beta and is measured as the volatility of share prices in the banking sector relative to the overall stock market. This measures potential insolvency and a strain on bank profitability, relative to broader institutions.
19	Equity risk premium: Spread between Eurostoxx returns and German 10 year BUND returns	Investor Uncertainty	This component uncovers the European-specific excess return that the Eurostoxx provides over the risk-free rate, which is denoted as the German 10 year bund. This excess return is viewed as compensation for investors accepting perceived higher risk on European equities than that of the perceived lower-risk bond markets.
20	Eurostoxx index of earnings per share (EPS) as expected and announced	Investor Uncertainty	The EUROSTOXX EPS index comprises the main earnings of the index and is indicative of the financial health of the constituent European corporates included.
21	EURIBOR futures implied volatility	Investor Uncertainty	This component is representative of the volatility of expectations of the short-term futures value of EONIA, which is indicative of financial market expectations.
22	Short-term European swap volatility: 1 year forward 1 year swaption implied volatility (euro vs EURIBOR)	Investor Uncertainty	This component measures the short-term European volatility indicated by an increasing value of the EURIBOR swaption with a one year strike price against the euro. Swaptions, from the viewpoint of the payer, increase in value based on the volatility of the underlying swap rate.
23	Long-term European swap volatility: 1 year forward 10 year swaption implied volatility (euro vs EURIBOR)	Investor Uncertainty	This component measures the long-term European volatility indicated by an increasing value of the EURIBOR swaption with a ten year strike price against the euro. The ten year horizon is associated with a large premium, but this is minimised through the use of the standardisation process, thus the component is measured in standard deviations from its own long-term mean.

Notes: The data for the above set of stress indicator components was taken from Bloomberg and Thompson Reuters Datastream. *A trade-weighted methodology is applied to averaging the basket of main European trading counterparties. **The German 10 year Bund is seen as representative of the benchmark European-wide bond and is used based on the absence of a suitable European-wide candidate.

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Table A2: *Headline European crisis events and actions by the European Central Bank (ECB)*

Date	European crisis event
September 11th 2001	International action taken to stem panic caused by the terrorist attacks of 9/11*
August 9th 2007	Liquidity shortages worldwide as interbank lending slows down
December 12th 2007	International central banks issue intentions to intervene to ease pressures in short-term funding markets
March 28th 2008	ECB offers refinancing operations with longer maturities
July 8th 2008	ECB increases interest rates by 25 basis points
September 15th 2008	Lehman Brothers files for bankruptcy
October 15th 2008	ECB facilitates access to refinancing
November 6th 2008	ECB cuts interest rates by 25 basis points (Crisis alleviation)
December 4th 2008	ECB cuts interest rates by 75 basis points (Crisis alleviation)
January 15th 2009	ECB cuts interest rates by 50 basis points (Crisis alleviation)
March 5th 2009	ECB cuts interest rates by 50 basis points (Crisis alleviation)
April 2nd 2009	ECB cuts interest rates by 25 basis points (Crisis alleviation)
May 7th 2009	ECB cuts interest rates by 25 basis points (Crisis alleviation)
June 4th 2009	ECB announces first covered bond programmes
March 25th 2010	EU offers support to Greece
April 23rd 2010	Greece seeks financial support
May 2nd 2010	Greece loan package agreed
June 7th 2010	European Financial Stability Facility is established
November 21st 2010	Ireland seeks financial support
December 7th 2010	EU/IMF package agreed for Ireland
March 3rd 2011	ECB announced details of refinancing programmes
March 11th 2011	Euro area leaders agree on 'Pact for the Euro'
April 6th 2011	Portugal requests activation of aid mechanism
April 7th 2011	ECB raises interest rates by 25 basis points (Inflationary fears)
June 23rd 2011	European Financial Stability Facility boosted
July 7th 2011	ECB raises interest rates by 25 basis points (Inflationary fears)
August 4th 2011	ECB announces details on refinancing operations
October 6th 2011	ECB announces second covered bond purchase programme
November 3rd 2011	ECB cuts interest rates by 25 basis points (Crisis alleviation)
December 8th 2011	ECB cuts interest rates by 25 basis points (Crisis alleviation)
December 22nd 2011	ECB allots €489 billion to 523 banks in the 1st 36-month longer-term refinancing operation
February 21st 2012	Eurogroup agrees on second financial aid package for Greece
February 28th 2012	ECB temporarily suspends Greek debt as collateral (28th Feb – 8th Mar)
March 1st 2012	ECB allocates €530 billion to 800 banks in the 2nd 36-month longer-term refinancing operation

Note: This list contains the primary crisis events that have engulfed the Eurozone since 2000 as stated on the European Central Bank website at www.ecb.int. The events listed above based on ECB interaction are of primary interest based on the implementation of the associated event primarily because of fears of an oncoming crisis event. There are minimal international events included in this list due to attempts to keep this index European-specific. Only the most extreme international 'stress' events are included based on the authors' judgement. *In a similar manner to Carlson, Lewis and Nelson (2012), the four week period prior to the terrorist attacks of 9/11 are not included as a building phase as it cannot be declared that it was 'foreseen' by international financial markets.