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Composite Indicator of Financial Stress for Portugal¹

José Pedro Braga, Inês Pereira and Teresa Balcão Reis²

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Abstract

This paper proposes a Composite Indicator of Financial Stress for Portugal (ICSF). Since financial stress can have a vast impact in the real economy, monitoring and measuring the level of stress can contribute to formulate appropriate policy measures. Similar to Holló et al. (2012), the construction of the ICSF involves the aggregation of five subindices from the money market, bond market, equity market, financial intermediaries and foreign exchange market into a composite indicator, using portfolio theory (where the subindices aggregation reflects their time-varying cross-correlation structure). The article shows that the ICSF identifies and measures adequately the most relevant stress events that affected the Portuguese financial markets since 1999, showing a clear divergence in some moments from euro area composite stress indicators.

Keywords: Financial stability, Financial stress, Financial stress indicator, Financial crisis, Portfolio theory.

JEL Classifications: G01, G10, G20, E44

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² Banco de Portugal (Markets and Reserve Management Department). E-mail addresses: jpsbraga@bportugal.pt, ijpereira@bportugal.pt, mtbreis@bportugal.pt

1. Introduction

The recent crisis in international financial markets has shown how widespread the effects of financial instability can be and, in particular, how financial instability can affect the real economy and the standards of living of the population. This crisis has also highlighted that the instruments previously available for monitoring and controlling financial instability were no longer appropriate. Against this background, a vast literature on how to identify, measure and monitor financial stress was produced and several indicators of financial stress were developed.

The main goal of this paper is to develop a Composite Indicator of Financial Stress for Portugal. That indicator should be able to identify the specificities of the Portuguese markets, in spite of their high degree of integration within the European financial markets.

In section 2, we try to identify what financial stress is and why it is important to measure it, highlighting the consequences of financial instability on economic growth. In section 3, a brief review of the literature on financial stress indices construction is provided. Section 4 describes the computation of the Composite Indicator of Financial Stress for Portugal (ICSF). Following Holló et al. (2012) methodology, the development of the ICSF involves the aggregation of several indicators from five market segments commonly identified as the most important (namely, money market, bond market, equity market, financial intermediaries and foreign exchange market). Its main methodological innovation is the application of standard portfolio theory to the aggregation into the composite indicator (where the subindices are aggregated on the basis of weights which reflect their time-varying cross-correlation structure). This section ends with an assessment of the ICSF's robustness properties. In section 5, an analysis of the ICSF performance is done, both in terms of its ability to identify well-known periods of financial stress in Portugal, and in terms of its usefulness to give indications about future developments in the Portuguese GDP. Some Granger causality tests between the subindices are also produced. Section 6 concludes.

2. Definition and measurement of financial stress

The recent crisis in international financial markets has highlighted the relevance of understanding, monitoring and measuring financial stress. The financial crisis that begun in 2008 soon became an economic crisis, with huge impact in the world economy and in the standard of living of a large portion of the world population. It was therefore a perfect example of how financial instability can easily lead to macroeconomic instability.

Measuring and monitoring financial stress is essential because it can contribute to formulate and put into practice suitable macroeconomic policies. According to vast literature, the recent crises showed that the existing frameworks for monitoring financial stress were not suitable for the present features of financial markets. Quoting Cevik et al. (2013), "While in normal times, the standard evaluation of macroeconomic prospects [...] is adequate and there are useful policy benchmark rules [...], heightened periods of financial stress may call for policy responses that are different than the usual prescriptions". Therefore, policy makers need tools that help them evaluate in which state they are. Looking further down the road, several authors (e.g. Hakkio and Keeton, 2009) suggest that measuring financial stress is also very

relevant when defining monetary policy exit strategies. Adding to the monitoring of the traditional variables (business and consumer activity, prices and wages), monetary authorities should also make sure that the level of stress is lower than the level that could jeopardize the economic recovery. Furthermore, monitoring and measuring financial stress can give important insights about the financial conditions and fragility or strength of the financial sector, which is very relevant for a supervisor body.

Although no single definition of financial stress exists, there is a consensus that i) it is an interruption of the normal or typical functioning of financial markets, ii) it is a multidimensional phenomenon and iii) it has an impact on the real economy, namely if financial stress is above some levels and/or if it lasts for a too long period of time. Some authors, giving particularly focus to potential concerns for the financial health of the banking system (e.g. Balakrishnan et al., 2011), define financial stress as periods of impaired financial intermediation.

Trying to evaluate a multidimensional phenomenon is hard. Several sub-markets of the international financial markets have to be monitored and, if sometimes they all show increasing instability, often they develop in distinct directions. There are also many ways for stress to manifest itself. According to Hakkio and Keeton (2009) in periods of stress some phenomena often take place: i) increased uncertainty about fundamental value of assets, ii) increased uncertainty about behavior of other investors, iii) increased asymmetry of information, iv) flight to quality, v) flight to liquidity.

It is through these channels that instability leads to macroeconomic disruptions. Financial stress is always a synonym of instability and instability generates the type of uncertainties mentioned before. Against this background, postponing economic decisions (buying or selling assets, investments, hiring, consumptions expenses, etc) is usually optimal, leading to a reduction in economic activity (Davig and Hakkio, 2010). Similarly movements of flight to quality (when only top rated investors are able to fund themselves at economically efficient prices, while lower rated investors can only find funds at very high prices or became totally unable to fund themselves) or flight to liquidity make the transmission of funds from savers to borrowers to become more complicated, and economic mechanisms become less efficient leading to lower growth.

To properly monitor financial stress it is necessary to measure it. Financial stress cannot be measured directly. However, as stated before, the literature suggests that periods of financial stress can be identified by the observation of several phenomena and these translate into “symptoms” (such as, e.g., higher asset price volatility, large asset valuation losses, increasing liquidity and risk premiums) that can be reasonably well measured by financial market indicators (Holló et al., 2012). The following step is to aggregate all this different variables in a composite indicator that can more easily be monitored.

Previously, literature on financial stress used mainly binary measures (markets were either in a crisis or in a normal state). In recent years this concept evolved and a clear preference is given to continuous measures. These latter have several significant advantages. First of all they allow comparisons and ranking between different past episodes of stress. They also allow the identification of periods of high levels of financial stress, that are relevant, but that for some reason didn’t turn into a crisis episode. At the same time, it is also important to measure the

rhythm of increasing or decreasing financial stress because it can provide some insight into the probability of being in a phase of entering or leaving a crisis episode.

3. Literature review

The measurement of financial conditions has been a focus of research studies for a long period. Early works have looked at the slope of the yield curve and its use as a reliable predictor of economic activity and inflation (Estrella and Hardouvelis, 1991; Stock and Watson, 1989; Miskin, 1988). Those papers aimed at showing that the analysis of the term structure had a higher predictive power than a set of economic and financial indicators such as simple short term interest rates. Credit risk measures, such as the spread between private and public debt, have also been used as a leading indicator for economic conditions since late 1980 (Friedman and Kuttner, 1992; Stock and Watson, 1989) with good forecasting power. Finally, simple stock market indicators also have been found to have useful information regarding economic performance.

Monetary conditions indices (MCIs) constituted a natural extension to those early works. Originally, MCIs consisted of weighted averages of an official (or short term) interest rate and the exchange rate, with the assign weights depending on the relative importance of internal and external demand on GDP. The Bank of Canada initiated this kind of analysis (Freedman, 1994), with the exchange rate assuming a weight of around one third of the weight of the refinancing rate, given that Canada is a relatively open economy. In the case of more closed economies, the relative weight of the exchange rate was lower. This kind of indicator was also produced for Portugal (Esteves, 2003), using the effective exchange rate for the escudo and the 3 month money market rate. Interest rates seemed to be more effective in explaining the short-run dynamics in GDP whereas the exchange rate plays a major role in the inflation behavior.

With the broad use of MCIs in a growing number of countries the scope of variables considered was gradually augmented with the new indices labeled Financial Stress Indices (FSIs) or Financial Conditions Indices (FCIs). Although their name are sometimes used interchangeably, FSIs focus solely on financial variables (that could be expressed in levels, spreads, correlation or volatilities) while FCIs tend to use both financial and nonfinancial variables to measure financial instability. For a more detail analysis on the differences between the two types of indices see Kliensen et al. (2012).

When creating an FSI the emphasis is put on assuring that it includes a selection of variables that reflect stress conditions in all dimensions of the financial system. Usually, the variables considered in these indices encompass different sets of short term/official interest rates, long term interest rates, term premia indicators, risk premia indicators, equity markets, liquidity premia, among others. In the case of FCIs, some fundamental indicators (money indicators, housing, credit, debt, inflation, oil prices,...) are added. The importance of having a long time series in order to better test the relationship between stress and economic conditions during several business cycles lead to the exclusion from most indices of more recent financial instruments, such as derivatives. The notion of an ideal number of indicators is nonexistent throughout the literature, with most authors focusing on a more parsimonious approach while others include a very large array of indicators. Among the latter it is worth mentioning the

Chicago Fed's National Financial Conditions Index (Following Brave and Butters, 2011) which uses a set of 100 financial indicators.

The frequency of the variables used in an FSI is also an important aspect, with an inevitable trade-off between the use of lower and higher frequency data. Higher frequency data (usually daily and weekly FSI) have the advantage of being able to more quickly identify potential stressful situations, which could also allow a faster reaction by policymakers to these new developments. However, using such high frequency data would normally lead to higher volatility in the FSI and an increase probability of capturing false stress events signals. The use of lower frequency data (monthly and quarterly) would reduce such false signals but would make its use more challenging as a monitoring/signaling tool. Also, the use of lower frequency data will mean a shorter sample for the FSI, making it more difficult to define the threshold for a stress event.

Once the data is selected it is necessary to convert the different indicators into a single index, making it easier to access the different levels of stress. However, it is necessary, before hand, to convert the data to a common unit. The most common method is to standardize each variable by subtracting its sample mean and then divide it by its standard deviation. Another approach is to transform the variables into percentiles based on their sample cumulative distribution function (CDF). The first percentile will have the smallest values, which correspond to the lowest level of stress, while high levels of stress will be on the highest percentiles. Again all variables will be on the same scale.

After the data is converted into a common unit, there are also several methods of aggregation. One method is a variance-equal weighting, where the index gives equal importance to each variable. Another approach is to weight each variable by the size of the market to which it belongs (credit weight). The larger the share of the market in the economy, the bigger the weight given to the variable used as a proxy of the stress in that specific market segment (Oet et al., 2011). Regression based weights can also be constructed, by regressing the variables on a dependent variable, usually a measure of output growth. In this method, an increase in stress is also more directly correlated to a change in GDP growth. Another approach is the use of Principal Component Analysis (PCA). In these cases, it is assumed that each variable used for the construction of the FSI captures some dimension of financial stress. Therefore, there is a common factor, which is assumed to be financial stress, that will be able to explain the comovement in the selected variables. This common factor is the first principal component and will be the FSI (Illing and Liu, 2006; Hakkio and Keeton, 2009; Brave and Butters, 2011). Another approach is the use of logistic regressions. In this case, the FSI is computed as the fitted probability from a logit model of the selected variables with a binary pre-defined crises indicator as the dependent variable (Nelson and Perli, 2007; Grimaldi, 2010). A more recent approach is the use of a portfolio theory based aggregation scheme which takes into account the correlation structure of the chosen stress indicators. The weights assign to each variable are dynamic, adjusting to the different situations in the markets (Holló et al., 2012; Louzis and Vouldis, 2011). For a more detail analysis on the differences methods of aggregation and a comparison between them see Illing and Liu (2006) and Kliensen et al. (2012).

Finally, it is worth mentioning that an FSI has no natural observable counterparty in the real world (contrary, for instance, to indices representing economic activity that can be checked

against GDP) making it more challenging to validate its quality. The simplest way to do this validation is to compare the derived index with known events of financial market stress, checking if they coincide. Another option is to conduct a survey among market experts to identify stress situations and to construct a chronology of financial crises (Illing and Liu, 2006; Dimitrius, 2011). A final alternative is the construction of a financial stress series based on a given factor (for instance, specific actions from the authorities) and to use it as a comparison with the derived FSI (Grimaldi, 2010 and Carlson et al., 2012).

4. The Composite Indicator of Financial Stress for Portugal

A financial stress index tries to capture the functioning and fragilities of financial markets. As mentioned, the fragility in financial markets can be seen in different forms, such as increased uncertainty about the future value of asset prices, increased asymmetry of information, funding problems, increased difficulty in executing operations, flight to quality or flight to liquidity. All these are important signs of increased impairment in the financial markets.

At the same time, increase financial stress is usually seen in several different market segments. As in Holló et al. (2012), we consider five market segments that collectively represent the core of the financial system. The five segments are: the financial intermediaries sector; the bond market; the equity market; the money market and the foreign exchange market.

The ICSF is constructed as a three-tier aggregation framework. On the lower level, we have the selection of individual stress indicators. The aim of each indicator is to capture a different dimension of the market thus reflecting different aspects of financial stress. The intermediate level is where the individual indicators for each market segment are aggregated creating five different market segments subindices. This aggregation is done not on the selected raw indicators but on the transformed values of the indicators, already converted to a common unit for aggregation. The upper level is the aggregation of the five subindices into the final financial stress indicator, taking into account the time-varying cross-correlations between the different market segments as well as market segment specific weights, calibrated to their impact on the economic activity of Portugal.

4.1. Selected Stress Indicators (lower level)

There are several financial variables that can be used to measure financial stress. Those variables can also be expressed in several ways, such as volatilities, spreads or cumulative losses. For the construction of our index the list was narrowed down based on specific requirements:

1. The indicators should be the most representative possible for the Portuguese financial markets. Only when an alternative is unavailable, euro area wide indicators could be used, adjusted the best way possible to reflect Portuguese financial markets developments;
2. The indicators should represent market-wide developments, including information about the five selected market segments. For each market segment the same number of indicators should be selected, to assure that the subindices do not have different

statistical properties by construction. Each one of the five subindices was restricted to include three indicators, obtaining a total of 15 individual indicators of financial stress.

3. The indicators should give complementary information, being perfectly correlated under levels of extreme stress while at lower levels of stress some differentiation between indicators is to be expected;
4. The indicators should be available at a daily frequency with a publication lag of one day at the most. This will assure that the constructed index is able to measure financial stress in real time;
5. The indicators should have a long data history to comprise several episodes of financial stress. Given regime change that result from the start of the euro, the goal was set to have financial indicators starting at least since the beginning of 1999.

Taking such requirements into consideration and trying to take into account different sources of risk, indicators for each market segment were chosen.

Money Market indicators:

- Realized volatility of the 3-month Euribor rate; exponentially weighted moving average of daily rate changes, with smoothing parameter of 0.93.
- Interest rate spread between the 3-month Euribor, adjusted for Portuguese risk, and the average of German and French 3-month Treasury Bills.
- Portuguese monetary financial institutions' funding at the Eurosystem.

Bond Market indicators:

- Realized volatility of Portuguese 10-year benchmark government yields; exponentially weighted moving average of daily rate changes, with smoothing parameter of 0.93.
- Spread between Portuguese and German 10-year benchmark government yields.
- Spread between a non-financial corporation Iboxx yields index, adjusted for the average rating of Portugal's main non-financial corporations, and German 10-year benchmark government yields.

Equity Market indicators:

- Realized volatility of Portugal's non-financial sector stock market index; exponentially weighted moving average of daily rate changes, with smoothing parameter of 0.93.
- Maximum cumulated loss (CMAX) of Portugal's non-financial sector stock market index over a 2-year window.
- Difference between CMAX of Portugal's main stock market index and CMAX of Germany's main stock market index.

Financial Intermediaries indicators:

- Realized volatility of Portugal's financial sector stock market index; exponentially weighted moving average of daily rate changes, with smoothing parameter of 0.93.
- CMAX of Portugal's financial sector stock market index over a 2-year window.
- Spread between a financial corporation Iboxx yields index, adjusted for the average rating of Portugal's main financial corporations, and German 10-year benchmark government yields.

Foreign Exchange Market indicators:

- Realized volatility of euro exchange rate against the US dollar; exponentially weighted moving average of daily rate changes, with smoothing parameter of 0.93.
- Realized volatility of euro exchange rate against the Japanese yen; exponentially weighted moving average of daily rate changes with smoothing parameter of 0.93.
- CMAX of the nominal effective exchange rate index for Portugal over a 2-year window.

In the case of money markets, stress is captured by the volatility of 3-month Euribor rates that is used as a measure of market uncertainty. The volatility considered was the realized volatility of the indicator, computed using exponential weighting moving averages to give more importance to the most recent information. Stress is also captured by the difference between an unsecured interest rate, such as the Euribor, and a secured interest rate. Given that the Eurepo faces the risk of being discontinued due to the small number of contributors, the average of German and French treasury bills were chosen as a proxy for the euro area money market secured interest rate. This spread is used as a measure of liquidity and counterparty risk in the money markets. To better reflect Portuguese risk, the Euribor was adjusted by the differential between Portuguese 3 month treasury bills and an average of German and French 3 month treasury bills. Finally, increased tensions in money markets are also captured by the level of funding at the Eurosystem by Portuguese institutions. The Eurosystem acts as a lender of last resource, therefore increasing funding is associated with increasing levels of stress.

In the Bond market, the levels of volatility in the Portuguese 10 year benchmark government yields are used as a measure of investor's uncertainty. The spread between Portuguese and German 10-year benchmark government yields was also utilized, giving information about the credit quality of the Portuguese sovereign. This series would reflect potential flight to quality and flight to liquidity movements in the bond market away from the Portuguese debt. The use of CDS information, although initially considered, was excluded since data is not available since the start of 1999. Finally, the spread between a non-financial corporation Iboxx yields index and German 10-year benchmark government yields is a measure of stress in the non-financial private bond market. The Iboxx index was adjusted taking into account Portuguese non-financial corporation ratings in each period.

In equity markets the volatility of Portugal's non-financial sector index was used as a measure of uncertainty about the future value of assets. The maximum cumulated loss of Portugal's non-financial sector index over a 2 year period (CMAX) was utilized as a measure of risk aversion. This indicator gives an absolute measure of pressure in the equity market. Finally, stress in equity markets is also measured by comparing the CMAX of Portugal's main stock market index with the CMAX of German main stock market index, a relative measure of pressure in the equity market.

Analogously, in financial intermediaries the volatility of Portugal's financial sector stock market index captures the level of uncertainty and the CMAX of Portugal's financial sector stock market index over a 2-year period is used as a measure of risk aversion. Finally, the spread between financial corporation Iboxx yields index and German 10 year benchmark government yields is used as a proxy for credit risk in financial intermediaries. As with the non-financial corporate index, the financial corporation Iboxx index takes into account the Portuguese financial institutions ratings in each period.

Stress in foreign exchange markets is represented by the volatility of the two main crosses of the European currency, the EUR/USD and the EUR/JPY. Additionally, the CMAX over a 2 year period of the nominal effective exchange rate index of Portugal is also considered.

4.2. Aggregation of individual variables into market segment subindices (intermediate level)

The ICSF should be computed using indicators that are comparable and capable of being aggregated. Therefore, in order to aggregate the individual indicators they must be transformed into standardized measures. Similar to Holló et al. (2012), this paper utilized the empirical cumulative distribution function (CDF) to transform each individual indicator. From an original series $(x_1, x_2, \dots, x_n)$, the observations are sorted in ascending order $(x_{[1]}, x_{[2]}, \dots, x_{[n]})$, such that the observation $x_{[n]}$ corresponds to the maximum of the sample and the observation $x_{[1]}$ to the minimum, being $[r]$ the ranking number assigned to a particular realization of x_t . The transformed individual indicators z_t are then obtained based on the following cumulative distribution function $F_n(x_t)$:

$$z_t = F_n(x_t) = \begin{cases} \frac{r}{n} & \text{for } x_{[r]} \leq x_t < x_{[r+1]}, r = 1, 2, \dots, n-1 \\ 1 & \text{for } x_t \geq x_{[n]} \end{cases} \quad (1)$$

For $t=1, 2, \dots, n$. The empirical cumulative distribution function $F_n(x^*)$ measures the total number of observations x_t that did not exceed a particular value of x^* (which is equal to the corresponding ranking number r^*) divided by the total number of observations.

This transformation is applied to the 15 selected indicators, creating new series, all of them ranging between 0 and 1. This allows the series to be easily comparable and passable of being aggregated.

In order to ensure stability in identifying periods of stress, the transformation of the raw indicators described previously is recursively applied when expanding the sample data. By recursively we mean that every time we add a new observation, the transformation described before is applied, resulting in the recalculation of the ordered samples with one new observation added at a time. We add the new value to the transformed series that we already have, keeping all the previous history. The whole series is maintained, only a new value is added with each passing day. This recursion occurs only after the period 1999-2001, since a non-recursive transformation is initially applied to this initial period.

After computing this transformation, the arithmetic average of the three indicators belonging to each segment is calculated in order to obtain five subindices.

4.3. Aggregation of subindices into the composite indicator (top level)

Once the indicators are transformed and each one of the five subindices computed, these latter subindices are aggregated into the final composite indicator of financial stress. The process is based on the portfolio theory, with the aim of taking into account the time-varying cross-correlations between subindices. This would lead to setting a higher weight to periods in which financial stress occurs simultaneously in the various market segments.

In the aggregation procedure there are two steps. The first one is to estimate the relative importance of each of the five market segments, seeking to measure the impact that a shock in each segment will have on the real economy. To that end, a standard linear VAR model was

estimated, having as endogenous variables the Portuguese Gross Domestic Product year-on-year change and each of the five subindices. The model was estimated using quarterly data, with the series of each subindex being the quarterly average of the daily data. Once the VAR model was estimated, the cumulative 8-quarter impulse responses of Gross Domestic Product to a unit shock in each segment were calculated. Then, the weight associated with each subindex was determined by the subindex's share in the sum of cumulated impulse responses across the five subindices. This approach leads to the following subindices weights: money market: 24%, bond market: 18%, equity market: 22%, financial intermediaries: 25%, and foreign exchange market: 11%.

The second step consists in computing the matrix of time-varying cross-correlations coefficients between subindices. The correlation coefficients $\rho_{ij,t}$ are estimated recursively on the basis of exponentially-weighted moving average (EWMA) of respective covariance $\sigma_{ij,t}$ and volatilities $\sigma_{i,t}^2$ as approximated by the following formulas:

$$\sigma_{ij,t} = \lambda \sigma_{ij,t-1} + (1-\lambda) \hat{S}_{i,t} \hat{S}_{j,t} \quad (2)$$

$$\sigma_{i,t}^2 = \lambda \sigma_{i,t-1}^2 + (1-\lambda) \hat{S}_{i,t}^2 \quad (3)$$

$$\rho_{ij,t} = \sigma_{ij,t} / \sigma_{i,t} \sigma_{j,t} \quad (4)$$

where $i = 1, \dots, 5$, $j = 1, \dots, 5$, $i \neq j$, $t = 1, \dots, T$ with $\hat{S}_{i,t} = (S_{i,t} - 0,5)$ standing for the demeaned subindices obtained by subtracting their “theoretical” median of 0.5. The smoothing parameter λ is held constant through time at a level of 0.93, the same value used by Holló, et al. (2012). This parameter determines the speed of adjustment of the correlation among the subindices to the latest information, i.e., the higher the value of this parameter, the lower the weight given to the last observation (as can be seen in equations (2) and (3)), and more smoothed is the series. The first value of the covariance and volatilities (i.e. 4 January 1999) is the only one that was not calculated using EWMA.

As referred before, these correlations coefficients capture the systemic dimension of the level of stress in the financial system. This is one of the major gains of the adopted methodology. By taking into account the interrelationship between the different market segments, it is possible to assign more relevance to situations where the instability is manifested in several segments at the same time, when the tension is systemic and could have more prolonged and significant consequences.

Finally, the Composite Indicator of Financial Stress is computed as follows:

$$ICSF = (w^o s_t) C_t (w^o s_t)' \quad (5)$$

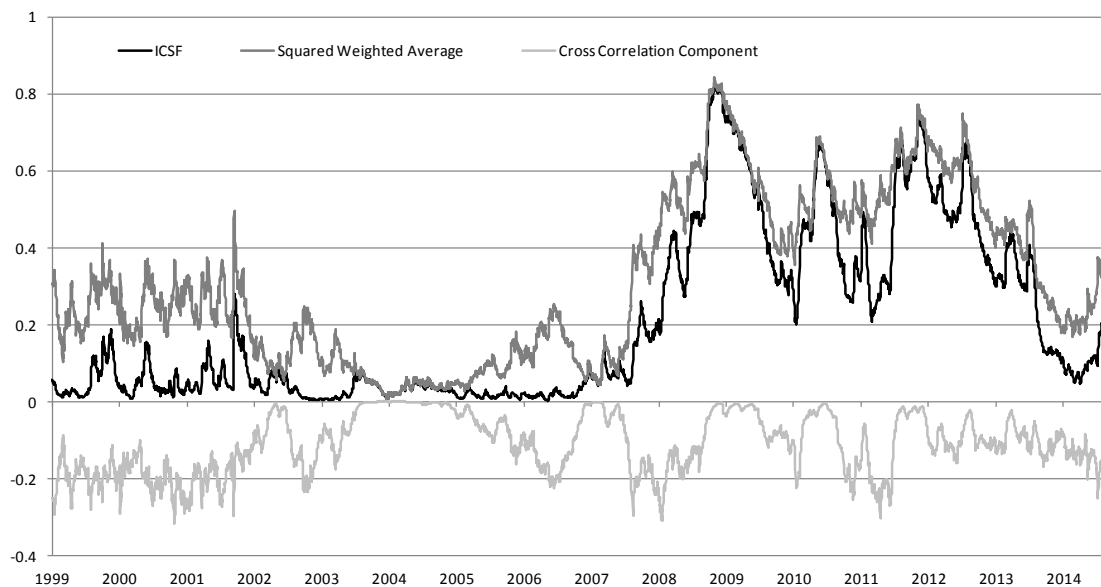
with $w = (w_1, w_2, w_3, w_4, w_5)$ the vector of constant subindex weights; $s_t = (s_{1t}, s_{2t}, s_{3t}, s_{4t}, s_{5t})$ the vector of subindices for all five segments; $w^o s_t$ the element by element multiplication of the vector of subindex weights and the vector of subindex values in time t ; and C_t is the matrix of time varying cross-correlation coefficients $\rho_{ij,t}$ between subindices i and j :

$$C_t = \begin{pmatrix} 1 & \rho_{12,t} & \rho_{13,t} & \rho_{14,t} & \rho_{15,t} \\ \rho_{12,t} & 1 & \rho_{23,t} & \rho_{24,t} & \rho_{25,t} \\ \rho_{13,t} & \rho_{23,t} & 1 & \rho_{34,t} & \rho_{35,t} \\ \rho_{14,t} & \rho_{24,t} & \rho_{34,t} & 1 & \rho_{45,t} \\ \rho_{15,t} & \rho_{25,t} & \rho_{35,t} & \rho_{45,t} & 1 \end{pmatrix} \quad (6)$$

4.4. Cross correlation component

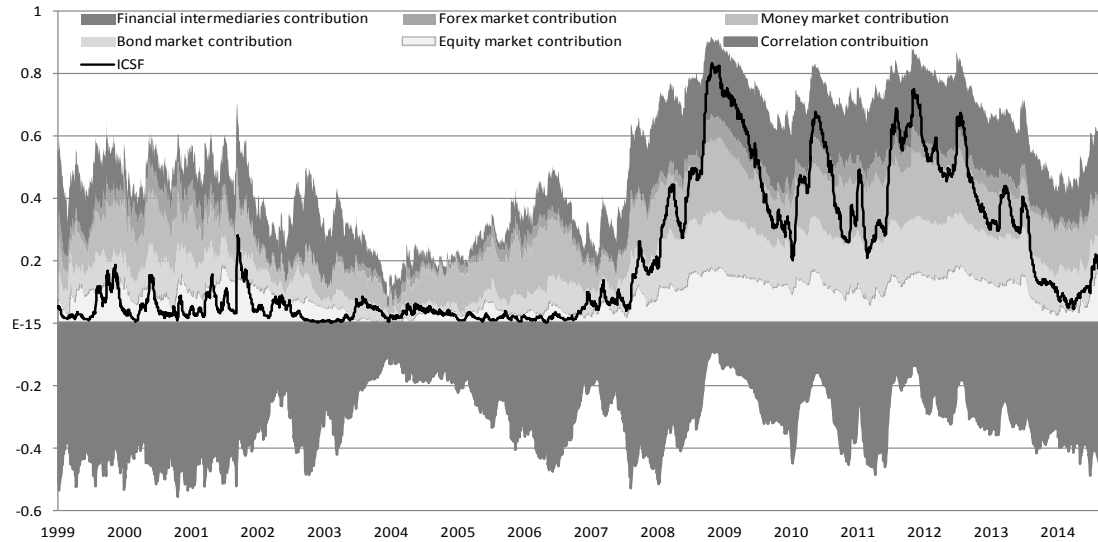
The methodology that is used to compute this composite indicator allows a direct identification of the cross correlation component of the ICSF. This component results from the difference between the ICSF obtained and the square of the weighted average of the five subindices (a special case where all the subindices are perfectly correlated). This latter case (when the indicator is obtained calculating the squared weighted average of the five subindices) implies a situation in which all subindices are improving or deteriorating at the same time. In both moments the cross correlation component will stand at high levels. Thus, the closer the ICSF is from the indicator computed using the squared weighted average of the five subindices, the bigger is that component (see Figure 1).

Figure 1 - ICSF, the squared weighted average of subindices and the cross correlation component



This analysis also enables decomposing the ICSF in its contributions from the different components: the correlation contribution component and each of the five subindices components (see Figure 2). It should be noted that in different episodes of instability, the cross correlation stress component and each of the five subindices components contributed differently to the variation of the ICSF.

Figure 2 - ICSF and contributions of its components

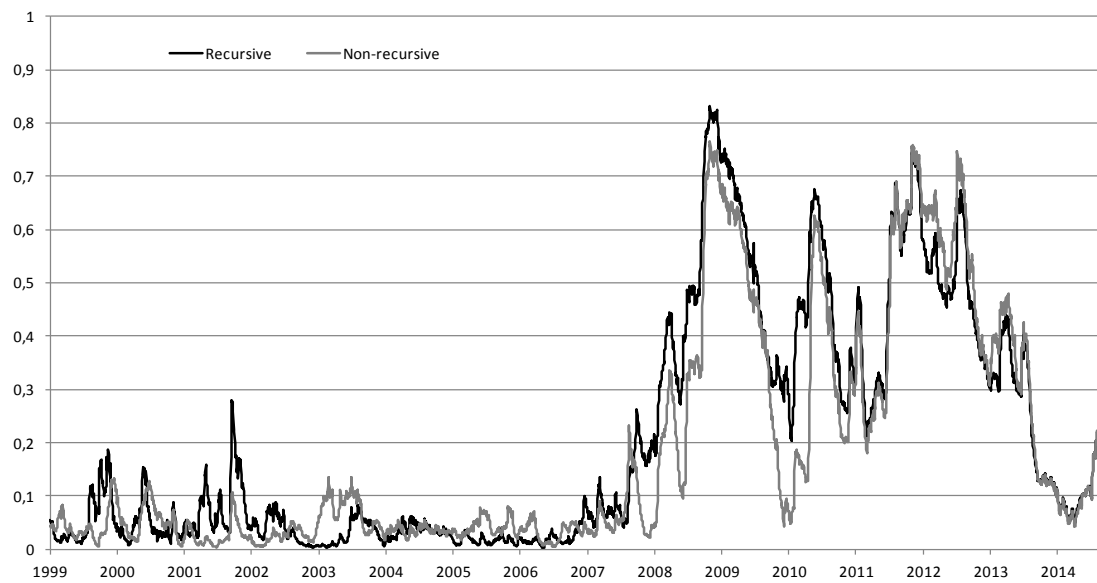


4.5. Robustness

One important characteristic of a stability indicator is that the results obtained should be stable over time under different methodological options. Thus, we attempt to evaluate the robustness of the presented composite indicator on several items: recursive vs non recursive method, different λ for the cross correlation adjustment speed and different weights for the subindices aggregation.

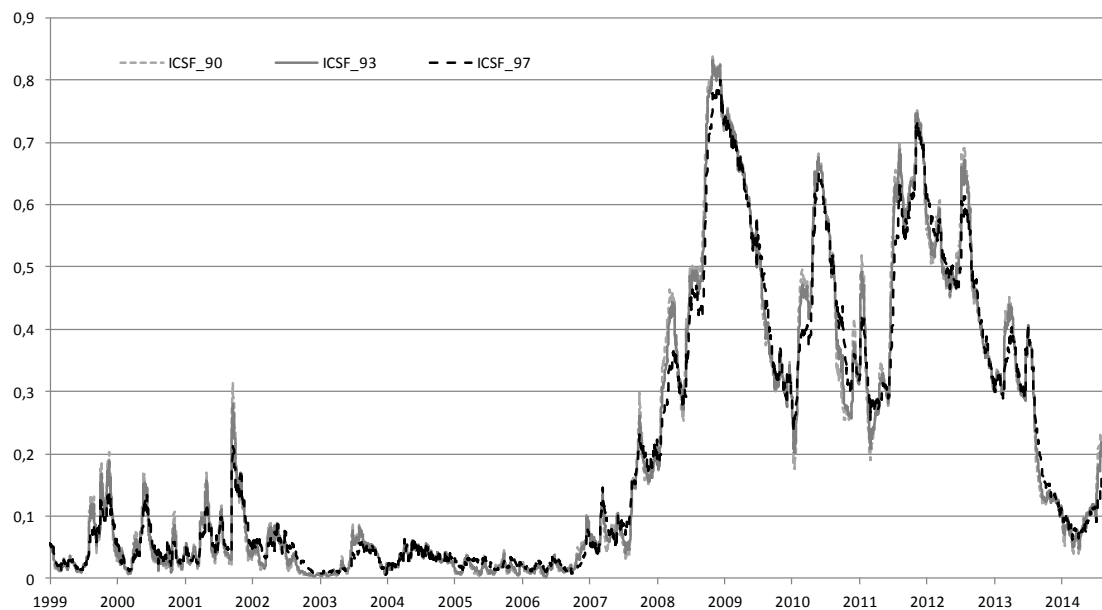
In the methodology used, the five subindices are calculated recursively (with the recursion starting in January 2002), which ensures the stability in the identification of the tension periods. The indicator calculated recursively has the ability to identify old events as relevant periods of tensions (even if in relative terms they have become less important stress events), while the indicator computed non-recursively tends to minimize them. However, when comparing the time series of the indicator computed recursively and non-recursively (computed only once using the full data sample) both series are very close, identifying the same stress events (see Figure 3), particularly in the case of more recent events.

Figure 3 - Recursive and non-recursive computation of the ICSF



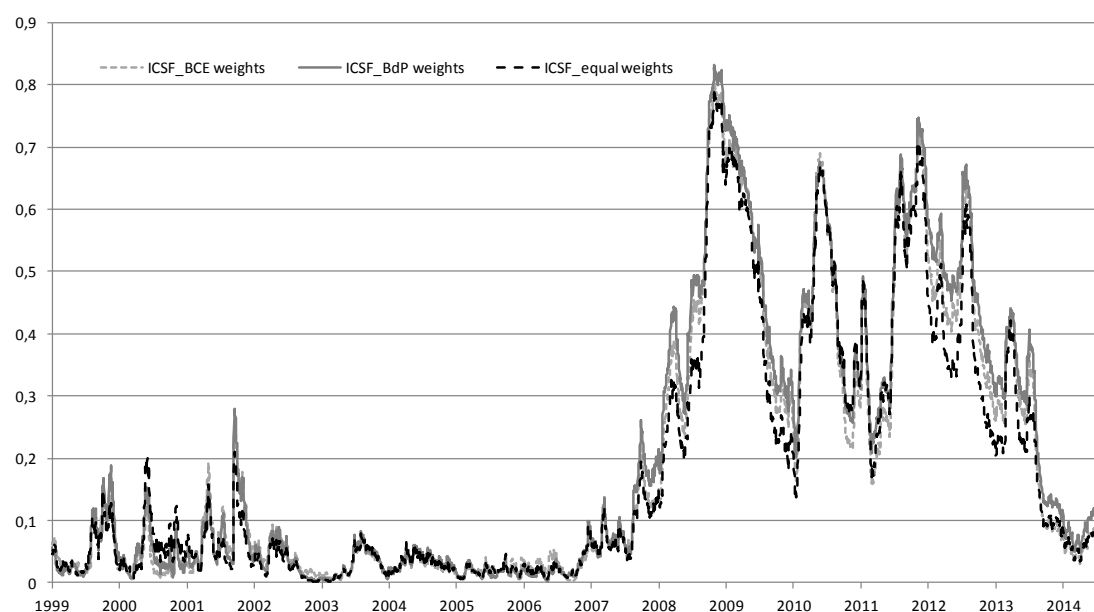
We also computed the composite indicator with different λ , the parameter that determines the adjustment speed of the estimated time-varying subindex cross-correlations to most recent information. Figure 4 shows three time series of the ICSF, each one calculated with a different smoothing parameter value. It is noticeable that the ICSF computed with a low parameter ($\lambda=0.90$) displays more spikes (more pronounced than when we use the chosen value $\lambda=0.93$), whereas when the parameter is set at a higher lever ($\lambda=0.97$) the movements in the ICSF are slightly smoother. However, the differences between the three time series are minimal, with the same stressed periods identified in all the series.

Figure 4 - ICSF for different values of the smoothing parameter lambda



A final robustness test was conducted by computing the indicator using different estimates for the weights associated to each of the five subindices. Figure 5 shows three time series calculated using the weights determined for the case of Portugal (described before), using the weight computed by the ECB (in Holló et al., 2012) and with the same weights for the five market segments. Also here it is evident that the differences between results are not significant.

Figure 5 - ICSF for different values of the weights in the aggregation of the five subindices



5. The performance of the Composite Indicator of Financial Stress for Portugal

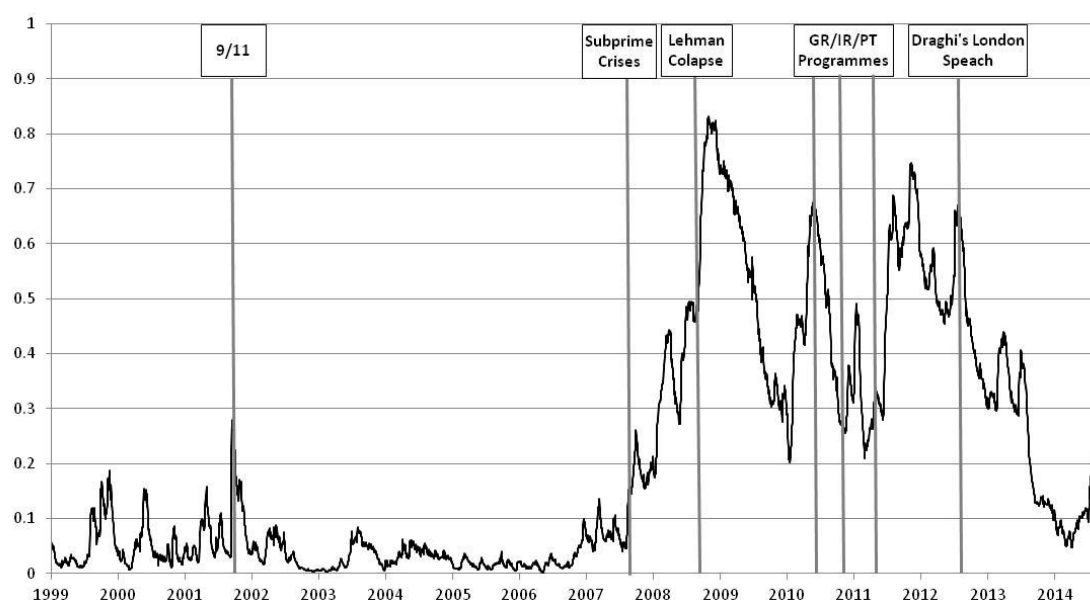
5.1. Ability to measure financial stress in Portugal

The quality of the indicator is closely linked to its ability to identify and measure an event of stress in financial markets. Therefore, any analysis of the Indicator's quality will always be made by comparing it with the perception financial markets had about a set of events in terms of the financial stress they have created.

The simplest way is to visually compare the indicator with periods where known stress events took place (see Figure 6). A list of the most important events is relatively easy to compile, by looking at regular reports of supranational institutions such as the IMF and the OECD or, alternatively, by making use of market research provided by private financial institutions. Looking at Figure 6, it is visually easy to see that the composite financial stress indicator calculated for Portugal is highly correlated with the main stress events usually identified. The first peak that is worth highlighting coincides with the 9/11 terrorist attack of 2001, which, judging by the indicator, had a relatively small duration in time in terms of the stress level it created. The next major event to highlight was the subprime crisis in 2007 that later led to the Lehman Brothers collapse of 2008. The series maximum level was achieved at this time, a

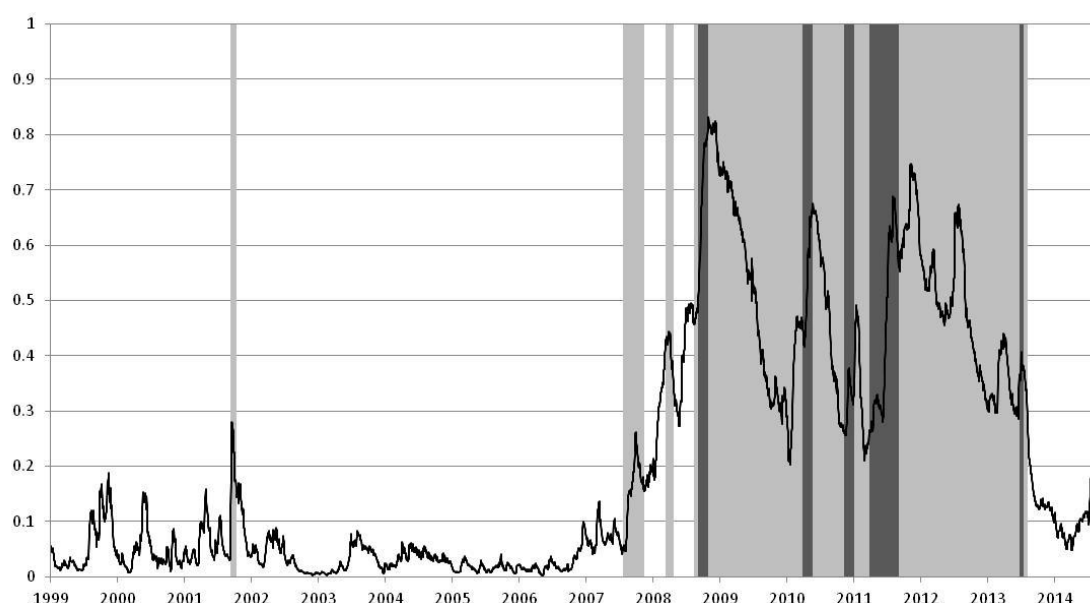
period that most analyses consider as the biggest financial crisis since the 1920s. The indicator is also highly reactive to the euro area sovereign debt crisis, first with the impact of the Greece/Irish aid requests and afterwards reacting to the more specific situation that occurred in Portugal. The level of stress seen at this time was almost as high as during the Lehman Brothers period.

Figure 6 - ICSF and most important financial stress events



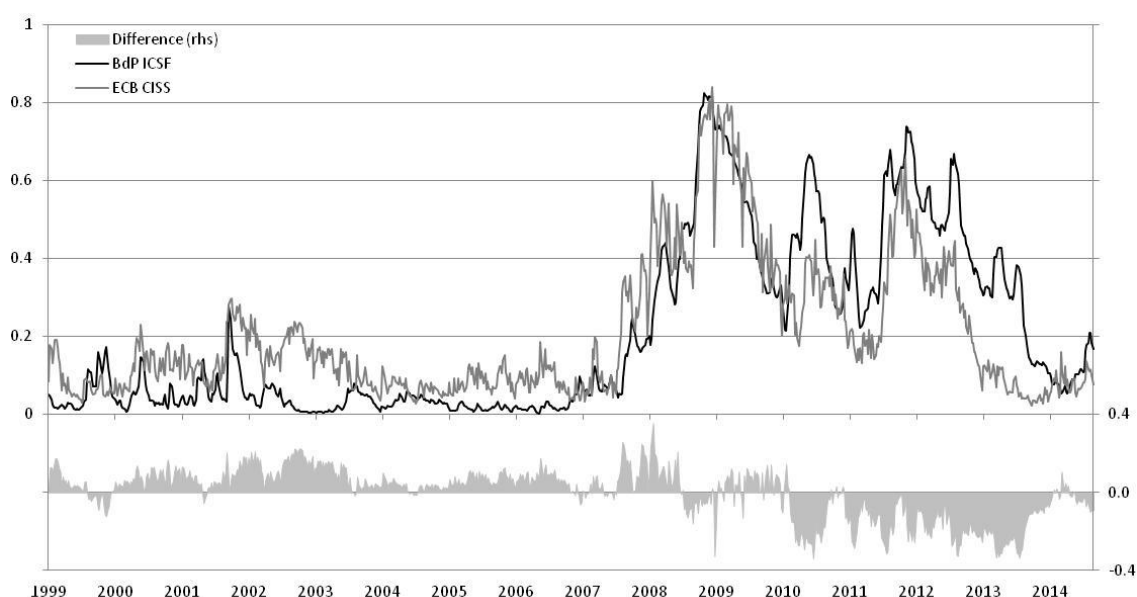
However, what the previous analysis showed is that the indicator reacted well in response to known stress events. It doesn't show if those stress events were specific to the evolution of the Portuguese financial markets or if any stress indicator for the euro area would convey the same result. Trying to assess that situation, a survey of domestic financial institutions and some international institutions operating in Portugal was conducted. In that survey a number of events were selected and the institutions were asked to assess the level of stress generated by each particular event in the case of the Portuguese markets and also the length of time of each stress event. The survey was an open one, with the financial institutions able to identify additional stress events that they considered relevant. 16 institutions participated in the survey and the main results (the questions and the average answers) can be found in the appendix. From the results, it seems that the indicator is able to capture all the relevant stress events in the case of Portugal (see Figure 7). Stress events with an average intensity higher than 3 were highlighted, with a darker grey assigned to stress events with an average answer above 4. The wideness of the bars take into consideration the average duration of the events, according to the answers obtained in the survey. Higher duration translates into wider bars.

Figure 7 - ICSF and the most important financial stress events identified by the survey



It was already shown that the calculated ICSF is able to capture the most relevant stress events that affected the Portuguese financial markets. Nevertheless, given that some of the stress events are common to Portugal and to all the euro area countries, one would expect that the stress indicator calculated for Portugal and the ECB's CISS (which uses the exact same methodology for the all of the euro area) would have an overall similar behavior but with some differences, particularly in the more recent period when Portugal was in the front line of the sovereign debt crisis. Figure 8 shows the ECB's CISS together with the ICSF (transformed by 5 day average of daily data for comparison with the CISS). From the figure it is very clear that the Portuguese indicator showed higher stress levels during the sovereign debt crisis and was also able to capture some idiosyncratic risk events such as the financial stress during the Portuguese political crisis in the summer of 2013. On the other hand, the stress levels of the Portuguese indicator during the subprime crisis, although still high, were lower than the levels seen in the euro area indicator. The negligible exposure of the Portuguese financial system to the US subprime sector could explain such difference in behavior. This difference in behavior between the euro area stress indicator and the Portuguese stress indicator also validates the ability of the indicator to capture the specific events that affected the Portuguese financial markets.

Figure 8 - ICSF and ECB CISS



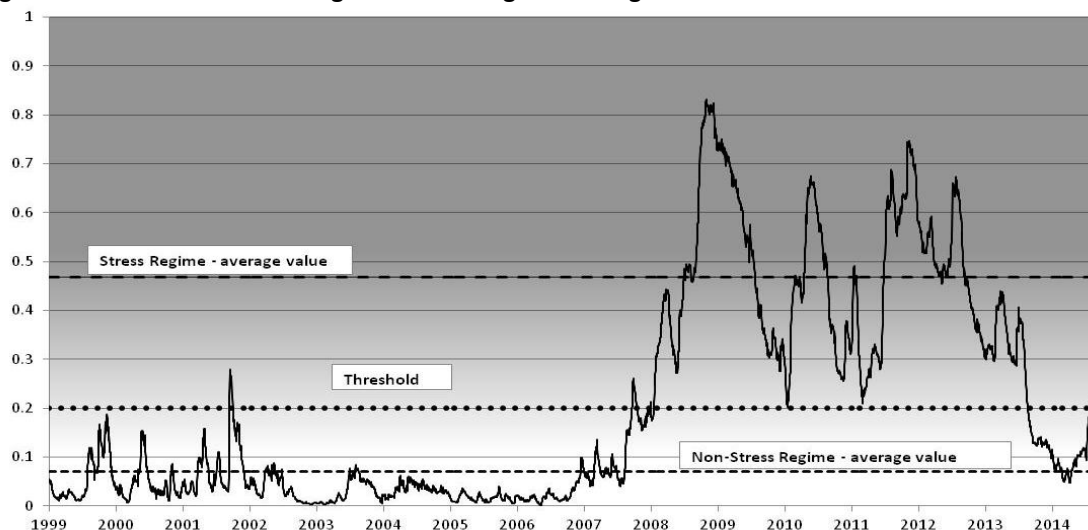
5.2. Threshold of stress for Portugal

Given the results of the survey, it is easy to identify two distinct regimes: low stress regime (non-highlighted periods in Figure 7) and high stress regime (highlighted periods). One simple way to assess a threshold of change between both regimes is to analyze the data associated with each regime.

In the case of the low stress level regime, the simple arithmetic average for the Portuguese Composite Stress Indicator is 0.073. For that regime, 95% of the data (more than 2500 observations) fall between 0 and 0.21. On the other hand, in the high stress regime the composite indicator has an average of 0.46. In this case, 95% of the data (around 1400 observations) belongs to the interval between 0.19 and 1 (the theoretical maximum of the indicator).

This analysis indicates that a threshold value for a change between regimes would be around 0.20 (see Figure 9).

Figure 9 - ICSF: the low stress regime and the high stress regime



Another method to determine a threshold of stress for the ICSF is linked to the notion that financial stress can affect the real economy. Therefore, whenever a given level of the ICSF is hit, one would expect a negative economic impact. With that in mind, a threshold vector autoregression (TVAR) was created to model the relationship between financial stress and the real economy, with the monthly ICSF (simple average of daily data) and the Coincident Indicator for Economic Activity (a proxy for the real GDP growth) used as endogenous variables. This method assumes that there are two regimes (high-stress regime and low-stress regime) and the transition between the states is triggered any time an observable variable crosses a certain threshold (a value that is estimated from the data). In this case, the ICSF was used as the threshold variable. The model is as follows:

$$x_t = c^H + \Phi_1^H x_{t-1} + e_t^H \quad \text{if } z_{t-d} > \tau \quad (\text{high-stress regime}) \quad (7a)$$

$$x_t = c^L + \Phi_1^L x_{t-1} + e_t^L \quad \text{if } z_{t-d} \leq \tau \quad (\text{low-stress regime}) \quad (7b)$$

Where $x_t = (C_t, y_t)'$ stands for the two-dimensional vector of the endogenous variables (ICSF and the Coincident Indicator for Economic Activity for Portugal), c^s the vector of intercepts and Φ_j^s the matrix of the slope coefficients for states $s = H, L$ (with H, L representing the high-stress and low-stress regimes, respectively) and lag j . The threshold variable is z_{t-d} with $d \in \{1, \dots, d_0\}$ and $d_0 = 2$ as the maximum threshold lag foreseen. τ is the threshold parameter and e_t^s is the vector that contains the state dependent regression errors.

The optimal threshold value is determined by a grid procedure over the range of the ICSF values with the goal of minimizing the Akaike information criteria. The optimal specification was found to be a VAR(1) model with the twice lagged ICSF ($d=2$) acting as the threshold variable. From this method, we obtained a threshold value of 0.185 that is very close to the value that resulted from the survey (around 0.20).

5.3. Causality with and within the Composite Indicator of Financial Stress

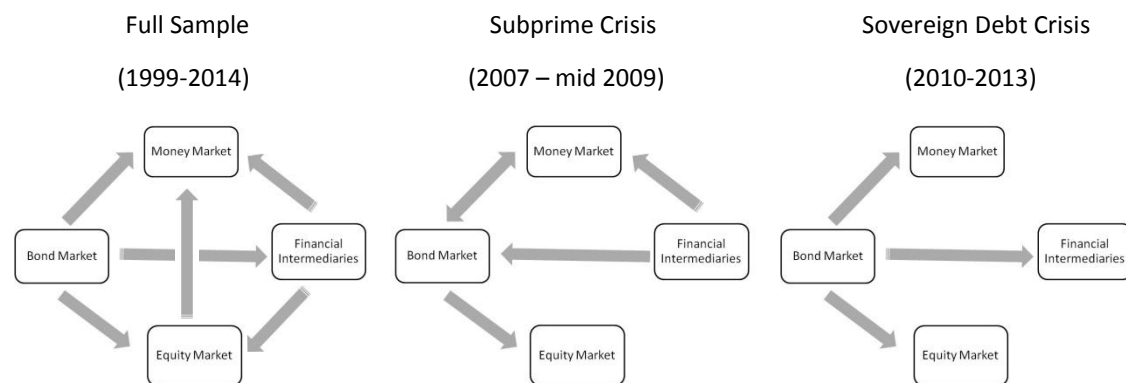
As was stated before, financial instability can affect the real economy and lead to macroeconomic instability. Using data for the entire sample, the ICSF and the real GDP growth in Portugal are negatively correlated with a coefficient of -0.60. Therefore, a VAR model was estimated (lag length specification tests based on the Schwartz criterion indicated lag length of 1) and the Granger causality test between the ICSF and the real GDP growth was determined, in order to understand if one time series is useful in forecasting another. Results indicate that the ICSF Granger cause real GDP growth (see Table1). Thus, values of ICSF provide statistically significant information about future values of real GDP.

Table 1 - Granger Causality Test Results

Null Hypothesis	F - Statistic	t-Statistic Prob.	Decision	Result
RGDP does not Granger cause ICSF	1.69663	0.1980	Non-reject	No Granger Causality
ICSF does not Granger cause RGDP	8.0069*	0.0064*	Reject	Granger Causality

Notes: * indicates significance at the 5% level of significance.

Furthermore, given the way the ICSF is constructed, with 5 subindices from different market segments, it is also interesting to study the way that financial stress evolves in the case of the Portuguese financial markets. For that, we did Granger causality tests on the several dimensions of the indicator (bond market, equity market, financial intermediaries, money market and foreign exchange market). The analysis was conducted with weekly data to mitigate the problem of different daily closing times for the information with standard VAR models estimated for the several relationships (the usual lag length specification based on the Schwart criteria indicated on most estimations a lag length of 3). The results for the foreign exchange market segment showed no significant Granger causality and are not presented in the analysis (see Figure 10).

Figure 10 - Granger Causality results for the subindices

For the full sample, a multitude of relationships can be seen, with the bond market and the financial intermediaries segments having a more predominant role. The bond market showed ability in predicting the future values of the remaining three market segments and the same was also true for the financial intermediaries' predictive power over the money market and the equity market segment. The equity market also passed the Granger causality test for the money market segment.

The results are significantly different when we consider the subsample related with the subprime crises (2007 – mid 2009). In this case, the financial intermediaries segment gains more prominence, having predictive power for the bond market and the money market segments. Also the money market segment has increased importance, Granger-causing the

bond market. The importance of the bond market segment is somewhat reduced compared with the full sample.

A more extreme result can be seen for the subsample related with the sovereign debt crisis (2010 – 2013). In this case, only the bond market shows predictive ability over all the remaining market segments.

6. Conclusions

After the recent international financial and economic crisis, vast literature on how to monitor financial stress was produced and many indicators of financial stress were developed. In this paper we developed a specific indicator for Portugal. Following Holló et al. (2012) methodology, indicators from five market segments that collectively represent the core of the financial system were considered (namely, money, bond, equity and foreign exchange markets and financial intermediaries). These indicators were then aggregated creating five different market segment subindices. To finish, these subindices were aggregated into a single indicator, taking into account the time-varying cross-correlations between the different market segments as well as market segment specific weights. These latter were calibrated by the impact of the instability caused by each market segment on the economic activity. The ICSF proved to be robust, in the way that the results were stable under different methodological options.

The ICSF ability to identify periods of stress is high, both when identifying internationally well known stress events and when identifying the most relevant stress events that impacted more specifically the Portuguese markets. Furthermore, when comparing ECB's CISS and the ICSF, the latter shows higher levels of stress during specific events that affected the Portuguese financial markets. Finally, values of ICSF provide statistically significant information about future values of real GDP.

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Appendix

During the months of August/September 2014 a survey was conducted to gauge the level of stress seen in the Portuguese markets during some selected periods. The survey identified a number of key stress events and asked for the classification of those events in two items: intensity and duration. The first item tries to acknowledge the level of stress that the specific event caused in the Portuguese financial markets while the second item tries to determine the time period that the stress event lasted in the Portuguese financial markets. The scale of the answers ranged in the intensity item from 5 (extreme stress) to 1 (very low level of stress) and in the duration item from 5 (long extreme long-lasting stress) to 1 (short-lived stress). The survey was open ended, allowing for the inclusion of further stress events in the list. 16 domestic and non-domestic (but operating in the Portuguese markets) financial institutions answer to the survey.

Event description	Average Intensity	Average Duration
1999 (January) – FX crisis in Brazil	1.6	1.3
1999 (2nd half) – Y2K bug	2.0	1.8
2000 (March) – Burst of tech bubble	2.3	2.2
2000 (Sep/Nov) – ECB intervention to support the euro	1.3	1.3
2001 (February) – FX crisis in Turkey	1.2	1.2
2001 (September) – Terrorist attack [9/11]	3.4	2.9
2001 (December) – Argentina financial crisis	1.6	1.6
2002 (July) – WorldCom bankruptcy	1.7	1.4
2003 (March) – War in Iraq	2.2	2.0
2004 (March) – Madrid terrorist attack	2.0	1.5
2005 (July) – London terrorist attack	1.7	1.6
2007 (August) – Subprime crisis	3.8	3.8
2008 (March) – Bear Stearns bailout	3.1	3.1
2008 (September) – Lehman Brothers bankruptcy	4.7	4.5
2008 (November) – BPN nationalization	3.1	2.7
2008 (December) – BPP liquidation	2.4	1.9
2009 (November) - Dubai World Crisis	1.1	1.7
2010 (April) – Greece applies for financial support	4.3	4.4
2010 (November) – Ireland applies for financial support	4.1	4.2
2011 (April) – Portugal applies for financial support	5.0	5.0
2012 (Janeiro) – Portugal rating downgrade and exclusion from investment grade indices.	3.8	3.8
2012 (February) – Greece 2nd financial support programme	3.4	3.3
2012 (June) – Cyprus applies for financial support	2.6	1.8
2012 (June) – Spain banking sector support programme	2.8	2.1
2012 (June) – Portuguese banking recapitalization	1.8	1.3
2013 (March) - Uncertainty over Portuguese constitutional Court decision on some budget measures	1.8	1.8
2013 (July) – Political crisis in Portugal	4.1	2.3
2014 (August) – BES resolution	3.4	3.3

