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Working Paper

Measuring financial stress – A country specific stress index for Finland

Bank of Finland Research Discussion Papers, No. 7/2015

Provided in Cooperation with:

Bank of Finland, Helsinki

Suggested Citation: Huotari, Jarkko (2015) : Measuring financial stress – A country specific stress index for Finland, Bank of Finland Research Discussion Papers, No. 7/2015, ISBN 978-952-323-034-7, Bank of Finland, Helsinki,
<https://nbn-resolving.de/urn:nbn:fi:bof-201503171116>

This Version is available at:

<https://hdl.handle.net/10419/212315>

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Jarkko Huotari

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7 • 2015

Measuring financial stress – A country specific stress index for Finland

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March 5, 2015

Abstract

I propose a financial stress index (FSI) for the Finnish financial system that aims to reflect the functionality of the financial system and provide an aggregate measure of financial stress in the money, bond, equity and foreign exchange markets and the banking sector. The FSI is a composite index that combines information from these markets and provides a measure of stress in the financial system as a whole. The FSI has obvious benefits for all participants in the financial markets who need a tool for monitoring the functioning of the financial markets, as it provides information on systemic stress events which are not as easily captured with the stress measures of individual markets or sectors. The ESRB recommendation (ESRB, 2014a) also states that national or international FSIs could be used when making a decision about the release of the counter-cyclical capital buffer. Hence, the index can also be used to support the macro-prudential policy decision making in Finland.

*Email: jarkko.huotari@aalto.fi. The views presented in this article are those of the author and do not necessarily represent the views of the Bank of Finland. This work was done while I was working as an Economist Trainee at the Bank of Finland (Address: Bank of Finland, Financial stability and Statistics Department, P.o.Box 160, 00101 Helsinki, Finland. Email: RMsiihteerit@bof.fi). A more comprehensive version of the study is going to be published as my Master's thesis in Aalto University, Department of Finance. I would like to thank Helinä Laakkonen for her valuable support and guidance throughout the study. I also thank Esa Jokivuolle and other seminar participants for valuable comments given in the Annual Meeting of the Finnish Economic Association as well as Simo Kalatie for the research assistance at the Bank of Finland. Finally, I thank Manfred Kremer for his helpful comments and suggestions.

1. Introduction

The need for understanding, analyzing and monitoring systemic risk became apparent after the Global financial crisis, which was unique in many respects. It reached an unforeseen magnitude and spread widely within the global financial markets and its effects on the real economy have been significant. In order to be able to monitor and analyze systemic risk, one needs a measure for system-wide financial (in)stability which shows when the financial system is stable, and when it is not, i.e. when the financial system is not functioning as it should due to increased uncertainty or stress and materialized systemic risk. A financial stress index (FSI) is an example of such a measure.

A financial stress index is a composite index that condenses several market specific stress indicators, such as market volatilities or risk spreads, into a single measure of financial stress. The specific aim of an FSI is to measure prevailing systemic stress in the financial markets as a whole. Hence, it has obvious benefits for all participants in the financial markets who need a tool for monitoring the functioning of the financial markets, as it provides information on systemic stress events which are not as easily captured with the stress measures of individual markets or sectors.

FSIs can also be used in identifying the dates of a systemic financial crisis. Determining the crisis dates is essential for any empirical study attempting to find indicators that predict financial crises (Illing and Liu, 2006). However, the task of determining the crisis dates is trickier than one might think, as the crises vary both in terms of the severity and in how many markets they hit. As there exists no commonly agreed way of determining when a crisis starts and when it ends, the use of a continuous system-wide stress indicator might give valuable information on the different levels of stress at different times and help to identify the exact start and end points of a systemic crisis (Cardarelli et al., 2011).

The use of FSIs has recently become a common method in describing system-wide stress in the financial markets. Illing and Liu (2006) develop an index of financial stress for the Canadian financial system and the Kansas City Financial Stress Index (KCFSI), built by Hakkio and Keeton (2009), is a comprehensive index for financial stress in the U.S. economy. Cardarelli et al., (2011) construct a monthly FSI for 17 advanced economies and use an FSI to identify episodes of financial turmoil and propose an analytical framework to assess the impact of financial stress on the real economy. Balakrishnan et al. (2011) build on the work

by Cardarelli et al. (2011) and develop FSIs for emerging economies using the same methodology. The Composite Indicator of Systemic Stress (CISS), by Hollo et al., (2012) is the first FSI to introduce the application of basic portfolio theory to the aggregation of market specific sub-indexes. The CISS measures stress in the financial system in the euro area and compared with earlier indexes, it is the first that takes into account the correlation between market specific stress indicators, and hence is more able to capture the concept of systemic stress. Islami and Kurz-Kim (2013) also develop a composite FSI for the euro area. The authors base their FSI on its ability to predict developments in the real economy and select risk variables based on their correlation with economic activity, measured by industrial production.

In this study, I develop a financial stress index for the Finnish financial system by combining 14 individual stress measures from five different markets: money, bond, stock, foreign exchange markets and the banking sector. I consider three different aggregation methods that have been used in the literature (equal-variance weighting, principal component analysis and a correlation based weighting method) and find that the FSI with the correlation based aggregation method proposed by Hollo et al., (2012) is the best in describing the past stress events and capturing the system-wide aspect of the stress that the FSI is meant for capturing.

To the best of my knowledge, this financial stress index is the first such index for the Finnish financial system. On top of all the market participants that are interested in monitoring the functioning of the Finnish financial system, the FSI might also be useful for Finnish macro-prudential authorities. Following the EU prudential rules for the banking system that came into effect on 1 January 2014, the European Systemic Risk Board (ESRB) published a recommendation on guidance on setting the counter-cyclical capital buffer (CCB) rates (ESRB, 2014a). In the recommendation it is noted that the decisions whether the buffer should be maintained, reduced or fully released should be based on a specific set of variables, which should include measures that indicate general systemic stress in the financial system on a national or EU level. This is what the FSI does and hence, the index can also be used to support the macro-prudential policy decision making in Finland.

The paper is structured as follows. The concepts of systemic risk and financial stress as well as a review of the previous literature on FSIs are described in Section 2. Section 3 presents the steps for selecting the markets and individual stress indicators used in the FSI. The different methodologies used to construct an FSI are described in Section 4. Different FSIs for the

Finnish financial system are presented in Section 5 and evaluated in Section 6. Section 7 concludes.

2. Measuring systemic stress

2.1. The concepts of systemic risk and financial stress

The challenge in measuring financial stress as well as in defining financial crisis periods lies in the lack of an unambiguous definition for financial stress or a financial crisis. Instead of an academic consensus, several definitions can be found in previous literature. As the concepts of systemic risk and systemic stress are essential for this study this section briefly introduces some of the definitions used in earlier studies that construct financial stress indexes.

According to Hakkio and Keeton (2009), financial stress, in general terms, stands for interruptions in the normal functioning of the financial markets. The authors also note that agreeing on a more specific definition is difficult, because each period of financial stress is unique and the same definitions do not hold through time. A competing definition of financial stress is the one suggested by Balakrishnan et al. (2011). The authors define financial stress as episodes when the financial system is under strain and its ability to intermediate is impaired. Cardarelli et al. (2011) state that financial stress is usually associated with the following: large shifts in asset prices, abrupt increase in risk or uncertainty, illiquidity of the financial system and concerns about the health of the banking system.

Hollo et al. (2012) focus on the concepts of systemic stress and systemic risk. They define systemic stress as instability in the financial system as a whole. On the other hand, the authors interpret systemic stress as the amount of systemic risk that has already materialized and rely on the definition of systemic risk by De Bandt and Hartmann (2000). De Bandt and Hartmann (2000) define systemic risk as the risk that financial instability becomes widespread and impairs the functioning of a financial system in such a way that economic growth and welfare suffer materially. According to ECB (2009) systemic stress consists of a horizontal perspective and a vertical perspective. Horizontal perspective refers to the spreading of financial instability within the financial system, whereas the vertical perspective refers to the two-sided interaction between the financial system and the economy as a whole. Moreover, the severity of systemic risk and systemic events should be evaluated based on the effects they have on consumption, investment, growth or more broadly to economic welfare (ECB, 2009). Similarly, Illing and Liu (2006) state that systemic stress is stress that results in

economic behavior being altered sufficiently and has adverse effects on the real economy. ESRB (2014b) define systemic risk to financial stability as a risk of disruption to the financial system with the potential to have serious consequences to the real economy.

In this study I will rely on the definition of systemic stress by Hollo et al. (2012), where stress is the amount of systemic risk already materialized and systemic risk, as defined by De Bandt and Hartmann (2000), refers to wide-spread financial instability with potential causes for the real economy. To summarize, for the remainder of the paper, systemic financial stress refers to stress that is spread widely within the financial system and has potential adverse effects on the real economy.

2.2. The features of financial stress

Even though an exact definition for financial stress may be hard to come by, there are certain phenomena that are usually associated with financial stress. Hakkio and Keeton (2009) provide a comprehensive presentation on the key features of financial stress. The authors note that even though financial stress might be hard to measure, certain key phenomena tend to be associated with financial stress over time. The authors list five features of financial stress: i) increased uncertainty about fundamental values of assets, ii) increased uncertainty about the behavior of other investors, iii) increased asymmetry of information, iv) decreased willingness to hold risky assets (flight to quality) and v) decreased willingness to hold illiquid assets (flight to liquidity). The relevance of these phenomena may differ from one episode of financial stress to another, but every episode of financial stress, according to Hakkio and Keeton (2009), involves at least one of the phenomena and often even all of them. As there is no economic or financial theory that FSIs can directly be built upon, the features of financial stress offer a valuable starting point to observe and measure financial stress empirically as well as to construct FSIs. Following Hakkio and Keeton (2009) this paper later exploits the stress features in finding indicators included in the FSI. The stress features are briefly presented below.

Increased uncertainty about the fundamental values of assets, especially among lenders and investors, typically shows as greater volatility in market prices. The uncertainty itself might result from uncertainty about the outlook for the economy, which affects the prospective cash flows of securities. Because of greater uncertainty, investors react more strongly to new information, which results in greater volatility (see, e.g., Pastor and Veronesi, 2009; Hautsch and Hess, 2007).

Increased uncertainty about the behavior of other investors also contributes to volatility in market prices. This is because the expected return of an asset for an investor depends as much on the actions of other investors as it does on the long-run or fundamental value of the asset. Thus, when investors base their decisions on guesses about other investors' decisions, market prices disperse from fundamentals and become more volatile. (Hakkio and Keeton, 2009).

Increased asymmetry of information, especially between the lenders and borrowers as well as buyers and sellers of financial assets, refers to situations where the other party knows more about the true value of the asset. These differences in information can lead to adverse selection or moral hazard which further leads to an increased average cost of borrowing as well as decreased average prices of assets on secondary markets. Hakkio and Keeton (2009) appoint two reasons why financial stress might increase the asymmetries of information: 1) the variation in the quality of borrowers or assets might increase and 2) lenders' confidence in the accuracy of their information about the borrowers might decrease.

Decreased willingness to hold risky assets, or flight to quality, causes lenders and investors to demand higher expected returns on risky investments. This will increase the cost of borrowing for risky borrowers. Prior literature has outlined the tendency of investors to underestimate risk during booms and overestimate risk in downturns (see, e.g., Berger and Udell, 2004). In addition, investors risk appetite decreases with financial stress, as investors become less certain about their future income.

Flight to liquidity, or decreased willingness to hold illiquid assets, is a similar concept. During increased financial stress, investors typically become less willing to hold illiquid assets for two reasons: 1) the demand for liquid assets increases since investors become willing to protect against unexpected cash needs and 2) the perceived liquidity of assets decreases, as market values fall following adverse selection, and investors view these assets as illiquid because they cannot be sold without facing a notable loss.

Hollo et al. (2012) point out that these features can be monitored through observable symptoms of financial stress, such as higher asset price volatility, large asset valuation losses or wider default and liquidity risk premia. This leads to the characteristics of financial stress by Hakkio and Keeton (2009) being captured, at least to some extent, by standard financial market indicators also used in the FSI for Finland constructed in this paper. Even though the exact measurement of these stress features might be challenging and the question of how to

measure the overall level over financial stress is less clear, the financial stress indexes provide one possible solution to this issue.

2.3. The link between financial stress and the real economy

Following the definitions of systemic financial stress, discussed above, systemic financial stress is such that i) it is widely spread within the financial system and ii) has adverse effects on the real economy. Financial stress poses apparent risks to the real economy, as businesses and households tend to withdraw from new investments and purchases following uncertainty and tighter credit conditions caused by increased financial stress. However, as noted by Davig and Hakkio (2010) the relationship between financial stress and the real economy in general is complex and poorly understood. The researchers argue that there is in fact a tight relationship between financial stress and economic activity, but the connection is far from obvious and that the effects of financial conditions vary over time.

Hakkio and Keeton (2009) list three possible channels through which an increase in financial stress can lead to a decline in economic activity. These include: i) an increase in uncertainty about the prices of financial assets and the economic outlook in general, ii) increases in the cost to businesses and households of financing spending and iii) tightening of credit standards by banks. The uncertainty about prices and the economic outlook leads to increased volatility in asset prices, which is followed by firms becoming more cautious and delaying investment decisions as well as households cutting back on spending. This is followed by an increased uncertainty of households about their future income. These reactions ultimately lead to decreased real economic activity. The increased cost of financing spending results from increased interest rates in the capital markets caused by flight to quality, flight to liquidity as well as increased asymmetry of information, that follow increased financial stress. The increase in the cost of financing may cause both businesses and households to cut back on spending, which will further decrease economic activity. Finally, financial stress can lead to decreased economic activity by causing banks to tighten their credit standards. Flight to quality, flight to liquidity and an increased asymmetry of information can also make banks less willing to lend, leading banks to raise interest rates charged on new loans as well as raising their minimum credit standards. Both may lead to a decline in spending, as financing is both more expensive and more difficultly available.

2.4. Financial stress indexes developed in previous literature

Illing and Liu (2006) develop an index of financial stress for the Canadian financial system. The paper is seminal in this strand of literature and to the best of my knowledge, the first actual FSI developed that aims to measure system wide stress in the financial system as a whole. The index measures financial stress as a continuum and extreme values of the index are called financial crises. The FSI is of daily frequency and covers the equity markets, bond markets, foreign exchange markets as well as the banking sector. The stress indicators are aggregated into a single index by weighting the variables by the size of each market to which they pertain. The authors also test three other aggregation methods, namely factor analysis, variance-equal weighting and transforming the variables using their cumulative distribution functions (CDFs).

Cardarelli et al., (2011) use an FSI to identify episodes of financial turmoil and propose an analytical framework to assess the impact of financial stress on the real economy. The authors focus on the impact of financial stress on economic activity, which according to the researchers is a matter of debate in both academic and policy circles. The authors' main contribution is the finding that financial turmoil characterized by banking distress is more likely to result in severe downturns compared to stress mainly in securities or foreign exchange markets. They construct a monthly FSI for 17 advanced economies. The authors use variance-equal weighting as their aggregation method and the final FSI is a variance-weighted average of three sub-indexes. Their objective is to build country specific FSIs using a uniform set of time series across the countries as well as to use a minimum set of time series or market specific stress indicators. Balakrishnan et al. (2011) build on the work by Cardarelli et al. (2011) and develop FSIs for emerging economies using the same methodology.

The Kansas City Financial Stress Index (KCFSI), built by Hakkio and Keeton (2009), is a comprehensive index for financial stress in the U.S. economy. The authors select eleven stress indicators based on the representation of the features of financial stress discussed earlier, the ability to reflect prices or yields on financial markets, frequency and availability. Hakkio and Keeton (2009) define financial stress as the factor most responsible for the co-movement of the eleven variables. The authors identify this factor by using principal components analysis. Along with variance-equal weighting, principal component analysis is one of the most common aggregation methods in previous FSI literature. Compared with Illing and Liu (2006)

and Cardarelli et al. (2011), Hakkio and Keeton (2009) also include measures of money market stress in their final FSI.

The Composite Indicator of Systemic Stress (CISS), by Hollo et al., (2012) is the first FSI to introduce the application of basic portfolio theory to the aggregation of market specific sub-indexes. The CISS measures stress in the financial system in the euro area. The authors use 15 individual stress measures to construct market specific sub-indexes. The portfolio-theoretic aggregation method takes into account the time-varying cross correlations between the sub-indexes. The authors state that the CISS, compared with earlier FSIs, puts more weight on situations in which stress prevails in several markets at the same time. The idea behind the portfolio aggregation is that stress prevailing at several markets simultaneously is more systemic and dangerous for the economy as a whole. This is because financial instability is spread more widely across the financial system. Compared with earlier indexes, taking into account the correlation between market specific stress indicators, the CISS is more able to capture the concept of systemic stress.

Islami and Kurz-Kim (2013) also develop a composite FSI for the euro area. The authors base their FSI on its ability to predict developments in the real economy and select risk variables based on their correlation with economic activity, measured by industrial production. From this respect, their approach is similar to the FSI developed in this study.

Nowadays, FSIs are widely used in financial crisis and stress literature and have been accepted as a benchmark method for measuring financial stress. FSIs have been exploited for example in assessing the transformation of financial stress from advanced economies to emerging ones as well as from an emerging economy to another (see, e.g., Balakrishnan et al., 2009 and Park and Mercado, 2013). Other studies have built FSIs and used them as the reference variable in early warning models (see, e.g., Lo Duca and Peltonen, 2013 and Oet, Bianco and Gramlich, 2013). Table 1 summarizes the FSIs developed in previous literature.

Table 1. Summary of the FSIs developed in earlier studies

The table summarizes the FSIs developed in earlier academic literature. It lists the FSIs, the stress indicators used in each FSI as well as the methodology used and geographical area covered with the FSI.

Study	Time span	Market specific stress indicators	Aggregation method	Geographical area covered
Park & Mercado (2013)	1992-2012	Banking sector beta, exchange market pressure index, stock market volatility, stock market returns, sovereign debt spreads	Variance-equal weighting, principal component analysis	25 emerging and 15 advanced economies
Lo Duca & Peltonen (2013)	1990-2009	TED-spread, negative equity returns, stock market volatility, nominal effective exchange rate volatility, 3M Government bill yield volatility	Arithmetic average	28 emerging and advanced economies
Islami and Kurz-Kim (2013)	2007-2013	CDS spread on iTraxx Europe Crossover, CDS spread on iTraxx Non-financials, EUR/USD exchange rate volatility, volatility of the future oil price, earning price ratio minus 10-year euro interest rate, Euribor/EONIA spread	Variance-equal weighting	Euro area
Oet et al. (2013)	1992-2012	Banking sector beta, bank bond spread, interbank liquidity spread, interbank cost of borrowing, weighted dollar crashes, covered interest spread, corporate bond spread, liquidity spread, commercial paper-T-bill spread, treasury yield curve spread, stock market crashes	Credit weights	U.S.
Hollo et al. (2012)	1999-2011	Euribor volatility, TED-spread, MFT's emergency lending, German 10-year government bond volatility, corporate bond spread, 10-year interest rate swap spread, stock market volatility, stock market CMAX, stock-bond correlation, bank stock idiosyncratic volatility, financial corporate bond spread, bank stock market CMAX, EUR vs. USD, JPY and GBP volatility	Portfolio-theoretic aggregation	Euro area
Cardarelli et al. (2011)	1980-2007	Banking sector beta, TED-spread, inverted term spread, corporate bond spread, stock index decline, stock market volatility, real effective exchange rate volatility	Variance-equal weighting	17 advanced economies
Balakrishnan et al. (2009)	1997-2009	Banking sector beta, stock market returns, stock market volatility, sovereign debt spreads, exchange market pressure index	Variance-equal weighting	26 emerging countries
Hakkio & Keeton (2009)	1990-2009	TED-Spread, 2-year swap spread, off-the-run/on-the-run 10-year Treasury spread, Aaa/10-year Treasury spread, Baa/Aaa spread, HY/Baa spread, Consumer ABS/5-year Treasury spread, Stock and Treasury bond correlation, VIX-index, bank stock idiosyncratic	Principal component analysis	U.S.
Illing & Liu (2006)	1980-2006	Banking sector beta, liquidity spread, corporate bond spread, covered interest rate spread, inverted yield curve, weighted dollar crashes, stock market crashes, covered bond-T-bill spread	Credit weights	Canada

3. Selection of markets and market specific indicators

The construction of FSIs includes four steps that all need to be carefully considered: the selection of financial markets to be included, the selection of market specific stress indicators to be included, the transformation of market specific stress indicators and finally, the aggregation of these stress indicators into the final FSI. The first two are mostly related to data availability and collection, while the latter two are associated with the selection of methodology and further discussed along with FSI methodology in Section 4.

3.1. The selection of financial markets

The selection of financial markets to be included is somewhat straightforward as the aim of an FSI is to cover the whole financial system. The majority of the previous literature measures stress in five different segments: the money market, the bond market, the foreign exchange market, the equity market as well as in the banking sector. As discussed by Hollo et al. (2012), even though a real world financial system is a very complex network, these sub-indexes are supposed to represent the core of most financial systems. From these sub-markets, market specific stress indicators are selected to calculate sub-market indexes and finally the FSIs.

In earlier papers the markets included in an FSI are mostly selected based on their relativeness to the financial system. Illing and Liu (2006) select banking, foreign exchange, debt and equity markets as they represent the most important credit channels in Canada. The FSI developed by Cardarelli et al. (2011) also excludes money markets from the index. However, for an index trying to capture wide-spread financial stress in the whole system, the money market plays an important role. In addition, the interbank market and short-term funding are essential for banks and other financial intermediaries and thus to the functioning of the whole financial system. For the Finnish FSI, I follow the majority of previous FSIs developed, and measure stress in the five sub-markets presented above.

Several different criteria were used in the selection of market specific stress indicators for the Finnish FSI. More precisely, I first selected a variety of financial variables that have been used in FSIs in previous literature, such as Illing and Liu (2006), Hakkio and Keeton (2009), Hollo et al. (2012) and Cardarelli et al. (2011). From this set of variables, those that met the following criteria were selected for the FSI. First, all variables had to represent at least one of the five features of financial stress as presented by Hakkio and Keeton (2009) and discussed

in Section 2. Second, following Islami and Kurz-Kim (2013), only variables showing a high correlation with the real economy were chosen. I measured real economy with the monthly industrial production and computed the correlation between the industrial production and six lags of a variable candidate for the stress index. If at least one of the lags of the variable showed high correlation¹ with industrial production, it was selected to be used in the FSI. This criteria derive from the objective of the FSI to capture systemic stress, that is, stress resulting in adverse effects on the real economy.²

Third, each stress indicator had to be available on a daily basis, or at least monthly in some cases, to be able to calculate a monthly FSI. In addition, only market-based indicators could be taken into account as they are published without a delay compared with macroeconomic or balance sheet data, for instance. In practice, this means that all of the chosen indicators reflect prices or yields. They embody a large amount of information and are quick to reflect changes in financial conditions. Finally, one of the most important criteria was the ability to identify past episodes of financial stress. With the exception of TED-spread as well as stock-bond correlation, the stress indicators had to also be available at least from the beginning of 1987 in order to examine the indicators' ability to reflect past periods of financial stress. For the case of Finland, data covering the early 1990's is crucial in this respect, since it includes the 1991-1992 Scandinavian banking crisis.

While there are a variety of indicators that capture financial stress not included in the FSI for Finland, the majority of these were rejected based on data availability or lack of correlation with the real economy. In addition to the selected indicators, I considered a wide range of other candidates for stress indicators. For the bond market, volatilities and spreads for government bonds of several maturities were considered. For the foreign exchange market, volatility and CMAX (the maximum cumulated loss over a specific time frame) for the exchange rate between the euro and the Japanese yen were also studied as well as the Finnish effective exchange rate. I also calculated the exchange market pressure index (EMPI) suggested by Eichengreen et al. (1996) and used in their respective FSIs for example by Balakrishnan et al. (2011) and Park and Mercado (2014). For the equity market, negative

¹ Following Islami and Kurz-Kim (2013) I calculate the critical value for the 90% significance level of $1.645/\sqrt{70} = 0.20$.

² Realized volatility of EUR/USD and CMAX (the maximum cumulated loss over a specific time frame) for the banking sector are included in the index while showing no significant correlation. EUR/USD volatility captures an essential part of the FX market, whereas CMAX calculated with Finnish banking stocks showed significant correlation. Scandinavian banks are used instead, because of the lack of publicly listed Finnish banks in the current data.

equity returns and different measures of volatility were considered. For the banking sector, I also studied the option of including the inverted term spread in the FSI. The inverted term spread or, the slope of the yield curve, is used by Cardarelli et al. (2011), for instance. It is measured as the difference between the short- and long-term yields on government issued securities. The authors argue that as banks generate income by intermediating short-term liabilities into longer-term assets, a negative sloping yield curve jeopardizes bank profitability. However, in the Finnish context, other measures of banking sector stress seem to be more efficient in capturing past periods of stress as well as more strongly linked to the real economy.

Another dilemma considering the construction of an FSI is whether to use a maximum set of indicators to capture financial stress as thoroughly as possible, or whether to use a minimum set of time series. Cardarelli et al. (2011) argue that adding indicators could possibly contaminate the final index with noisy indicators and the added information of more and more indicators diminishes quite rapidly. Hollo et al. (2012) also note that the indicators in an FSI should not express identical information about the stress level in the same market segment.

The above discussed criteria lead to the selection of 14 stress indicators, each of which is discussed in more detail below. The amount of individual indicators in the Finnish FSI is mainly in line with previous FSI literature. Hollo et al. (2012) combine 15, Cardarelli et al. (2011) 12 and Hakkio and Keeton (2009) 11 stress indicators in their respective FSIs.

3.2. Money market

Realized volatility of the 3 month - interbank rate: The realized volatility is calculated from the three-month Euribor rate from January 1999 onwards. Pre-1999, three-month Helibor is used. Realized volatility is calculated as the square root of the monthly sum of squared daily log returns using the following formula:

$$rvol = \sqrt{\sum_{t=1}^n R_t^2} \quad (1)$$

where R is the daily log return of the interbank rate, t represents each trading day and n is the number of trading days in the measurement time frame. Realized volatility of the interbank rate is also used e.g. by Hollo et al. (2012).

TED-spread: The euro area TED-spread is calculated as the spread between the three-month Euribor rate and three-month Euro Generic government bond yield from 1999 onwards. Pre-1999 the 3-month Helibor and Finnish 3 month Treasury bill are used. Among volatility, the risk spreads between different securities are a widely used stress measure. The widening of risk spreads between risky assets and safe assets reflects the declined willingness of investors to hold risky financial assets (flight to quality). The spread between an interbank rate and a government bond reflects liquidity and counterparty risk in the interbank loan market. Government bonds are considered as less risky compared with interbank loans. Along with being a widely used measure of credit risk, the TED-spread is also commonly used in earlier FSIs (see, e.g., Hakkio and Keeton, 2009; Cardarelli et al., 2011 and Lo Duca and Peltonen, 2013). The spread is calculated daily and the monthly arithmetic average is used for the index.

3.3. Bond market

The realized volatility of 10 year - government bond yield: Used in earlier FSIs by for example Hollo et al. (2012) and Lo Duca and Peltonen (2012) the realized volatility of 10 year - government bond yield is also adapted for the Finnish FSI. Calculated from the yield of the Finnish 10 year - government bond, the realized volatility measures stress in the bond market. Realized volatility is calculated analogously to the realized volatility of the interbank rate.

10 year government bond yield spread to Germany: Calculated as the Finnish 10 year yield minus the German 10 year yield, the spread also measures stress in the bond market. It reflects the risk spread that investors require for investing in Finnish government bonds as opposed to the less risky German ones. The German government bond is a widely used reference bond especially in Europe. When uncertainty and stress in the bond market rises, the demand for the safer and more liquid bond increases, which increases its price and lowers the yield. The widening of the spread to Germany can be interpreted as the Finnish bonds viewed as riskier by investors. The spread is calculated daily and the monthly arithmetic average is used in the index. Similarly to the spread between Finnish and German government bonds, Park and Mercado (2014) use to the spread between 10-year local government bonds and US Treasuries in their FSIs for a range of emerging markets.

3.4. Foreign exchange market

Stress in the foreign exchange markets can be measured by a variety of variables and the exchange rate regime naturally affects the selection of indicators. In a fixed exchange rate

regime, stress results in losses in exchange reserves and increases in interest rates (Illing and Liu, 2006). For a floating currency, such as the euro, both the depreciation of the currency or unexpected volatility signal stress in the foreign exchange markets. The majority of the previous FSIs focus on volatility and not on depreciation. However, as noted by Illing and Liu (2006) volatility might come from an appreciating currency, which might imply overvaluation. Overvaluation can be interpreted as a leading indicator of stress rather than a stressful event. Thus, both volatility and depreciation are taken into consideration for the foreign exchange market. Hakkio and Keeton (2009), for example exclude stress measures from the foreign exchange market in their FSI for the US financial system. However, for an open economy such as Finland, including foreign exchange market stress measures can be seen as essential. On the other hand, measuring stress concerning the euro might reflect stress outside Finland and not concerning the Finnish financial system. It is even though likely that such stress would be contagious and have an effect in Finland as well.

Realized volatility of the euro exchange rate against the US dollar and the British Pound: Stress in the foreign exchange market is measured as realized volatility between the Euro and three other main currencies. Pre-1999 the euro is replaced by the Finnish Markka. Increased volatility reflects uncertainty in the foreign exchange market and increases hedging costs. Realized volatility is computed analogously to the bond and money market indicators. Exchange rate volatility is used in earlier FSIs e.g. by Hollo et al. (2012), Cardarelli et al. (2011) and Lo Duca and Peltonen (2014).

CMAX for the euro exchange rate against the US dollar and the British Pound: In addition to volatility, also large valuation losses are a symptom of stress in the financial markets. As uncertainty increases, investors sell investments they view as risky. This leads to decreased prices for these investments. Patel and Sarkar (1998) identify equity market crises using the CMAX method, which measures the maximum cumulated loss over a specific time frame. For the purpose of this paper, I compare the exchange rate with its maximum value over the past year, using the following formula:

$$CMAX_t = \frac{x_t}{\max[x \in (x_{t-j} | j = 0, 1, \dots, T)]} \quad (2)$$

where x is the stock market index and the moving time window is determined by T (usually 1-2 years). The CMAX thus compares the current value of a variable with its maximum value over the sample, T . The CMAX has been used later on e.g. by Vila (2000), Illing and Liu

(2006) and Hollo et al. (2012) for the stock market as well as by Illing and Liu (2006) for the foreign exchange market. CMAX is calculated from the daily exchange rates, with a backward rolling one year - window. For the first year of data, the window is fixed as the whole year.

3.5. Equity market

The realized volatility of the total market equity index: Calculated using the Datastream Finland market total return index, the realized volatility aims to capture stress in the equity market. Calculated as the monthly sum of daily log returns. Equity index volatility is a widely used indicator in FSIs, and as Hollo et al. (2012) note, a financial stress indicator should represent market-wide developments. Thus, broad market indexes should be preferred.

CMAX for the total market equity index: The equity market CMAX is calculated similarly to the foreign exchange version. The same equity indexes are used for both CMAX and realized volatility.

Stock-bond correlation: During tranquil periods the returns on stocks and government bonds are unrelated or move together in response to changes in risk-free rates (Hakkio and Keeton, 2009). As stocks are usually viewed by investors as much riskier than government bonds, especially in times of financial stress, investors will move away from stocks into bonds (flight to quality). This will lead to the returns of the two asset classes to move in opposite directions. As discussed by Hakkio and Keeton (2009) as well as Hollo et al. (2012) heightened financial stress drives the return correlation negative. The stock-bond correlation in this case gives an additional measure of equity market stress and flight to quality. Following Hakkio and Keeton (2009), the correlation is calculated over rolling three-month periods. The Datastream Finland market total return index and the Datastream 10-year Finland government benchmark bond total return index are used to calculate daily log returns. To make increases in the indicator correspond to increases in financial stress, a negative value of the correlation is used in the FSI.

3.6. Banking sector

The realized volatility of the banking sector equity index: Calculated using the Datastream Scandinavia Banks total return index, the realized volatility aims to capture stress in the banking sector. As the corresponding index for Finland consists of one minor bank (Aktia Bank Plc) as of December 2015, the Scandinavian index was chosen as a proxy for stress in

the Finnish banking sector. As the Scandinavian banking sector is highly linked and three fourths of the largest banks operating in Finland are non-Finnish and Scandinavian, this should be a more appropriate measure compared with the volatility of a single Finnish bank.

CMAX for the banking sector equity index: The banking CMAX is calculated similarly to the foreign exchange and equity market version using the Datastream Scandinavia Banks total return index.

Banking sector beta: The banking beta measures whether the banking sector stock returns are more volatile than the overall market stock returns. It provides a measure of the relative return volatility of the banking sector and isolates banking sector stress from overall stock market stress. The banking sector beta is given by:

$$\beta = \frac{\text{cov}(r, m)}{\text{var}(m)} \quad (3)$$

where r and m are the returns to the Datastream Scandinavia Banks total return index and the Datastream Scandinavia market total return index. The beta is calculated over rolling three month periods and the monthly average beta is used in the FSIs. Following standard CAPM, if beta is larger than one, the volatility of the banking sector is greater than the volatility of the overall market and the banking sector is relatively risky. The higher the beta, the higher is stress in the banking sector. Banking sector beta is also included in the FSIs built e.g. by Illing and Liu (2006), Cardarelli et al. (2011) as well as Park and Mercado (2014).

3.7. Data availability

The data gathered for the construction of the FSIs consists of 14 individual series: three-month interbank rate, three-month Finnish treasury bill yield, 10-year government bond yields for Finland and Germany, the currency spot rates between the euro (Finnish Markka pre-1999) and the US Dollar, and the British Pound, total market equity index, 10-year Finnish government benchmark bond index and banking sector equity index. The sample spans from January 1986 to December 2014. The data has been gathered mainly from three sources: Bloomberg, Thomson Reuters Financial Datastream and the Bank of Finland database.

The starting point for the data gathering was to be able to calculate stress indicators starting from January 1987. This implies that for some indicators, daily data from January 1986 is required. However, the time period for each indicator varies slightly because of data limitations. Daily data is supplemented with monthly observations were applicable. Table 2

summarizes the market specific stress indicators, the features of financial stress captured by each indicator and data availability.

Table 2. Market-specific stress indicators included in the FSI for Finland

The table lists the stress indicators used in the FSIs for the Finnish financial system. The indicators are grouped by the sub-markets. Along with data availability and statistical properties, the features of financial stress captured by each indicator are presented.

Market sector	Indicator	Feature of financial stress	First date available	Mean	Standard deviation
Money market	Realized volatility of the 3 month interbank rate	Uncertainty about fundamentals and	Jan 1987	0.03	0.03
Money market	TED-spread	Flight to quality, flight to liquidity,	Jan 1995	0.25	0.40
Bond market	Realized volatility of the 10 year government bond yield	Flight to quality, flight to liquidity	Aug 1991	0.06	0.03
Bond market	10 year government bond yield spread to Germany	Flight to quality, flight to liquidity	Jan 1987	0.32	0.45
Foreign exchange market	EUR/USD realized volatility	Uncertainty about fundamentals and	Jan 1987	0.03	0.01
Foreign exchange market	CMAX EUR/USD	Flight to quality, flight to liquidity	Jan 1987	0.06	0.05
Foreign exchange market	EUR/GBP realized volatility	Uncertainty about fundamentals and	Jan 1987	0.02	0.01
Foreign exchange market	CMAX EUR/GBP	Flight to quality, flight to liquidity	Jan 1987	0.05	0.04
Equity market	Realized volatility of the total market equity index	Uncertainty about fundamentals and	Jan 1987	0.08	0.04
Equity market	CMAX for the total market equity index	Flight to quality, flight to liquidity	Jan 1987	0.15	0.15
Equity market	Stock-bond correlation	Flight to quality	Sep 1991	0.20	0.29
Banking sector	Realized volatility of the banking sector equity index	Uncertainty about fundamentals and	Mar 1987	0.07	0.05
Banking sector	CMAX for the banking sector equity index	Flight to quality, flight to liquidity	Mar 1987	0.11	0.13
Banking sector	Banking sector beta	Uncertainty about fundamentals and	Mar 1987	0.83	0.54

Table 3 shows the cross-correlations between the market specific stress indicators discussed above. In general, the components are correlated and sometimes quite strongly. However, the correlation coefficients do not seem as high that any of the indicators would be redundant.

Table 3. Cross-correlations between market specific stress indicators

The table shows the cross-correlations between market specific stress indicators, calculated from the time period of Jan 1995 – Dec 2014.

	Realized volatility, interbank	TED spread	Spread to Germany	Realized volatility, gov. bond	Realized volatility, EURUSD	CMAX, EURUSD	Realized volatility, EURGBP	CMAX, EURGBP	Realized volatility, equity index	CMAX, equity index	Stock-bond correlation	CMAX, bank index	Realized volatility, bank index	Banking beta
Realized volatility, interbank rate	1													
TED spread	0.0762	1												
Spread to Germany	0.096	-0.0494	1											
Realized volatility, gov. bond	0.3792	0.3885	-0.024	1										
Realized volatility, EURUSD	-0.0354	0.1649	0.0773	0.0353	1									
CMAX, EURUSD	0.1259	0.2801	0.0058	0.2125	0.4683	1								
Realized volatility, EURGBP	0.1026	0.2238	0.361	0.0684	0.6855	0.4458	1							
CMAX, EURGBP	0.1265	-0.2759	-0.0038	0.0514	0.0702	0.4637	0.141	1						
Realized volatility, equity index	-0.0176	0.2186	-0.0124	-0.0709	0.503	0.3541	0.3797	-0.0388	1					
CMAX, equity index	0.0196	0.3748	0.0728	0.0083	0.3973	0.2403	0.284	-0.1847	0.6264	1				
Stock-bond correlation	0.0488	0.6124	-0.2604	0.3705	0.0412	-0.0056	-0.0201	-0.3541	0.1507	0.3563	1			
CMAX, bank index	0.1027	0.6022	0.1249	0.2583	0.456	0.4522	0.4537	-0.0115	0.4072	0.6207	0.3234	1		
Realized volatility, bank index	0.0406	0.646	0.0213	0.356	0.5045	0.3615	0.4776	-0.0265	0.4222	0.5382	0.4192	0.7975	1	
Banking beta	0.1638	0.1374	0.4278	0.3569	-0.0774	-0.0705	0.1316	0.0579	-0.3549	-0.3137	0.0856	0.1064	0.1398	1

4. Construction of the FSI

The remaining steps in constructing an FSI discussed in this section are the transformation of market specific stress indicators and the aggregation of these stress indicators into the final FSI. The above discussed variables represent raw market specific stress indicators. Before aggregating the stress indicators, they need to be transformed on a common scale in order to make them comparable. The FSIs developed in earlier literature suggest several methods of transforming variables, the most common ones being standardization and transforming the variables based on their cumulative distribution functions (CDFs). I consider both of these methods. After the stress indicators have been transformed, the FSI is constructed by aggregating the stress indicators. Most FSIs built earlier aggregate the market specific stress indicators directly into the final stress index. Others, such as the FSIs by Cardarelli et al. (2011) and Hollo et al. (2012) start by computing segment-specific stress sub-indexes and then aggregate these sub-indexes into the final stress index. I consider the three most common aggregation methods used in previous FSIs.³

4.1. Transformation of stress indicators

The individual stress indicators need to be transformed to consider the differences in the absolute values as well as distribution of the original indicators. I use two different methods to transform the raw stress indicators. As the first method, I use the standardization approach, where the stress indicators are assumed to be normally distributed and standardized using the sample mean and standard deviation. Each indicator is demeaned and standardized by

³ The principal component analysis forms the final stress index directly from the market-specific stress indicators.

subtracting the sample mean from each variable before it is divided by its standard deviation. Each indicator at time t is computed as:

$$y_t = \frac{(x_t - \bar{x})}{\sigma} \quad (4)$$

where y_t is the standardized series, \bar{x} the mean of the series and σ the standard deviation of the series. The standardization approach is the most common one in previous literature, which might mainly result from its simplicity and parsimony. The main setbacks of this approach are the assumption that the variables are normally distributed as well as possible revisions in the final FSI if more and more outliers are added to the sample. As the final FSI is updated with additional observations, the mean and standard deviation in equation (4) will change as will the past values of individual indicators and the final FSI. That is, the value of the stress index of a specific month today may change in the future when additional data is added to the sample. This shortcoming is particularly challenging, as the FSI is designed to be updated and used e.g. in comparing stress with historical stress periods. For example Cardarelli et al. (2009) as well as Hakkio and Keeton (2009) use the standardization approach in their FSIs.

As the second transformation method, the variables are transformed based on their cumulative distribution functions (CDFs) following Hollo et al. (2012). In this approach, stress indicators are normalized by transforming the values of each series into the corresponding value of their empirical CDF. In other words, the values are ranked and divided by the total number of observations. The values of each stress indicator are first arranged in ascending order such that $x_{[n]}$ is the sample maximum and $x_{[1]}$ represents the sample minimum. The indicators are then transformed on the basis of their empirical CDF as follows:

$$z_t = \begin{cases} \frac{r}{n} & \text{for } x_{[r]} \leq x_t, r = 1, 2, \dots, n-1 \\ 1 & \text{for } x_t \geq x_{[n]} \end{cases} \quad (5)$$

where z_t is the standardized series, r the ranking number of x_t and n the total number of observations in the sample. If a specific value x occurs more than once, the ranking number assigned to each of these observations is the average of the rankings involved. Following Hollo et al. (2012), the empirical cumulative density distribution is calculated over an initial time period or, the pre-recursion period. After this period, the transformation is applied recursively over expanding samples. That is, the observations outside the pre-recursion period are computed using ordered samples calculated with one new observation added at a time. Through this approach, the individual indicators are transformed into unit-free variables

measured on an ordinal scale ranging from zero to one (Hollo et al., 2012). This recursive transformation provides a solution for the so called reclassification problem, present in the variance-equal weighting method.

The main setback of the CDF transformation method is that it might lead to a loss of information at least to some extent, as it assumes equal distance between any two ranked observations. This is because after the stress indicators have been transformed, all of the subsequent observations are equally far from one another even though the distance between two observations pre-transformation might vary significantly. That is, the approach assumes equal distance between any consecutive observations. This might distort econometric analysis with the FSI. This approach might diminish the effect of extreme events on the stress indicators, making the approach inadequate for detecting systemic events. The transformation of stress indicators based on their empirical CDF has been used in their respective FSIs e.g. by Hollo et al. (2012) and Louzis and Vouldis (2013).

4.2. The aggregation method

After the stress indicators have been transformed, they need to be aggregated into the final index. As noted widely in the FSI literature, the aggregation method, or weighting scheme, is one of the main challenges in constructing an FSI. Illing and Liu (2006) state that it is the most difficult aspect of constructing such an index. The main challenge in combining the variables (the weighting method) results from the lack of a reference series upon which different weighting schemes can be tested (Park and Mercado, 2014). As the several weighting methods introduced in previous literature differ in many respects and produce very different end-results, the weighting method is also an important step in constructing an FSI. However, the majority of the previous FSI studies select a single weighting method, mostly variance-equal weighting, based on qualitative arguments. Often equal weighting or PCA is simply selected without being explicitly discussed. Illing and Liu (2006) offer an exception in this respect, as they compare empirically four different weighting methods. The authors construct an index using factor analysis, credit-weights, variance-equal weights and sample cumulative distribution functions (CDFs). The four constructed indexes are then evaluated based on their ability to match the results of a survey on the most stressful events to the Canadian financial system. While the authors provide a valuable solution for comparing the different weighting schemes, using a survey leaves room for subjectivity in the reference variable.

This study aims to fill the gap in the FSI literature by comparing different weighting schemes and the ability of the resulting indexes to reflect systemic financial stress. While Illing and Liu (2006) compare some of the methods included in this study as well, their study does not include the portfolio-theoretic aggregation. Additionally, their focus is less detailed on systemic financial stress. To form the FSI for Finland, I consider the most common weighting methods used in previous literature: variance-equal weighting, principal component analysis and a portfolio theoretic aggregation method. These methods differ from each other also with regards to the transformation method used, as discussed in the following subsections.

4.2.1. *Variance- equal weighting*

The most common weighting method in previous FSI literature is the use of variance-equal weights (e.g. Balakrishnan et al. (2009), Cardarelli et al. (2011); Lo Duca and Peltonen (2013); Park and Mercado (2013)). Variance-equal weighting is furthermore the most straightforward and perhaps also the most intuitive weighting method. In this approach, the financial stress index is generated by giving equal importance to each component in the index. That is, it assumes that each of the market sectors (e.g. the money market or the stock market) are equally important to the financial system as a whole. The variables are assumed to be normally distributed and the stress indicators are first transformed using the standardization approach described earlier. The division of the indicators by their respective variances can be interpreted as a risk or a variance-equal weight and it avoids the over weighting of more volatile stress indicators (see, e.g., Illing and Liu, 2006; Nelson and Perli, 2005 and Islami and Kurz-Kim, 2013). In other words, the approach adjusts the stress indicators for differences in volatility. The transformed indicators are used to form market or sub-indexes by taking simple averages. The final FSI is simply the arithmetic average of the five market specific stress indicators at each point in time. It is calculated by the following formula:

$$FSI = \frac{\sum_{i=1}^5 s_i}{n} \quad (6)$$

where s_i represents the sub-indexes, and n refers to the number of sub-indexes in the final FSI. Some previous studies (e.g. Islami and Kurz-Kim (2013)) do not calculate market specific sub-indexes but compute the final FSI directly as an arithmetic average of the transformed stress indicators. However, additional information can be provided by the market indexes, as they reveal the conditions prevailing in different parts of the financial system. While the financial stress index indicates the level of stress in the financial markets as a

whole, a closer look at the sub-indexes reveals the different stress levels in different parts of the system.

As said, there are a few issues considering the variance-equal weighting method. Firstly, it assumes the demeaned and standardized stress indicators to follow a normal distribution. This assumption is clearly violated for example in the case of volatilities that are used in practically all the FSIs discussed in this paper. Secondly, the method suffers from a reclassification issue, as the sample mean and standard deviation change whenever new data are added to the sample. This might make comparing historical stress levels more difficult, as a period once defined as a stress period or crisis might later be reclassified as a low stress period if new extreme values are added to the sample. However, it should be noted that even though historical stress levels might change, the ordinal ranking between different stress events should remain the same. One important setback, especially from the perspective of systemic stress, is that variance-equal weighting fails to incorporate the correlation between different stress indicators or submarkets. As this method produces an index which is an arithmetic average of standardized variables, the co-movement of indicators as such does not affect the stress level signaled by the index. Using principal component analysis or portfolio theoretic aggregation, discussed below, higher co-movement between different indicators and markets automatically leads to a higher stress level, which is in line with the definition of systemic financial stress. As correlation between variables does not have an effect on the final index, the variance-equal weighting implicitly assumes perfect correlation across all sub-indexes during the period and fails to account for the changes in correlations over time. The clear benefits of this approach are interpretation and simple decomposition. Because the stress indicators are standardized, the final index measures the distance of each observation of the index, in standard deviations, from the sample mean of the stress index. Moreover, the equal-variance weighting allows for a simple decomposition of sub-indexes and individual stress indicators.

4.2.2. *Principal component analysis*

The variance-equal weighting method does not take into account the possible co-movement of the market specific stress indicators. However, financial stress is more severe in situations when stress prevails in several market sectors at the same time (Hollo et al., 2012). Therefore, methods taking into account this systemic aspect of financial stress might produce better results. One such method is factor analysis and more specifically principal components

analysis, applied for example by Hakkio and Keeton (2009). Here, financial stress is assumed to be the factor most responsible for the co-movement of the market specific variables, identified by principal components. More specifically, stress is defined as the factor most responsible for the observed correlation between individual stress indicators and the factor is identified by the first principal component of the sample correlation matrix that is calculated for the standardized stress indicators (Hakkio and Keeton, 2009). The weight of each indicator in the final index is calculated from the indicator's loadings to the first principal component. The principal component analysis is conducted on transformed stress indicators, commonly transformed by the standardization approach.

Hakkio and Keeton (2009) rationalize their selection of the weighting method by stating that financial stress should make the variables move together. The authors also note that other factors, unrelated to financial stress, may cause the indicators to diverge. The underlying idea is to capture the structural movements in a group of financial variables and especially variables that are believed to move contemporaneously with financial stress. The approach reduces the number of variables and detects the structure in the relationship between the variables. Principal component analysis is widely used to reduce the dimensionality of a data set consisting of several interrelated variables. While reducing dimensionality, the method aims at retaining as much of the variation in the variables as possible. As noted by Louzis and Vouldis (2013), principal components can be used to generate a factor that embodies most of the common variation in a set of variables, while some of the minor variation that might be viewed as noise is ignored. In line with Hakkio and Keeton (2009), the authors define their FSI sub-indexes as the first principal component in a set of financial variables. On the contrary, Park and Mercado (2014) define their emerging market FSIs as the sum of the first three principal components. The decision on the amount of principal components included affects the information captured by the final index, as the more components are included the more information is captured as well. However, as Park and Mercado (2014) note, fewer components might lead to a better index when it comes to identifying crisis periods. Naturally, the more components are included in the final index, the less the method actually reduces the dimensionality in the data.

As the application of principal components in financial stress indices usually involves the standardization of the stress indicators, it suffers from the same reclassification problem discussed above with variance-equal weighting. However, it takes into account the co-movement between the stress indicators. As the method is more complicated, it naturally

leads to an FSI that is more difficult to interpret and construct. Compared with variance-equal weighting, the dynamics and variations in the final index and the underlying indicators are also less intuitive.

4.2.3. *Portfolio theoretic aggregation*

The most recent development in the FSI methodology is the introduction of simple portfolio theory into combining market specific sub-indexes into the final stress index. Hollo et al. (2012) apply this method in their FSI for the euro area called the Composite Indicator of Systemic Stress (CISS). The sub-indexes are first calculated as the arithmetic averages of the market specific stress indicators transformed based on their empirical CDFs. The sub-indexes are then aggregated similarly to the aggregation of individual asset risks into overall portfolio risk. This means that the method, in addition to their variances, takes into account the cross-correlations between all market sectors. Thus, the resulting FSI also involves the systemic aspect of financial stress and puts more weight on situations where high stress prevails in several market segments at the same time. The stronger the correlation of financial stress is across sub-indexes, the more widespread is the financial uncertainty. Following Hollo et al. (2012) the portfolio theoretic FSI is calculated by the following formula:

$$FSI = (w \circ s_t) \times C_t \times (w \circ s_t)', \quad (7)$$

where $w = (w_1, w_2, w_3, w_4, w_5,)$ is the vector of sub-index weights, $s = (s_1, s_2, s_3, s_4, s_5,)$ the vector of sub-indexes, and $(w \circ s_t)$ the Hadamard-product of the vector of sub-index weights and the vector of sub-indexes in time t . $(w \circ s_t)'$ is the transpose of this matrix. C_t is the matrix of time-varying cross-correlation coefficients between sub-indexes i and j :

$$C_t = \begin{pmatrix} 1 & \rho_{12,t} & \rho_{13,t} & \rho_{14,t} & \rho_{15,t} \\ \rho_{21,t} & 1 & \rho_{23,t} & \rho_{24,t} & \rho_{25,t} \\ \rho_{31,t} & \rho_{32,t} & 1 & \rho_{34,t} & \rho_{35,t} \\ \rho_{41,t} & \rho_{42,t} & \rho_{43,t} & 1 & \rho_{45,t} \\ \rho_{51,t} & \rho_{52,t} & \rho_{53,t} & \rho_{54,t} & 1 \end{pmatrix} \quad (8)$$

The time-varying cross-correlations $\rho_{1j,t}$ are estimated recursively on the basis of exponentially weighted moving averages (EWMA) of respective covariances $\sigma_{ij,t}$ and volatilities $\sigma_{i,t}^2$:

$$\begin{aligned}
\sigma_{ij,t} &= \lambda \sigma_{ij,t-1} + (1 - \lambda) \tilde{s}_{i,t} \tilde{s}_{j,t} \\
\sigma_{i,t}^2 &= \lambda \sigma_{i,t-1}^2 + (1 - \lambda) \tilde{s}_{i,t}^2 \\
\rho_{ij,t} &= \sigma_{ij,t} / \sigma_{i,t} \sigma_{j,t}
\end{aligned} \tag{9}$$

where $i = 1, \dots, 5$, $j = 1, \dots, 5$, $i \neq j$, $t = 1, \dots, T$ and $\tilde{s}_{i,t}$ are the demeaned sub-indexes computed by subtracting their theoretical median of 0.5. λ is the decay factor or the smoothing parameter which is held constant through time at a level of 0.75.⁴ Importantly, as pointed out by Hollo et al. (2012) the cross-correlations calculated above indicate whether the level of stress in two market segments is relatively similar in any point in time. That is, the aim is not to offer an econometric prediction of future co-movement risk between the sub-indexes, but to provide a statistic measure of the real-time co-movements.

The portfolio theoretic aggregation has been recently widely used in the FSI literature. After it was introduced by Hollo et al. (2012) it has thereafter been used e.g. by Louzis and Vouldis (2013) and Johansson and Bonthron (2013). Its popularity could at least partly be due to its specific aim and ability to capture the systemic aspect of financial stress, as the index takes into account the correlation between different market sectors. Thus, wide-spread financial stress will automatically lead to higher stress values indicated by the index. Compared with especially a variance-equal weighted index, however, the portfolio theory based index can be more difficult to interpret. As the index is more complicated to construct it is also more difficult to decompose into its sub-market and indicator components.

In their original application, Hollo et al. (2012) also determine the so called portfolio share of each sub-index on the basis of its relative importance for real economic activity. In other words, this refers to the weight of each sub-index in the final FSI, analogously to asset risk in the total portfolio risk. However, the authors note that the differences with an FSI calculated with these real-impact weights and one calculated with equal weights are minor. Thus, for the purpose of this paper, I use equal portfolio weights to calculate the FSIs as it also makes the interpretation and construction of the index less complicated. That is, the sub-index weights used in formula (7) are 25% for each of the five sub-indexes.

⁴ In the original paper by Hollo et al. (2012) a lambda of 0.93 is used as a weekly index is constructed. For a monthly index, the lambda is simply $0.96^4 = 0.75$, assuming 4 weeks per month.

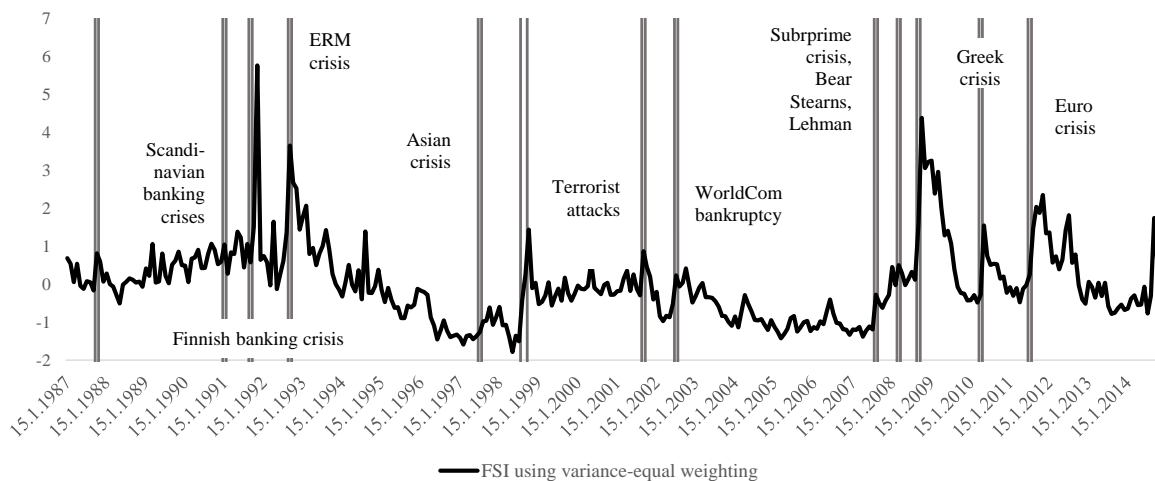
5. Financial stress index for the Finnish Financial system

This section presents the alternative FSIs constructed for the Finnish financial system. Using the methodology described in the previous section, three alternative FSIs are constructed. The FSIs are evaluated based on their ability to reflect past well-known periods of financial stress. Additionally, their respective construction methods are discussed from the perspective of the definitions of systemic stress.

5.1. FSI using variance-equal weighting

Figure 1 presents the financial stress index calculated with the variance-equal weighting method. As discussed, this is the most commonly used method in previous literature. Moreover, the index is simple to construct and interpret compared with the two more advanced construction methods. In this approach, the market-specific stress indicators are transformed using the standardization approach. Market sub-indexes are calculated as the arithmetic average of market specific stress indicators. The final FSI is the arithmetic average of the five sub-indexes, which is again standardized by subtracting the sample mean and the sample standard deviation. Thus, the index values can be interpreted as the number of standard deviations from the sample mean.

Figure 1. The Finnish FSI using variance-equal weighting



5.2. FSI using principal component analysis

Figure 2 presents the financial stress index calculated using the principal component analysis approach. The approach is applied in earlier FSI literature e.g. by Illing and Liu (2006) and Hakkio and Keeton (2009). The index is defined as the first principal component, which captures most of the variation present in the individual stress indicators.

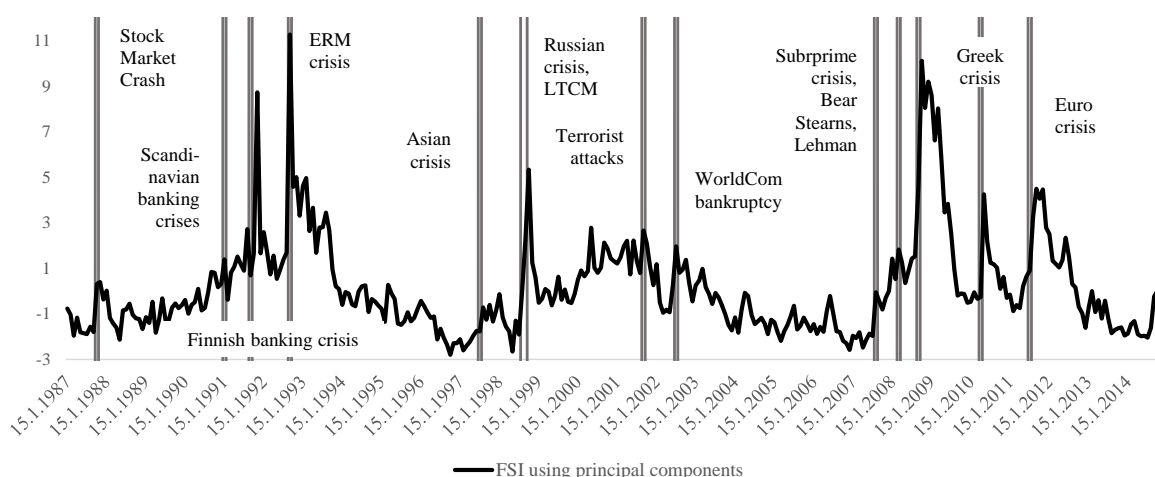
Figure 2. The Finnish FSI using principal components

Table 4 presents the proportion of eigenvalue components or, the total variation within the stress indicators captured by the respective principal components. As can be seen from Table 4, the first principal component captures approximately 31% of the total variation within the indicators. Naturally, the more principal components used in the final stress index, the more of the total variation can be captured. However, adding principal components to the index also adds noise and makes the identification of crisis periods more difficult.

Table 4. Principal component analysis results, eigenvalue components

The table presents the eigenvalue components of the first five principal components as well as the sum of the components 6-14. The component indicates the total variation within the individual stress indicators captured by each principal component.

Eigenvalue components	1	2	3	4	5	6-14
Finnish FSI	0.3141	0.1537	0.1436	0.0977	0.0670	0.2250

Table 5 presents additional results of the principal component analysis, namely the coefficients of the individual stress indicators obtained by principal component analysis. According to the signs of the coefficients, all of the indicators except for the CMAX for the exchange rate between the Euro and the British Pound act to raise financial stress in Finland. Because all of the indicators are standardized, each coefficient represents the effect of one standard deviation change in the respective indicator on the final FSI, defined as the first principal component. The coefficients range from a low of -0.0137 for the EUR/USD CMAX

to 0.4139 for the realized volatility of the banking sector equity index. The differences seem quite large, as they imply, for example, that a one standard deviation change in the banking sector CMAX has almost ten times as big an effect on the final stress index compared with the government bond yield spread to Germany.

Table 5. Principal component analysis results, estimated coefficients of stress indicators

The table presents the coefficient for each stress indicator on the final stress index. The coefficients can be interpreted as the effect of a one standard deviation change in the indicator on the final stress index.

Stress indicator	Coefficient in FSI
Realized volatility, interbank rate	0.0638
TED-spread	0.3262
Spread to Germany	0.0446
Realized volatility, government bond	0.1644
Realized volatility, EUR/USD	0.3196
CMAX, EUR/USD	0.2749
Realized volatility, EUR/GBP	0.3051
CMAX, EUR/GBP	-0.0137
Realized volatility, equity index	0.2986
CMAX, equity index	0.3379
Stock- bond correlation	0.2163
CMAX, banking sector	0.4098
Realized volatility, banking sector	0.4139
Banking sector beta	0.0107
Total variance explained (%)	31.41

5.3. FSI using portfolio theoretic aggregation

Figure 3 presents the financial stress index calculated using the portfolio theoretic aggregation method. In this approach, the market specific stress indicators are standardized recursively using their empirical CDFs. Market sub-indexes are computed as the arithmetic averages of the stress indicators belonging to each sub-market. As discussed in more detail earlier, the final index is calculated by taking into account the time varying cross-correlation coefficients between the sub-indexes and with using equal weights for the sub-indexes. Figure 4 presents the cross-correlations between the market-specific sub-indexes. These time varying cross-correlations are an essential part of the portfolio theoretic FSI, as a higher correlation between the sub-indexes leads to a higher stress level indicated by the final FSI. Figure 4 also reflects

the systemic aspect of this version of the FSI as the truly systemic stress periods are the ones where all of the cross-correlations are close to one. The figure shows the difference between some of the most well-known financial stress periods. The banking crisis of early 1990s, the financial crisis that began in 2007 as well as the euro area government credit crisis all had a significant effect on the Finnish financial system. However, as pointed out by Figure 4, the latter two periods seem to have been more systemic, as they are practically the only periods in the sample when all of the cross-correlations between the sub-indexes are close to one.

Figure 3: The Finnish FSI using portfolio theoretic aggregation

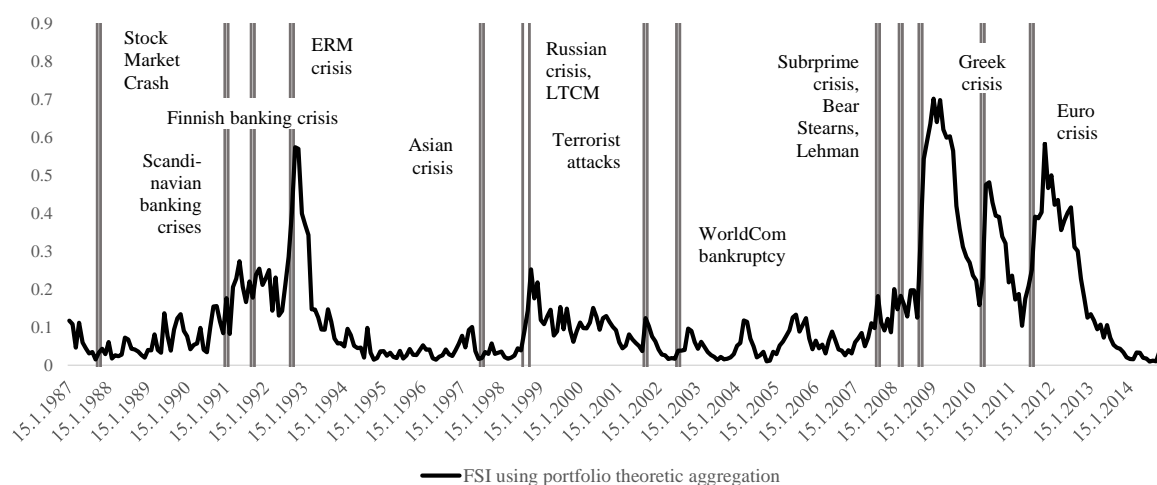
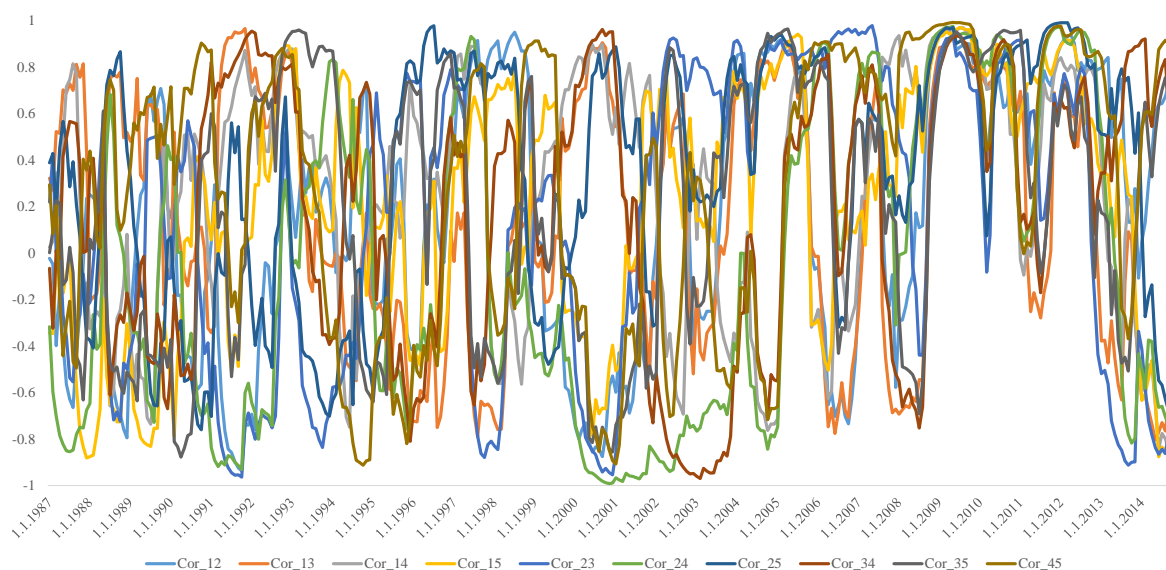


Figure 4: Cross-correlations between sub-indexes

The Figure shows the cross-correlations between the market sub-indexes. The cross-correlations are labelled as follows: 1- money market, 2-bond market, 3-foreign exchange market, 4-equity market and 5-banking sector.



6. Identification of past stress events

As stated by Islami and Kurz-Kim (2013), the most interesting concern in evaluating an FSI is how it works in practice. The researchers evaluate this with the predictive power of the FSI for the real economy. The most common evaluation criterion for financial stress indicators, however, is their ability to identify well-known past periods of financial stress (Hollo et al., 2012). Hakkio and Keeton (2009) assess the performance of their FSI by seeing whether the peaks in the index occur in known periods of financial stress. As there is no observable counterpart of financial stress that the FSIs can be tested against, I follow the approach of Hakkio and Keeton (2009) and simply discuss the peaks in the FSIs constructed in this paper, and whether they can be associated with well-known financial stress episodes. Full discussions of the historical financial crises are left beyond the scope of this study.

Looking at Figures 1-3, it is safe to say that all of the FSIs do react to historical stress periods. Figure 5 plots the three indexes in the same graph and shows the well-known historical financial crisis periods. The historical stress events are picked up from Cardarelli et al. (2009), Hollo et al. (2012), Islami and Kurz-Kim (2013) and placed on the month where each crisis started. For the Finnish banking crisis, the collapse of Skopbank in September 1991 is used as the starting point of the crisis (see, e.g., Nyberg and Vihriälä, 1993). Figure 5 shows that all the Finnish FSIs have reached high levels during five periods. Firstly, all indexes peak during the early 1990s reacting to the Scandinavian banking crisis, the Finnish banking crisis as well as to the ERM crisis, where the European Exchange Rate Mechanism (ERM) was abandoned. The next point in time when all of the three FSIs seem to peak coincides with the Russian crisis as well as with the collapse of Long-Term Capital Management (LTCM). Compared the early 1990s these peaks are less extreme, especially for the portfolio aggregated index. This suggests that the crisis was less systemic in comparison with the earlier peak. All of the indexes, except for the portfolio aggregated index, show minor peaks during the uncertainty related to the burst of the tech-bubble during the early 2000s. However, these peaks do not compare in magnitude with the five periods clearly signaled as stressful by all three indexes. Next, the FSIs peak simultaneously with the bankruptcy of Lehman Brothers in September 2008. For the portfolio aggregated index, the event leads to the highest peak in the sample. The next two peaks in the FSIs can be associated with the Greek crisis and the euro area debt crisis. The application of Greece for financial support in April 2012 is used as the starting point for the Greek crisis. For the euro area debt crisis, the starting point is

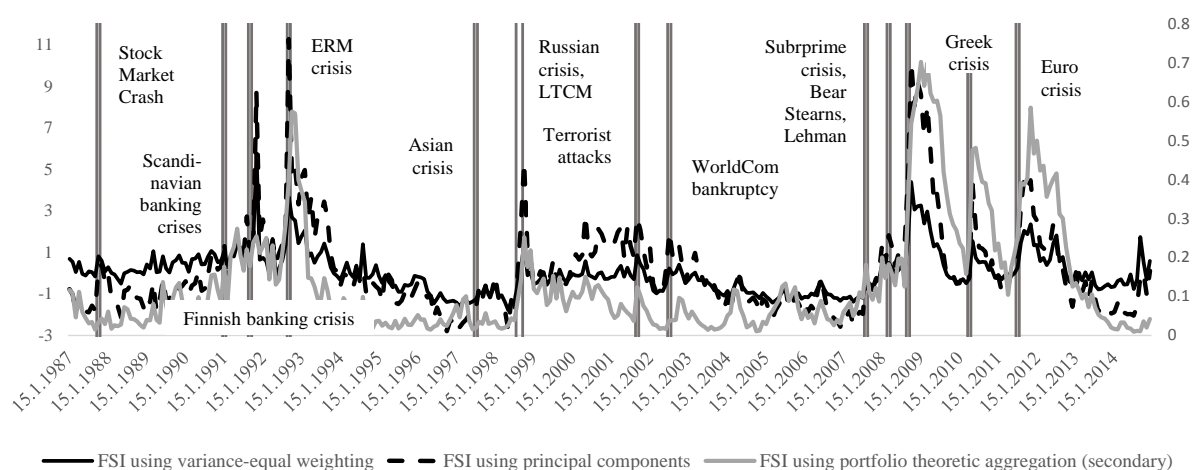
selected as the authorization of the European Financial Stability Board to purchase sovereign bonds in July 2011 (Hubrich and Tetlow, 2015).

After 2012, the principal component index as well as the portfolio aggregated index remain relatively stable. Interestingly, the equal-variance weighted index shows a clear peak in September 2014. This is mainly due to the high realized volatility for the three month Euribor rate. In September 2014 the European Central Bank (ECB) decreased the interest rate on the main refinancing operations, on the marginal lending facility as well as on the deposit facility by 10 basis points.⁵ Additionally, the ECB launched an asset-backed securities program and a new covered bond purchase programme.⁶ While these decisions naturally increase the volatility of the interbank rate, the event as such cannot be assessed as being highly stressful. The equal-variance weighted index however shows a peak comparable to the one following the Greek crisis.

To summarize, it seems that the peaks in the FSIs can almost always be associated with the well-known episodes of financial stress. September 2014 offers an exception for the variance-equal weighted index. Generally, it seems that the FSIs do not falsely report high-stress events. However, another important question is whether there have been any well-known financial stress periods where the FSIs for Finland do not increase. The stock market crash of 1987, the Asian crisis in 1997 and the terrorist attacks of 2001 are examples of events that might have been highly stressful but are not captured by the FSIs. As noted by Cardarelli et al. (2009) the crash of 1987 was purely a securities market stress event and concentrated on the US stock market. Naturally, its effects on the Finnish financial system as a whole might have been limited. In the Asian crisis on the other hand, mainly Thailand, Indonesia, Korea and Malaysia were effected (Cardarelli et al., 2009). The terrorist attacks of 2001 are an example of an event where the uncertainty in the global financial markets increased sharply, but the financial system recovered relatively quickly (Hollo et al., 2012). It could be stated that the Finnish FSIs fail to capture this stress event compared with the CISS index by Hollo et al., (2012), for instance. However, as the Finnish FSIs are monthly indexes and the indicators are largely computed as monthly averages, it is natural that such a short stress event is not well recognized in comparison with more prolonged stress periods.

⁵ <http://www.ecb.europa.eu/press/pr/date/2014/html/pr140904.en.html>

⁶ <http://www.ecb.europa.eu/press/govcdec/otherdec/2014/html/gc140919.en.html>

Figure 5: Finnish FSIs and episodes of financial stress

7. Conclusions

In this study, I have constructed a financial stress index for the Finnish financial system by using three optional methods. The FSIs are monthly indexes, which aim to measure the state of instability in the financial system. After studying the various measures of financial stress used in prior research as well as the relationship with these measures and the real economy, 14 individual stress indicators are selected into the Finnish FSI. Three commonly used aggregation methods, i.e. variance-equal weighting, principal component analysis as well as a portfolio theoretic aggregation method were considered in constructing the Finnish FSI.

Graphical examination of the indexes reveals that the extreme values of the FSIs are generally associated with well-known past financial stress episodes. The principal component method and portfolio theoretic approach seem to produce FSIs that react to the same known stress events, while the variance-equal weighting method produces a FSI that shows significant stress at the end of the sample that is difficult to justify. The portfolio theoretic approach, on the other hand, seems to capture the systemic nature of the stress events better than the principal component method. It also makes a more clear difference between the stable and unstable times at the financial system. Hence, I consider the Finnish FSI constructed with the portfolio theoretic approach to be the best of the three alternative FSIs.

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Appendix A. Market specific sub-indexes

Figures 6-10 show the five market specific sub-indexes that are used to form the final FSIs. The sub-indexes are calculated as arithmetic averages of market-specific stress indicators. The stress indicators are shown in Appendix B.

Figure 6: Money market sub-index

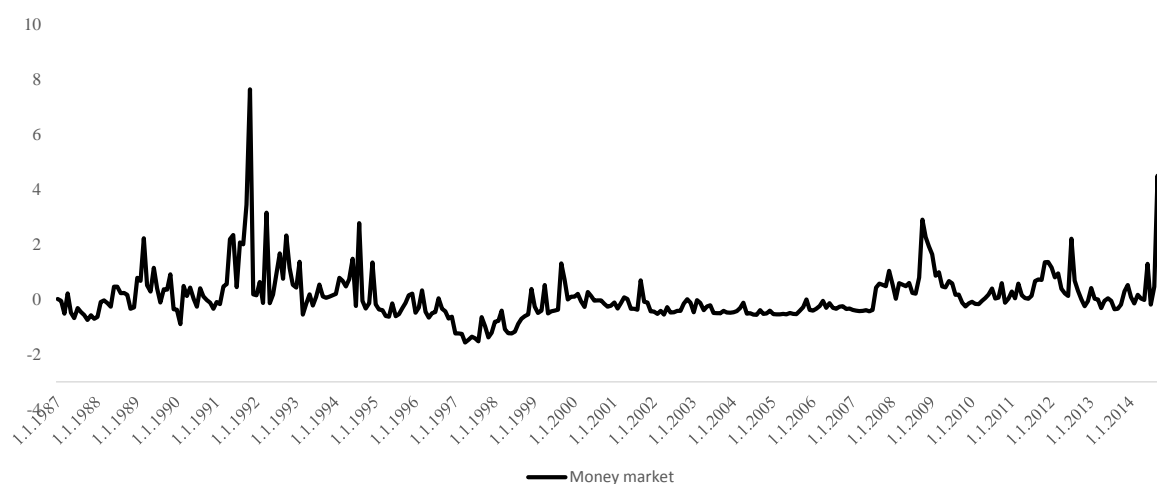


Figure 7: Bond market sub-index

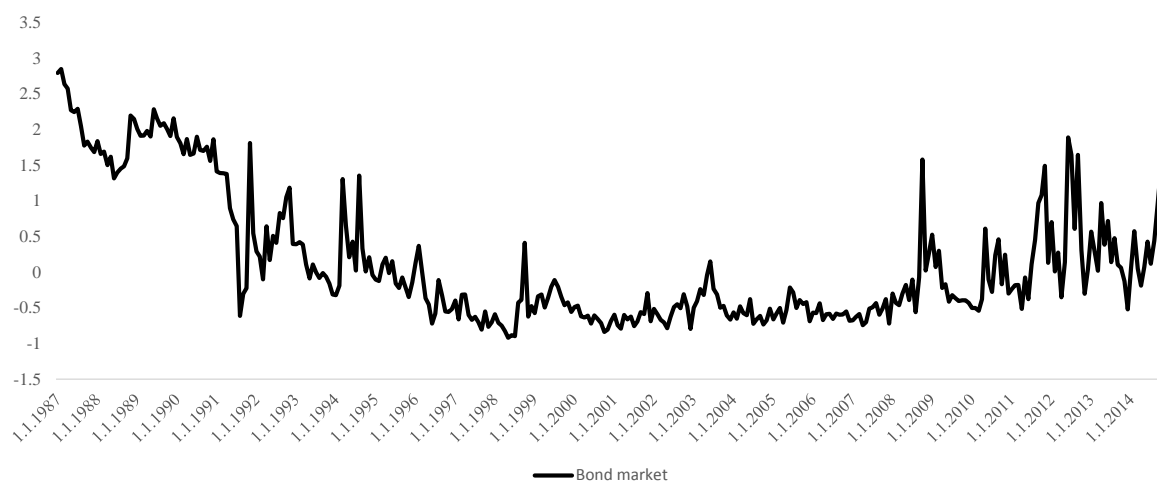
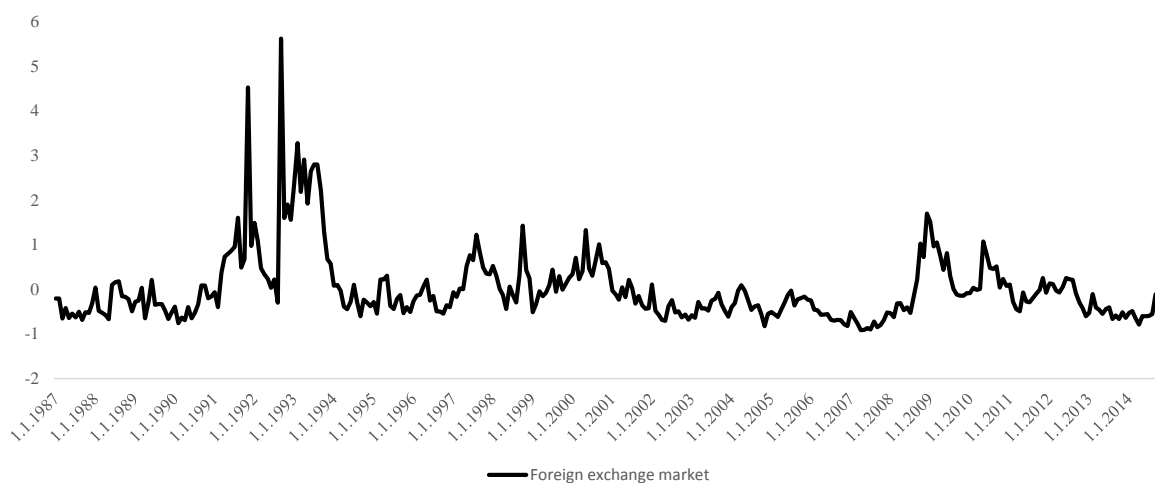
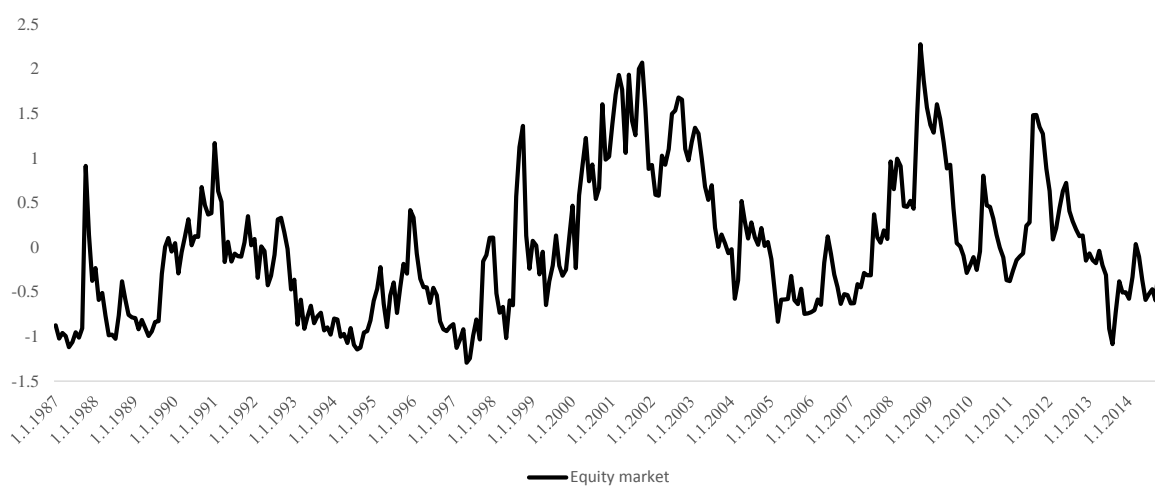
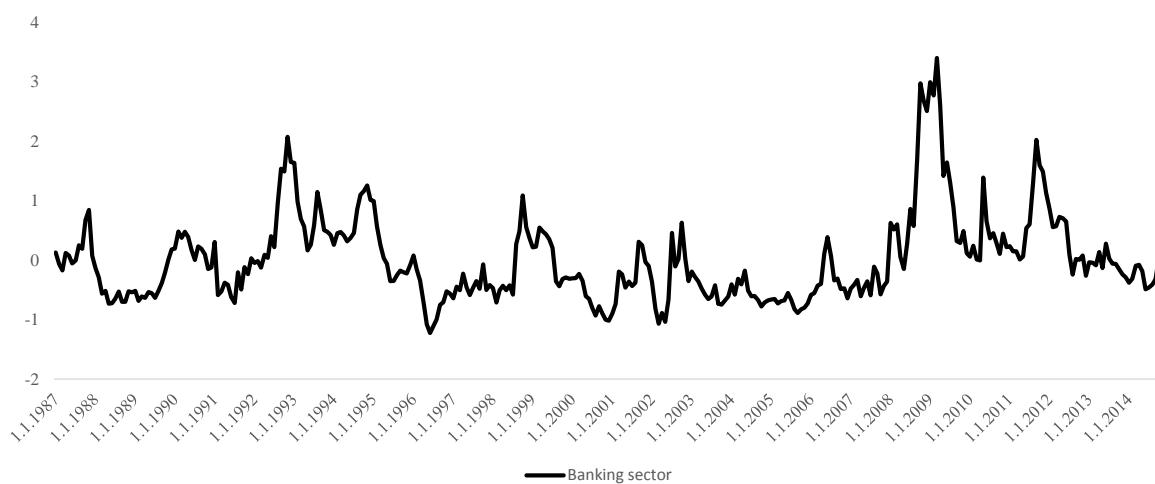


Figure 8: Foreign exchange market sub-index**Figure 9: Equity market sub-index****Figure 10: Banking sector sub-index**

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