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MAGYAR NEMZETI BANK

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A system-wide financial stress indicator for the Hungarian financial system*

(Rendszerszintű stresszindex a magyar pénzügyi rendszerre)

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Contents

Abstract

In this study, a system-wide financial stress index (SWFSI) for the Hungarian financial system is developed. The indicator measures the joint stress level of the Hungarian financial system's main segments: the spot foreign exchange market, the foreign exchange swap market, the secondary market of government bonds, the interbank unsecured money market, the equity market and the banking segment. Stress indices of the six financial system segments are aggregated on the basis of weights which reflect their time-varying cross-correlation structure. As a result, the system-wide financial stress indicator puts greater emphasis on periods in which stress presents permanently in several market segments at the same time. Our results indicate that after February 2005 the default of Lehman Brothers and its global consequences unambiguously acted as a lasting stress event with systemic risk importance from the perspective of the stability of the Hungarian financial system. Finally, the results suggest that the Hungarian financial system's stress level in the period under review (February 1, 2005–September 16, 2011) was driven mainly by disorders in the banking and the foreign exchange swap market segments.

Keywords: financial stress, system-wide financial stress index, financial stability, systemic risk.
JEL: G01, G10, G20, E44.

Összefoglaló

E tanulmányban a magyar pénzügyi rendszerre fejlesztett rendszerszintű pénzügyi stresszindexet (REPSI) mutatjuk be. Az indikátor a spot devizapiac, a devizaswappiac, az államkötvények másodpiaca, a fedezetlen bankközi forintpiac, a tőkepiac valamint a bankrendszer együttes stressz-szintjét méri. A pénzügyi rendszer hat szegmensének stressz-szintjét kifejező indexeket e szegmensindikátorok időben változó korrelációs szerkezetét figyelembe véve aggregáltuk rendszerszintű pénzügyi stresszindexé. E módszernek köszönhetően a rendszerszintű stresszindex relatíve nagyobb súlyt rendel azon időszakokhoz, amikor stressz a pénzügyi rendszer egyszerre több szegmensében is tartósan jelen van, vagyis amikor a súlyos reálgazdasági következményekkel járó kockázatok (rendszerkockázatok) materializálódásának az esélye a legmagasabb. Eredményeink szerint 2005 februárját követően a magyar pénzügyi rendszer stabilitása szempontjából egyértelműen rendszerkockázati jelentőséggel bíró tartós stresszeseménynek a Lehman Brothers 2008. szeptemberi csődje és ennek globális következményei voltak tekinthetők. Végül eredményeink szerint a pénzügyi rendszer stressz-szintjét a vizsgált időszakban (2005. február 1.–2011. szeptember 16.) főként a banki szegmens- és a devizaswappiac zavarai mozgatták.

1 Introduction

The recent global financial and economic crisis has highlighted many weaknesses in financial systems.[1] One of the important lessons from this crisis is that regulators and other authorities responsible for oversight of the financial system did not have tools which could have facilitated an understanding of the risk build-up process and real-time measurement of the risks inherent in the financial system. Another problem was that even when regulators were aware of the build-up of risks, they lacked regulatory tools which allowed for immediate intervention when unfavourable trends affecting the entire financial system were detected. The financial crisis made it clear that the micro-prudential oversight of financial markets and intermediaries should be added to the so-called macro-prudential regulation and oversight, the task of which is to identify imbalances and vulnerabilities at the level of the financial system as a whole, and if necessary to intervene in the processes. A number of initiatives have been launched along these lines, which aim at rethinking the existing regulatory and oversight structure (see Brunnermeier et al., 2009). In parallel, intensive research work has been initiated with the goal of providing those authorities responsible for macro-prudential oversight with analytical tools to help them conduct their tasks.

Prerequisites for developing analytical tools for the identification of systemic risk[2] are, on the one hand, an understanding of the economic processes which lead to the build-up of these risks and, on the other hand, an analysis of events which may eventually induce their materialisation (i.e. the occurrence of a financial crisis with significant real economic costs). In the literature, three main sources of systemic risk can be identified (for a comprehensive overview, see ECB FSR June 2010): the build-up of financial imbalances (e.g. persistent and excessive credit growth associated with significant asset price growth), exogenous external and/or internal shocks affecting financial market participants at the same time, and contagion.

International experience suggests that financial crises with high real economic costs are often preceded by persistent and excessive credit growth associated with significant asset price growth (Borio and Lowe, 2002, 2004; Cardarelli et al., 2011), which typically evolve under favourable economic circumstances. During these periods, growth in consumption and investment, and the expansion of credit to finance further growth in such, can become a self-perpetuating process, accompanied by a latent build-up of risks.[3] This seemingly endless growth in the consumption, investment and credit cycle can come to an end even in the event of a minor financial shock, when a sudden re-pricing of risks affects several segments of the financial system at the same time. In addition, financial instability can become system-wide via exogenous external and/or internal shocks, if financial system agents are affected simultaneously. As a result – depending on the accumulated tensions and imbalances in banks' balance sheets – a number of financial institutions may face capital shortages and an even worse outcome can occur if one or more financial intermediaries go bankrupt (first-round effects). If, as a result of the adverse external and/or internal shocks, the defaulted bank or banks trigger the collapse of other financial institutions or even financial markets, then contagion is present. When contagion takes place via this mechanism, it is considered to be a second-round effect.[4]

[1] The financial system is defined as a set of financial markets, intermediaries and infrastructure.

[2] According to De Bandt and Hartmann (2000), De Bandt, Hartmann and Peydro (2009), "systemic risk can be defined as the risk that financial instability becomes so widespread that it impairs the functioning of a financial system to the point where economic growth and welfare suffer materially."

[3] These periods are usually characterised by the easing of banks' lending standards. This often leads to the access to bank funding by households and firms with unstable income and financial position that is in parallel with the loosening of lending standards the dilution of bank's portfolio quality may also begin.

[4] Contagion, however, can also occur endogenously, irrespective of the above mentioned processes. This occurs most often in the case of an unexpected failure of a systemically important financial institution which may involve the bankruptcy of further banks and the collapse of financial markets. It is important to emphasise that in this case contagion does not arise from the fundamental problems of the systemically important intermediary's operational environment, but from the bank's inappropriate business and operating model, as well as bad management decisions. When contagion and the incidental financial and real economic collapse associated with it is triggered by the default of a systemically important financial intermediary, then contagion is considered as a first-round effect.

It follows that the identification of systemic risk requires the simultaneous use of various tools.

1. Periods characterised by the build-up of financial imbalances can be identified using so-called "early warning" systems.

2. Channels of interbank and financial market contagion as well as key financial market players can be identified, using a variety of contagion models.

3. Finally, central banks' stress tests are often employed to measure the impact of a variety of real economic and financial risks on financial institutions' solvency or rather stress tests can identify those major risks that can threaten financial institutions' stability in the narrow sense and the entire financial system's stability in the broad sense.

Obviously, the longer the period characterised by a build-up of financial imbalances inducing tensions in banks' balance sheets, the more integrated the financial system is, and the more complex the financial products sold, the more serious the adverse consequences of a financial crisis triggering shock or shocks in the financial system and the real economy can be.

The analytical tools listed above (early warning systems, models of interbank and financial market contagion, stress tests) are complemented with one more instrument: financial stress indices that measure the **current** level of frictions, strains and tensions in the financial system as opposed to "early warning" models and stress tests, which in turn provide information on the **prospective** development of system-wide processes.

It is important to emphasise that proper measurement of financial stress is an extremely difficult task. The difficulty lies mainly in the definition of financial stress. In addition, data constraints represent a barrier. Furthermore, the comparison of financial stress indicators developed for different economies might be restricted by structural differences between the individual countries' financial systems, namely the presence or absence of various financial markets and financial products. Moreover, financial innovation can make financial stress measurement and comparison of different countries' financial stress indicators particularly difficult. Financial innovation transforms financial systems; new financial markets and financial products may emerge, the significance of certain financial markets and products may shrink, and the importance of others may increase.[5] If the structure and composition of a financial stress indicator does not follow these developments, then the stress levels signaled by a stress indicator built on a previous information set can be misleading. These difficulties can be extremely acute if one aims to develop and compare "real time" financial stress indices of emerging economies.

Despite the aforementioned difficulties, several attempts have been made to measure financial stress in emerging countries. Balakrishnan et al. (2009), for instance, have constructed financial stress indices for 17 advanced and 26 developing economies to study stress transmission between the two country groups. Their emerging market stress indices capture stress developments in the securities and foreign exchange markets, as well as the banking sector. Lo Duca and Peltonen (2011) developed a framework for assessing systemic risk and for predicting systemic events. In their analysis the authors identify past systemic stress events by using a composite financial stress index, capturing the level of tensions in a country's financial system. Their empirical work covers a set of 28 emerging market and advanced economies. Páles and Varga (2008) developed a composite liquidity stress measure for Hungary, covering the four main Hungarian financial markets (spot foreign exchange market, secondary market of government bonds, interbank unsecured money market, foreign exchange swap market); this is, however, a narrower financial stress concept than the one employed in this study. Finally, Kota and Saqe (2011) constructed a monthly "Financial Systemic Stress Index" for Albania, which captures stress developments in the banking sector, money, spot foreign exchange and housing markets.

But what is meant by financial stress, and when can the degree of financial stress be considered serious (systemic)? In a broad sense, financial stress is a situation when disorders in the financial system unexpectedly influence the price and turnover of financial products, which may be accompanied by the default of systemically important financial institutions and the collapse of the financial resource allocation ability of the financial system, leading to a severe real economic downturn.

[5] In Hungary for example the foreign exchange swap market started to play a dominant role from the beginning of 2005 in parallel with the run-up in foreign currency lending.

The degree of financial stress depends primarily on four things: the size of the shock hitting the system, the extent of accumulated tensions and imbalances in the financial system (e.g. the high share of illiquid assets, maturity mismatches, leverage), and the reactions of decision-makers responsible for financial stability to the shock(s) hitting the financial system, as well as market expectations in relation to such reactions. The degree of financial stress is clearly described as severe when significant tensions and imbalances have built up and the system is hit by a shock of a considerable size. The other extreme is when the financial system is not characterised by imbalances and it only encounters small shocks. Naturally, an infinite number of combinations of these factors can occur. When accumulated asymmetric information problems (moral hazard, adverse selection) and characteristics of the financial system (i.e. unhealthy asset and liability structure) lead to powerful feedback and amplification mechanisms between the financial and real sectors, a financial system can easily move from an apparent resting position to a state of significant financial turbulence.

Accordingly, a financial stress indicator primarily measures the financial system's current stress level, but does not provide guidance as to how the measured stress is being created by different factors: the shock(s) hitting the system, the extent of financial imbalances accumulated, extraordinary turbulence-mitigating actions, and market expectations of external interventions to ease tensions.

A high stress level of the financial system primarily signals the system's instability, but it may also hamper the transmission mechanism of monetary policy. If the link between the central bank's base rate and broad financial indicators (e.g. money market rates, yield spreads, stock prices, etc.) is unstable, on the one hand it may reduce the effectiveness of monetary transmission; on the other hand, the impact of base rate changes on inflation and growth is difficult to predict. Hence, a low stress level in the financial system is a precondition for conducting effective monetary policy.

In this study, a system-wide financial stress index (SWFSI) for the Hungarian financial system is developed. If carefully constructed, by quantitatively expressing the financial system's **current** stress level, it can be used for the following purposes: the identification of financial stress events with systemic risk importance, the timing of entry/exit of unconventional policy measures and strategies (e.g. the introduction and withdrawal of extraordinary liquidity support to the banking system),[6] and comparison of the relative severity of past financial stress events over time. The system-wide financial stress index presented in this study comprises 15 market-based risk measures divided into six main segments of the Hungarian financial system, namely the spot foreign exchange market, the foreign exchange swap market, the secondary market of government bonds, the interbank unsecured money market, the equity market and the banking segment. A separate stress index is computed for each of these six segments after bringing the individual risk measures ("raw" input variables) into a common scale. In aggregating the subindices into a system-wide indicator, the methodology of Holló, Kremer and Lo Duca (2012) is employed: namely the six subindices are aggregated by taking into account their time-varying cross-correlations and "portfolio weights" are attached to each of the six segments on the basis of the relative strength of their dynamic impact on a real economic activity measure. The main methodological innovation of this study is that an empirical critical stress threshold and the risk-preference level of the MNB's decision-makers are calibrated, based on the financial turbulence-mitigating measures introduced by the MNB during the crisis. The result of this exercise suggests that MNB decision-makers prefer to avoid losses due to "Type one" errors (i.e. they do not want to miss events, important from a systemic risk perspective).

Additionally, our results show that after February 2005 the default of Lehman Brothers and its global consequences were clearly a lasting stress event with systemic risk importance from the point of view of the stability of the Hungarian financial system. Furthermore, the results indicate that the financial system's stress level in the period under review (February 1, 2005 – September 16, 2011) was driven mainly by strains in the banking and the foreign exchange swap market segments.

It is important to note that although financial stress indices can be useful tools for identifying systemic stress events, any robust, consistent assessment of systemic risk must also include the parallel use of other analytical tools (stress tests, "early warning" systems, etc.) and expert evaluations. The paper is structured as follows: section two presents the concept of financial stress measurement, section three shows empirical results, and finally section four presents the concluding summary.

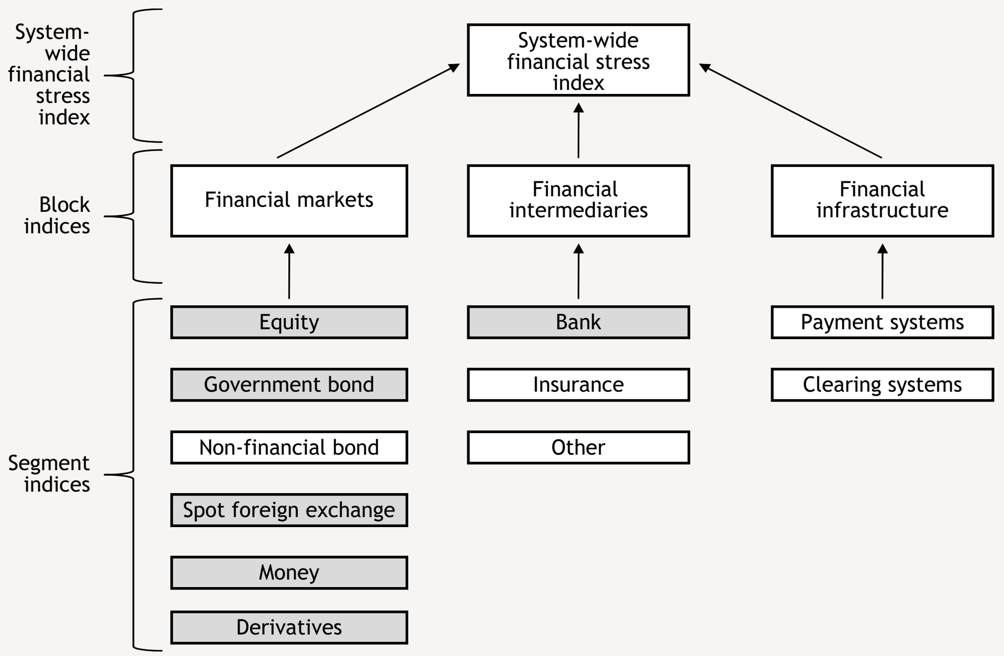
[6] This property is somewhat constrained by the fact that market expectations on interventions are often reflected in the component variables of a financial stress index.

2 The concept of financial stress measurement

Numerous central banks, international financial organisations and investment banks employ financial stress indices for measuring the stress level of financial systems (e.g. Canada: Illing and Liu 2006; USA: Hakkio and Keaton 2009; ECB: Holló, Kremer and Lo Duca, 2012; IMF: Cardarelli et al., 2009; for example, see Hatzius et al. (2010) for a comprehensive comparative analysis). These indicators, however, differ in complexity and in terms of financial system coverage. A financial stress indicator is considered to be system-wide if it measures the joint level of stress in different segments of the financial system.[7] Chart 1 presents an overview of the overall structure of the system-wide index. The basic structure is virtually identical for all financial systems, but – depending on the level of financial development of the various economies – the presence and composition of the distinct blocks can be different.

The structure shown in Chart 1 is useful since, in addition to allowing for the measurement of stress at the level of the entire financial system, it also makes it possible to quantify the extent to which the individual segments contribute to system-wide stress developments (i.e. those segments which drive system-wide stress can be identified). Optimally, there are three levels at which financial stress indices can be computed. The lower level is composed of stress indicators within each building block. These indicators are calculated by aggregating the segment-specific risk factors or "raw" input

Chart 1
Structure of the system-wide financial stress index (SWFSI)



Source: Holló, Kremer and Lo Duca (2012). The grey rectangles indicate the segments covered by the Hungarian system-wide financial stress index.

[7] The coverage of a number of stress indicators is confined only to the banking system (Segoviano and Goodhart, 2009; Avesani, 2005).

variables (e.g. price and non-price variables of financial products). The intermediate level is composed of stress indices for each of the three building blocks. They are computed by aggregating the lower level stress indices. Finally, the top level constitutes the system-wide financial stress indicator for the entire financial system. It comprises the sub-indices belonging to the lower level building blocks. The system-wide financial stress indicator is calculated in three steps.

The first step is the selection of the so-called "raw" input variables for each segment. These variables must be chosen carefully, as the stress levels signaled by the system-wide indicator may change in relation to alterations in the variable composition of its segments. The selection of potential "raw" input variables to be included in the segments should be based on both qualitative and quantitative requirements. Criteria for selecting variables on a qualitative basis are as follows:

- **Data availability in "real time".** Since the system-wide financial stress index measures stress more or less in real time, the data must be available at high frequency (daily/weekly) with a short publication lag. This somewhat constrains the size of the set of potential "raw" input variables, especially for economies with less developed financial systems.

- **Coverage of main segments of a country's financial system.** Variables should be available to capture "real time" risk developments in the main segments of a country's financial system (i.e. in those markets that, due to their size, carry significant financial stability risk).

- **Capturing common features of financial stress leading to financial crises.** Selected variables should capture different symptoms of financial stress, such as rising uncertainty about asset values, the behaviour of investors, and increasing information asymmetries between lenders and borrowers (i.e. the intensification of moral hazard and adverse selection problems, as well as refraining from the possession of risky, illiquid assets). Depending on the intensity of these aspects, market liquidity[8] can decrease, asset price volatility and default risk can rise, risk premiums between risky and less risky assets can widen, and the magnitude of current and anticipated financial losses can increase as well.

Based on the above criteria, 27 potential "raw" input variables are selected for the six financial system segments covered by the Hungarian system-wide financial stress index (the exact variable list can be found in the methodological annex). The selected risk factors can be grouped into four main categories: bid-ask spreads, turnover and transaction number measures, volatility measures and other measures. **Bid-ask spreads** (i.e. the difference between the best bid and ask prices) are widely used measures of liquidity risk. Low bid-ask spreads signal liquid markets and low transaction costs for the liquidation of a position. Under normal circumstances, structural factors (e.g. frequency and size of new issuances, market concentration, etc.) determine the bid-ask spread, while under adverse market conditions market makers increase the spread in order to be compensated for liquidity risk. **Turnover and transaction number measures** of financial markets can provide useful signals about the gravity of asymmetric information problems. In times of financial market turbulence, market participants are more concerned with the solvency position of trading partners (i.e. they are not fully informed about the strength of each others' balance sheets). The more intense these concerns (e.g. the higher the counterparty credit risk concerns), the less market participants are willing to trade (i.e. declining number and volume of transactions) with each other at short notice. **Volatility measures** capture investors' uncertainty about asset values or the behaviour of investors. Finally, the last category (**other measures**) comprises variables capturing flight-to-quality and flight-to-liquidity phenomena (e.g. time-varying correlation coefficient between stock and government bond returns), risk factors embracing the default risk of financial institutions (e.g. default probability and distance to default measures of listed banks),[9] and the so-called CMAX that measures maximum cumulated loss over a moving 3-month period on the equity market. The use of flight-to-liquidity, flight-to-quality and CMAX indicators is motivated by Holló, Kremer and Lo Duca (2012), who also employ similar variables to capture stress in the equity and financial intermediaries segments. Beyond the above considerations, quantitative criteria are also indispensable in narrowing the number of "raw" input variables to those risk

[8] Market liquidity means the sale of different financial instruments without any significant asset price shifts and a decrease in asset values. Market liquidity is distinct from so-called funding liquidity; according to Drehmann and Nikolaou (2009), this is the ability to fulfil financial obligations when they mature. Based on this definition of funding liquidity, risk is driven by the possibility that – over a pre-defined time horizon – a bank cannot meet its payment obligations.

[9] Banking segment stress can also be captured by the yield spread of rated bonds of financial firms against a comparable government bond. Due to the low level of liquidity of bonds issued by financial firms, calculated default probabilities or distance to default measures of listed financial institutions can be better proxies of banking segment stress than yield spreads.

factors with the utmost information content from the potential segment-specific indicator sets. To meet this objective, in the methodological annex we present a method for quantitative variable selection.

The second step in calculating the system-wide financial stress indicator is to bring the individual raw risk factors into a common scale[10] by means of appropriate transformation; the arithmetic averages over the transformed input variables in each segment constitute the six indices of segment-specific stress.

Finally, the segment stress indicators are aggregated into a system-wide financial stress index guided by standard portfolio-theory. As mentioned in the introduction, it is required from a financial stress index to be able to identify stress events with systemic risk importance. If the systemic nature of stress is ignored during the aggregation of segment stress indices into a system-wide indicator, it can result in the system-wide stress index giving higher indicated stress levels than the "actual or true ones"[11] in less turbulent periods. The second factor which can affect the level of system-wide stress and needs to be taken into account during calculation of the system-wide stress indicator is the relative real economic importance (weight) of each segment. Obviously, if the stress level of a relatively more important financial system segment increases, the stress level of the financial system as a whole increases as well (compared to the effect of the stress level of a relatively less important segment rising to the same extent).

The system-wide financial stress indicator is designed to capture two aspects of systemic risk (see Holló, Kremer and Lo Duca, 2012 for details), namely that financial instability is widespread and costly for an economy. The first aspect is captured by weighting based on the time-varying cross-correlations among the segment stress indices, with a simple application of standard portfolio theory (i.e. segment stress indicators are aggregated in the same way as individual asset risks are aggregated into the measure of overall portfolio risk). The second element of the aggregation scheme characterising systemic risk is that portfolio weights are attached to each of the six segment stress indices on the basis of their average relative impact on industrial production ("real-impact weights") by using simple bivariate macro models (see methodological annex).

The underlying supposition is based on an empirically observable phenomenon, namely that during periods characterised by significant financial turbulence, risks in financial markets strongly co-move and opportunities for risk diversification narrow. This can generate a further increase in risks and thus a rise in the financial system's stress level, which could also lead to the collapse of the financial system. **Strong positive co-movement of financial market risks and the persistence of these processes may indicate the presence of financial stress with systemic risk importance**. If the intensity of the financial market turbulence is not significant, the segment-specific stress indices do not move in conjunction strongly and permanently, and hence the turbulence-triggering event is not likely to be a stress episode with inherent systemic risk. Thus, the stress level signaled by a system-wide financial stress index is considered to be significant from a systemic risk perspective if the following two conditions are fulfilled simultaneously:

- signaled stress levels of the segment-specific stress indices are steadily high
- cross-correlations among the segment stress indicators are strong and positive

It needs to be emphasised that a variety of administrative measures (e.g. central bank and government interventions) taken to mitigate financial turbulence and market expectations in relation to these may influence the signals of a financial stress index. Since the variables which the financial stress indicator contains may incorporate this information (e.g. expectations for external interventions), a financial stress index is not an appropriate tool for determining what the financial system's stress level would have been without the introduction of extraordinary measures.

[10] As the ex-post stability of a financial stress index (that is, the stability of signaled stress levels in the past) is an important requirement, the variable normalisation technique must be able to handle the arrival of new information. The percentile-based transformation suggested by Illing and Liu (2006) satisfies this condition; therefore this method was followed during the transformation of the raw risk factors of the Hungarian system-wide financial stress index. The violation of the ex-post stability requirement results in the so-called event reclassification problem. An example of this would be when at a particular point in time a financial stress indicator suggests that an event is highly stressful by historical standards, but when twenty years of data is added to the sample used to compute the indicator the event is no longer classified as a particularly stressful episode.

[11] Regarding the so-called "true" or theoretical stress level, one might ask what it is and how it can be measured. These questions are not a matter of course, but in our view a "true" stress level can be signaled by an index, which is ex-post stable, contains only a limited number of variables with an utmost degree of information content, and is able to differentiate between systemic and non-systemic financial stress episodes.

2.1 COMPUTATION OF THE SYSTEM-WIDE FINANCIAL STRESS INDICATOR

Due to data limitations, the Hungarian system-wide financial stress index cannot provide full-range coverage of the financial system as shown in Chart 1; thus, our system-wide stress index measures the joint stress level of the spot foreign exchange market, the foreign exchange swap market, the secondary market of government bonds, the interbank unsecured money market, the equity market and the banking segment. As indicated previously, both qualitative criteria (i.e. which aspects of financial stress are captured by the given variable) and quantitative methods were employed in selecting the scope of segment-specific variables (i.e. "raw" input variables).

Accordingly, the variable composition of the six segments is as follows:[12]

Spot foreign exchange market

- Average daily bid-ask spread calculated from firm quotations (EUR/HUF spot foreign exchange market)
- 1-month EUR/CHF implied volatility

Secondary market of government bonds

- CEBI[13] (Central European Bond Indices) bid-ask spread index of Hungarian government bonds
- Daily turnover/daily number of transactions
- 5-year Hungarian CDS spread

Interbank unsecured money market

- Average daily bid-ask spread calculated from indicative quotations
- Daily change in average overnight interest rate/daily turnover

Foreign exchange swap market

- Average daily bid-ask spread approximated from implied yields (USD/HUF foreign exchange swap market)[14]
- Daily change in average Tomnext implied yield/daily turnover (USD/HUF foreign exchange swap market)

[12] Data comes from the following sources: Spot foreign exchange market: bid-ask spreads originating from firm quotations are available from the Reuters electronic dealing system (Reuters D3000), while 1-month EUR/CHF implied volatility comes from Bloomberg (Bloomberg code: EURCHFV1M curncy); Secondary market of government bonds: the bid-ask spread originating indirectly from government bond market brokers, calculated from the CEBI (Central European Bond Indices) bid-ask spread index for Hungarian government bonds, while the 5-year Hungarian CDS spread comes from Bloomberg (Bloomberg code: REPHUN CDS USD SR 5Y Corp), and the number and turnover of transactions in the secondary market of government bonds are estimated on the basis of securities account transfer data from the Central Clearing House and Depository Ltd. (KELER); Interbank unsecured money market: bid-ask spread can be calculated from indicative quotations from Reuters, and the daily turnover of the overnight interbank unsecured money market was calculated on the basis of data reported by domestic credit institutions; Foreign exchange swap market: daily bid-ask spreads were computed on the basis of data reported by domestic banks, and the total value of the FX-swap market daily turnover was estimated on the basis of domestic credit institutions' transactions reports to the MNB; Equity market: source of BUX/BUMIX indices: http://www.portfolio.hu/history/adatletoltes.tdp and 10-year German government bond index: Datastream (Datastream code: BMBD10Y); Banking segment: Datastream's Hungarian financial corporate index: Datastream (Datastream code: FINANHN), banks' stock price and capitalisation data (necessary inputs for Merton's default probability model): http://www.portfolio.hu/history/adatletoltes.tdp and http://bet.hu/magyar_egyeb/dinportl/instrdatadownload, banks' asset and liability data (necessary inputs for Merton's default probability model): data reported by domestic banks to the MNB.

[13] The CEBI indices contain government bonds denominated in Central European (Czech, Hungarian, Polish and Slovak) currencies, traded in local markets and calculated and published by Dresdner Kleinwort Wasserstein (DrKW), a London-based investment bank.

[14] Since 95 per cent of Hungarian foreign exchange swap market turnover is comprised of transactions in USD-HUF relations (see Csávás et al., 2006), in determining the variable composition of the foreign exchange swap market segment we relied on price and non-price information of the USD/HUF swap market.

Equity market

- CMAX[15] for the equity market index (BUX)
- CMAX for the equity market index of small-cap and mid-cap stocks (BUMIX)[16]
- Stock-bond correlation: time-varying correlation between the BUX and 10-year German government bond indices[17]

Banking segment

- Default probability of Bank "A"[18]
- Distance to default of Bank "B"
- CMAX of DataStream's Hungarian financial corporate index

Computing the arithmetic average of the transformed segment-specific variables,[19] we arrive at stress indices for each segment. Due to the percentile-based transformation of the "raw" input variables, the measured stress level ranges within the (0,1] interval; high stress index values indicate higher levels of stress, while low values signal lower levels of stress. The time-varying cross-correlations used for aggregating the segment indices were estimated recursively with an IGARCH(1,1) model, which is the approximate version of exponentially weighted moving averages (EWMA) used by many practitioners to forecast daily conditional asset price volatilities and correlations (e.g. see Resti and Sironi, 2007). Time-invariant weights of the segments were derived from bivariate reduced form macro models (VARs).[20] Formally, the system-wide financial stress indicator (SWFSI) can be calculated as follows (see Holló, Kremer and Lo Duca, 2012):

$$SWFSI_t = (x_t \circ s) \cdot C_t \cdot (x_t \circ s)' \qquad (1)$$

where x_t is the vector of segment indices $x_t = (x_{1,t}, x_{2,t}, x_{3,t}, x_{4,t}, x_{5,t}, x_{6,t})$, at time t, s is the vector of constant (time-invariant) segment index weights[21] $s = (s_1, s_2, s_3, s_1, s_4, s_5, s_6)$, and C_t is the matrix of time-varying cross-correlation coefficients $\rho_{ij,t}$ between segment indices i and j at time t. The "$\circ$" sign indicates the element-by-element multiplication of vectors x and s.

$$C_t = \begin{pmatrix} 1 & \rho_{12,t} & \rho_{13,t} & \rho_{14,t} & \rho_{15,t} & \rho_{16,t} \\ \rho_{21,t} & 1 & \rho_{23,t} & \rho_{24,t} & \rho_{25,t} & \rho_{26,t} \\ \rho_{31,t} & \rho_{32,t} & 1 & \rho_{34,t} & \rho_{35,t} & \rho_{36,t} \\ \rho_{41,t} & \rho_{42,t} & \rho_{43,t} & 1 & \rho_{45,t} & \rho_{46,t} \\ \rho_{51,t} & \rho_{52,t} & \rho_{53,t} & \rho_{54,t} & 1 & \rho_{56,t} \\ \rho_{61,t} & \rho_{62,t} & \rho_{63,t} & \rho_{64,t} & \rho_{65,t} & 1 \end{pmatrix} \qquad (2)$$

---

[15] CMAX compares the value of a variable at time t to its maximum over a specified period, according to the following formula: $CMAX_t = 1 - \frac{z_t}{\max[z \in (z_{t-j} | j = 0,1,...T)]}$ where z denotes the variable and T indicates the fixed size of the moving window. In computing CMAX a 90-day moving window was employed.

[16] BUMIX is an index of listed shares with medium and small capitalisation since June 1, 2004.

[17] This calculated variable tries to capture the so-called "flight to quality" phenomena. This means that during periods of extreme financial turbulence, investors refrain from holding risky assets (e.g. stocks) and prefer ones that are considered safe, such as government bonds. As a result, the price of the former decreases, while the price of the latter increases; if this phenomenon prevails, the correlation among the price movements of the two types of assets is negative. The more negative this correlation, the stronger the "flight to quality" effect.

[18] Banks "A" and "B" are two dominant listed institutions in the Hungarian banking system. Default probabilities and distance to default of banks "A" and "B" were computed with the model of Merton (1974) by using the stock price and balance sheet information of these financial institutions. A brief description of Merton's model can be found in the methodological annex.

[19] As Holló, Kremer and Lo Duca (2012) highlighted (see p. 16 footnote 9), the correlation-weights within each segment index could be also applied instead of computing the arithmetic average of the transformed segment-specific variables to arrive at the segment stress indicators. "However the contribution of changes in subindices to changes in the composite indicator would tend to dominate. (Asymptotically, if more and more correlated assets are added to a portfolio the joint contribution of individual asset-return variances to portfolio variance goes to zero)." As another alternative, one could apply principal component analysis (PCA) to aggregate the segment index components, which is however "more sensitive to changes in subindex compositions over time."

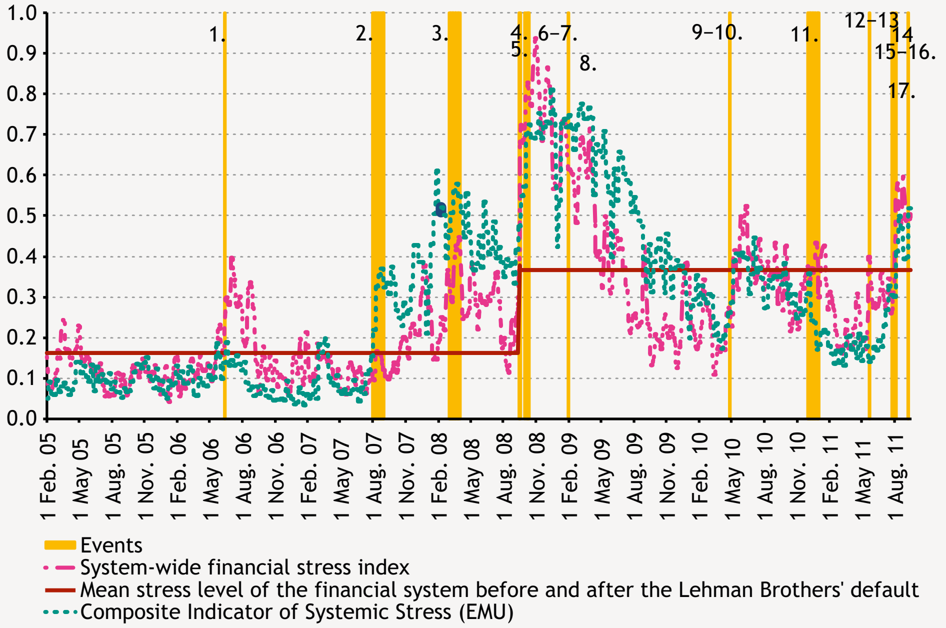
[20] Computation of the relative segment weights is described in the methodological annex.

[21] Relative segment weights can also be time-varying, since the real economic importance of the different financial system segments can change over time, suggesting that periodic revision of the fixed segment-weights might be necessary.

3 Results

Charts 2 and 3 show the system-wide financial stress index (SWFSI), known international and domestic stress events in the last six years (Chart 2), and the contribution of the individual segments to the system-wide stress level (Chart 3).

Chart 2
The system-wide financial stress index (SWFSI)



Note: the composite systemic stress index of the EMU (CISS) is a weekly frequency stress indicator, while the Hungarian system-wide financial stress index (SWFSI) is a daily frequency stress indicator.

In Chart 2, the following financial stress events are marked in chronological order:

1. June 12, 2006: Introduction of the fiscal austerity package ("Programme of new balance 2006–2008") (Hungary)

2. August 2007: Outbreak of the subprime mortgage crisis (USA)

3. March 2008: Turbulence in the Hungarian government bond market

4. September 15, 2008: Default of Lehman Brothers (USA)

5. September 16, 2008: Moody's and Standard and Poor's downgrade ratings on AIG's credit on concerns over continuing losses in mortgage-backed securities, triggering fears of insolvency in relation to the company (USA)

6. September 29, 2008: Emergency Economic Stabilization Act is defeated 228-205 in the United States House of Representatives (USA)

7. **October 6–10, 2008:** Worst week for the stock market in 75 years. The Dow Jones loses 22.1 per cent, its worst week on record, down 40.3 per cent since reaching a record high of 14,164.53 on October 9, 2007. The Standard & Poor's 500 index loses 18.2 per cent, its worst week since 1933, down 42.5 per cent from its high on October 9, 2007

8. **January 30, 2009:** Start of turbulence in the spot foreign exchange market (EUR/HUF exchange rate breaks through the 290 level, reaching EUR/HUF 316 on March 6, 2009) (Hungary)

9. **April 27, 2010:** Downgrade of Greece to junk bond category (S&P: BBB+ → BB+ with negative outlook), start of the euro area's sovereign debt problems

10. **April 27, 2010:** Downgrade of Portugal (S&P: A+ → A–)

11. **December 2010:** Turbulences in the foreign exchange swap market (Hungary)

12. **May 21, 2011:** S&P raises possibility of a downgrade of Italy

13. **July 25, 2011:** S&P closely monitors the sovereign debt processes of the United States

14. **July 25, 2011:** CHF/HUF exchange rate breaks through the 230 level (Hungary)

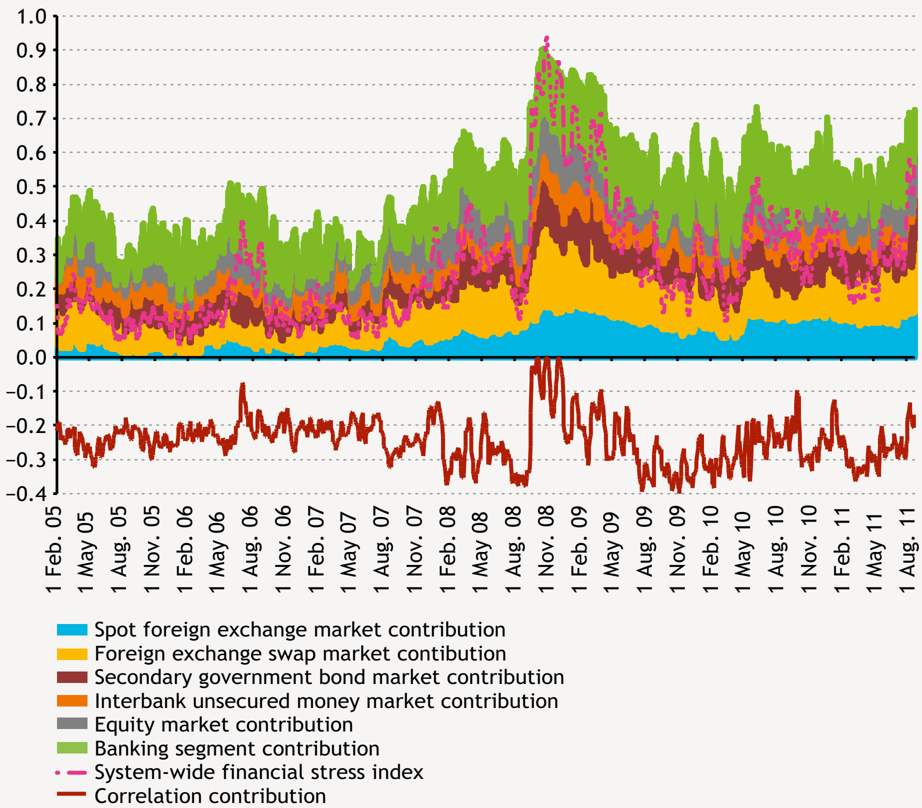
15. **July 27, 2011:** Further downgrade of Greece to the very speculative grade (S&P: CCC → CC)

16. **August 5, 2011:** Downgrade of the United States (S&P: AAA → AA+)

17. **September 9, 2011:** Announcement of government plans related to the final payment of foreign currency denominated loans (Hungary)

Chart 2 suggests that the system-wide financial stress index indicated an increase in the financial system's stress level for all the known stress episodes, although it rose remarkably during the default of Lehman Brothers and the spot foreign exchange market turbulence. While the stress indicator signaled an increase in the Hungarian financial system's stress level due to the outbreak of the US subprime mortgage crisis, system-wide stress was considerably lower than the stress level observed in the EMU's financial system at the same time. This can be mainly explained by the fact that the Hungarian banking system did not have a substantial amount of "subprime" exposure, neither directly nor indirectly, through the parent banks. "Globalisation" of the crisis and the parallel decrease in global risk appetite narrowed Hungary's opportunities to access market funding and raised the price of funds. These developments were further amplified by the deterioration of macroeconomic fundamentals. Concerns about Hungary's financing briefly emerged in the government bond market turbulence in March 2008. The deepening of the global economic recession following the Lehman bankruptcy, uncertainty in relation to the solvency of unhedged Hungarian foreign currency debt holders, and concerns about the stability of the Hungarian banking system further exacerbated fears about the financing of the economy. As a result, the system-wide financial stress indicator jumped to its historical peak. Due to the credit-line agreement with the IMF at the end of October 2008, the Hungarian financial system's stress level declined steadily from its historical peak after the Lehman default, but compared to the pre-Lehman bankruptcy period the system's stress level fluctuated at a higher average level of stress. Starting in mid-July 2011, the Hungarian financial system's stress level once again began to rise steeply. In particular, this was a result of mounting sovereign debt problems in some euro-area member countries and the United States. This phenomenon was mainly due to the unfavourable international processes that boosted demand for "safe-haven" Swiss assets ("flight to quality"), leading to dramatic appreciation of the Swiss franc. The drastic appreciation of the franc significantly heightened concerns about the solvency position of unhedged Hungarian foreign currency – mainly Swiss franc debt holders – and the liquidity and solvency situation of Hungarian banks, which triggered an intense but temporary rise in the financial system's stress level. Due to the intervention of the Swiss National Bank on September 6, 2011, when it fixed the euro-franc exchange rate at the 1.2 level, a gradual decrease of the Hungarian financial system's stress level has begun. The action of the Swiss National Bank directly and positively affected unhedged Hungarian foreign currency debt holders and, accordingly, the entire banking system.

Chart 3
Contribution of various financial system segments to system-wide stress



Note: The extent of correlation contribution can be considered as a separate metric of systemic stress. The smaller the co-movement between the segment stress indices, the less systemic risk is present. When cross-correlations between the segment stress indices are smaller than one, the correlation contribution to the system-wide financial stress index is negative. If the system-wide financial stress indicator would have been computed as a simple arithmetic average of the segment stress indices, then perfect cross-correlations would have been assumed, which in less turbulent periods would result in overestimation of the system-wide stress level. The system-wide financial stress index computed with the "correlation weights" eliminates this problem. Hence, the system-wide financial stress indices coincide with or approach each other only in situations when the stress trigger event is important from a systemic risk perspective (i.e. there is a strong, positive co-movement between the segment-specific risks). Correlation contribution = difference between SWFSI with correlation weights and SWFSI computed as a simple arithmetic average of the segment stress indices.

It is also worth mentioning that the impact of global financial stress events in different countries' financial systems can vary significantly, as suggested by the differences in the signaled stress levels of the Hungarian and the euro-area indices. However, this is not astonishing as the structure and development of distinct financial systems, the composition and complexity of banks' portfolios, and risk concentrations can show substantial variation. Hence, the propagation of common global shocks and their impacts may differ considerably between financial systems (see, for instance, the signaled stress levels by the Hungarian and EMU indices at the time of the outbreak of the subprime mortgage crisis). Chart 3 and Table 1 show the decomposition of the financial system's stress level: those segments can be identified which reacted most intensely to the occurrence of a given stress event, therefore driving the entire financial system's stress.

As Table 1 shows, in June 2006 the stress level of the financial system rose primarily due to the announcement of the economic stabilisation package and was mainly driven by rising stress in the banking segment. This is not surprising, given the negative economic growth, worsening income and financial prospects of households and firms induced by the stabilisation package, which foreshadowed an accelerated deterioration in banks' portfolio quality. It can be also seen in Table 1 that while upon the outbreak of the subprime mortgage crisis the Hungarian financial system's stress level was primarily driven by the foreign exchange swap market, during the government bond market turbulence the system-wide stress (aside from the government bond segment) was triggered by a stress increase in the banking and the foreign exchange swap market segments. In the period following the bankruptcy of Lehman Brothers, the foreign exchange swap market and the strong co-movement of cross-segment correlations (see Chart 3) were responsible for the evolution of system-wide stress, which then reached a historical peak. From mid-July 2011, the sovereign debt problems in some euro-area countries and the United

Table 1
Known financial stress events and financial system segment contributions to system-wide stress

Date	Event	Spot foreign exchange market contribution	Foreign exchange swap market contribution	Secondary government bond market contribution	Interbank unsecured money market contribution	Equity market contribution	Banking segment contribution
June 12, 2006	("Programme of new balance 2006–2008" (Hungary)	11.41%	12.07%	21.12%	10.00%	18.80%	26.58%
August 2007	Outbreak of the subprime mortgage crisis (USA)	15.91%	29.06%	17.10%	11.94%	16.37%	9.62%
March 2008	Turbulence on the Hungarian government bond market	14.24%	17.44%	22.66%	9.12%	17.31%	19.23%
September 15, 2008	Default of Lehman Brothers (USA)	15.19%	27.89%	15.83%	10.93%	13.30%	16.85%
September 16, 2008	Moody's and Standard and Poor's downgrade ratings on AIG's credit (USA)	15.19%	27.89%	15.83%	10.93%	13.30%	16.85%
September 29, 2008	Emergency Economic Stabilization Act is defeated (USA)	12.54%	23.52%	13.21%	7.56%	10.28%	14.31%
October 6–10, 2008	Worst week for the stock market in 75 years	14.24%	23.96%	14.08%	8.05%	10.64%	15.93%
January 30, 2009	Start of turbulence on the spot foreign exchange market (Hungary)	18.27%	19.75%	15.74%	10.61%	13.08%	22.54%
April 27, 2010	Downgrade of Greece to junk bond category	17.95%	21.72%	19.09%	15.48%	7.79%	17.97%
April 27, 2010	Downgrade of Portugal	17.95%	21.72%	19.09%	15.48%	7.79%	17.97%
December 2010	Turbulences on the foreign exchange swap market (Hungary)	19.13%	27.31%	13.51%	11.78%	8.88%	19.38%
May 21, 2011	S&P raises possibility of a downgrade of Italy	19.31%	31.81%	13.59%	10.04%	12.35%	12.90%
July 25, 2011	S&P closely monitors the sovereign debt processes of the United States	19.69%	29.29%	10.54%	10.25%	14.85%	15.38%
July 25, 2011	CHF/HUF exchange rate breaks through the 230 level (Hungary)	19.69%	29.29%	10.54%	10.25%	14.85%	15.38%
July 27, 2011	Further downgrade of Greece to the very speculative grade	19.32%	29.41%	10.69%	10.75%	14.65%	15.19%
August 5, 2011	Downgrade of the United States	17.99%	29.18%	13.89%	9.96%	14.42%	14.55%
September 9, 2011	Announcement of government plans related to the final payment of foreign currency denominated loans (Hungary)	16.95%	17.93%	19.02%	9.00%	17.24%	19.86%

Note: in the table, the primary stress driver segment is market with bright red, while the second and third stress drivers are indicated by brown and mauve. The stress contributions were quantified by taking the 10-working day average of the segment-specific stress indices following the stress events' occurrence. For those stress episodes whose exact starting date could not be identified, calculations were performed using the monthly average of the segment-specific stress levels.

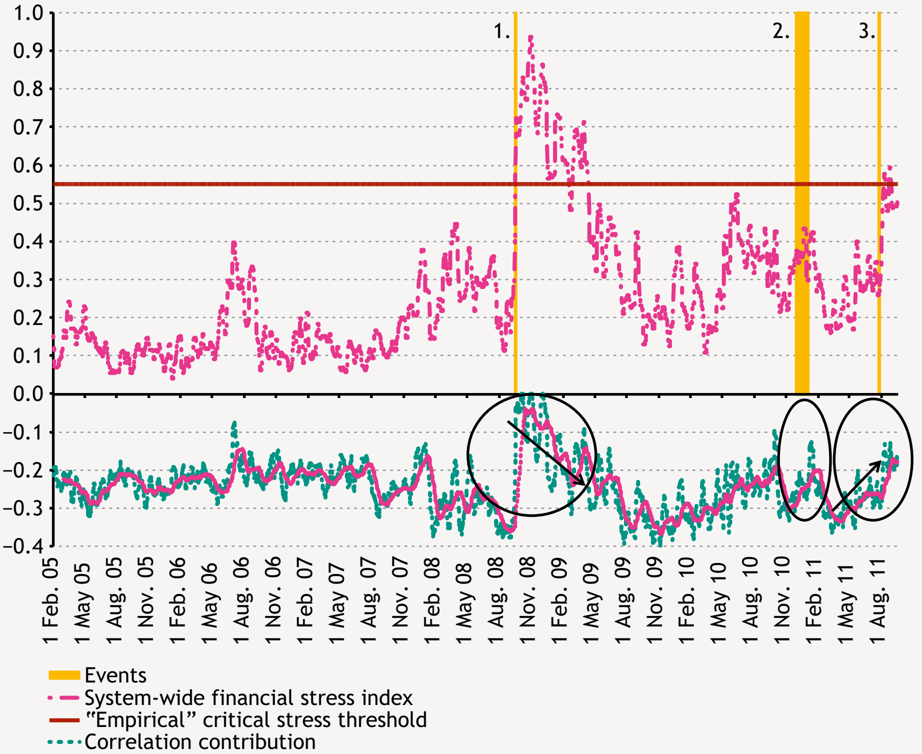
States started to intensify. Since then, the stress level of the Hungarian financial system has been driven by turbulences in the foreign exchange swap, in the spot foreign exchange market and in the banking segments. Finally, the results of the decomposition exercise suggest that in the period under review (February 1, 2005–September 16, 2011), the foreign exchange swap market and the banking segments were the primary drivers of stress developments in the Hungarian financial system.

3.1 EVENT STUDY USING THE SYSTEM-WIDE FINANCIAL STRESS INDICATOR (SWFSI)

Chart 4 presents the system-wide financial stress index (SWFSI), with the correlation contribution expressing the co-movement of the financial system segment stress indices, known financial stress events and the empirical stress threshold.[22] In Table 2, three stress events are compared, based on the behaviour of the system-wide financial stress index (SWFSI), its segment indicators and the correlation contribution. These three events are the default of Lehman Brothers and the period immediately thereafter, the tensions in the foreign exchange swap market in December 2010, and the financial market developments from the second half of July 2011, which became more turbulent due to sovereign debt problems in some peripheral euro-area economies, the United States and the related downgrade of the US sovereign credit rating.

Based on Chart 4 and the data in Table 2, it can be stated with certainty that the default of Lehman Brothers and its direct global consequences created a financial stress event with systemic risk importance for Hungary.[23] Our goal is to analyse

Chart 4
System-wide financial stress index (SWFSI) and the empirical stress threshold



Note: in the chart, the analysed stress events are marked with numbers: default of Lehman Brothers (1), turbulence in the foreign exchange swap market (2), and financial market turbulence from mid-July 2011 (3).

whether the two other events resembled or differed from the processes following the Lehman default, the respective aspects of their resemblance or differences, and whether the foreign exchange swap market turbulence and the financial distress from the second half of July 2011 included the nature of systemic risk. In Table 2, mean values of the system-wide financial stress index, its segment indicators and the percentage differences from their historical maximums can be seen. According to the results, the foreign exchange swap market turbulence in December 2010 was not a financial stress event which was significant from a systemic risk perspective. On the one hand, the average values of the segment stress

[22] Calculation of the "empirical" critical stress threshold will be presented in section 3.3.2.

[23] Values of the segment stress indices were permanently high and co-moved in a positive direction. As a result, cross-correlations between the segment-indices increased permanently, the correlation contribution was close to zero, and values of the system-wide financial stress index were permanently higher than the empirical critical stress threshold, which was followed by the materialisation of systemic risk (i.e. a significant recession began).

indicators during the 10 days after the event were, on average, 53 per cent below their historical maximums, compared to the average 24 per cent difference observed during the Lehman bankruptcy period. On the other hand, cross-correlations between the segment indices were more than five times higher during the time of the Lehman bankruptcy than they were during the period of the foreign exchange swap market turbulence.[24] It can also be read from Chart 4 that the system-wide financial stress indicator throughout the foreign exchange swap market turbulence fluctuated below the "empirical" critical stress threshold (calculation of the "empirical" critical stress threshold will be presented in section 3.3.2 below).

Based on these events, the question arises as to whether the intensification of financial turbulence from mid-July 2011 can be considered as relevant from a systemic risk viewpoint. The first clue to this is whether or not the system-wide financial stress indicator (SWFSI) during this stress event permanently exceeded the MNB's empirical stress threshold. According to the results of Table 2, the mean stress levels of the financial system's segments during 10 days after the event were on average 38 per cent lower than their historical maximums, in contrast to the average 24 per cent difference observed at the time of the Lehman bankruptcy and the 53 per cent mean difference experienced during the period of the foreign exchange swap market turbulence. In the case of the financial turbulence which started in mid-July 2011, compared to the period of foreign exchange swap market disorders, growth in the average stress level in all segments and a tendentious increase in the segments' cross-correlations can be observed. Not surprisingly, due to the simultaneously rising stress levels of the financial system's segments and hence the strengthening of cross-correlations among the segment stress indicators, the financial system's stress level increased here more than during the period of foreign exchange swap market turbulence and **temporarily** exceeded the empirical critical stress threshold. By analysing the strength of correlations, it can be said that for 10 days after the Lehman bankruptcy the average correlation level was three times stronger than observed during the financial turbulence which began in mid-July 2011, while this figure was more than five times greater at the time of the foreign exchange swap market turmoil. However, by analysing the signals of the system-wide financial stress indicator over a longer horizon (one month after the event), gradual normalisation of financial system disorders could be observed; the system-wide financial stress indicator (SWFSI) returned to levels below the critical stress threshold. The

Table 2
Mean values of the system-wide financial stress index and its segment indices associated with known financial stress events

	Mean values within 10 days after the event occurs (percentage deviation from the historical maximum)		
Date	**2008th September 15**	**December 2010**	**2011th July 25**
Market segment/Event	**Default of Lehman Brothers (USA)**	**Turbulences on the foreign exchange swap market (Hungary)**	**S&P monitors closely the sovereign debt processes of the United States**
Spot foreign exchange market	0.110 (−28%)	0.090 (−41%)	0.120 (−21%)
Foreign exchange swap market	0.202 (−18%)	0.128 (−48%)	0.180 (−27%)
Secondary market of goverment bonds	0.115 (−20%)	0.065 (−55%)	0.065 (−54%)
Interbank unsecured money market	0.08 (−35%)	0.054 (−56%)	0.063 (−48%)
Equity market	0.096 (−15%)	0.04 (−65%)	0.091 (−20%)
Banking segment	0.122 (−32%)	0.092 (−49%)	0.094 (−47%)
Correlation contribution	−0,047	−0,266	−0,134
System-wide financial stress index (SWFSI)	0.678 (−26%)	0.365 (−60%)	0.48 (−48%)
SWSFI continously above the critical stress threshold?	Yes	No	No

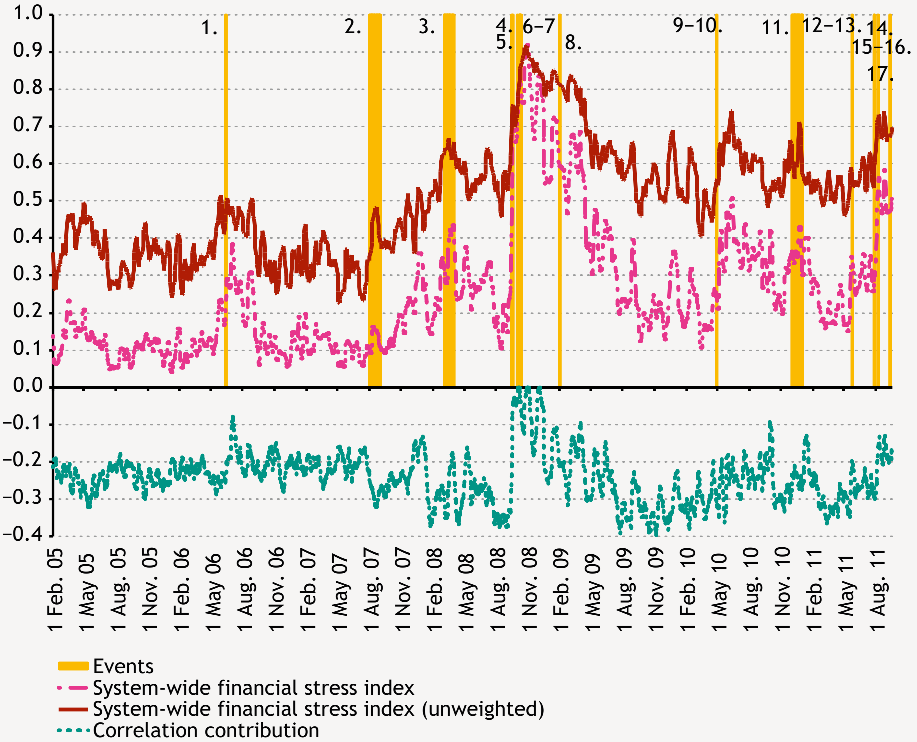
[24] It is important to note again that the strength of cross-correlations among the segment stress indicators is indicated by the correlation-contribution, which is the difference between the cross-correlation weighted system-wide financial stress index and the system-wide stress indicator, computed as an arithmetic average of the segment indices. Since the latter implicitly assumes perfect cross-correlations between the segment stress indices, the two indicators only coincide when the stress event is relevant from a systemic risk perspective (i.e. when more segments of the financial system are simultaneously and permanently affected by financial turmoil). By comparing the values of correlation-contribution related to distinct stress events, the role of the co-movement of the segment-specific stress indicators in shaping the system-wide stress level can be determined. The idea can be illustrated via a simple example by using the data seen in Table 2. During the period of foreign exchange swap market turbulence in December 2010, the 10-day average value of the correlation-contribution was −0.266, while during the Lehman bankruptcy period it was −0.047. The ratio of the first and second values is 5.66, denoting that at the time of the Lehman default cross-segment correlations exceeded on average to such a degree the cross-correlations observed at the time of foreign exchange market turbulence.

temporary normalisation of disorders in the Hungarian financial system can mainly be explained by the extraordinary and continuous financial turbulence-mitigating measures taken by the world's leading central banks (e.g. the Swiss National Bank's euro-franc exchange rate fixing decision on September 6, 2011) and the MNB as well as their commitment to reduce financial turmoil. As a result the segment-specific stress levels started to decline and the strong, positive co-movement of the segment stress indices broke, as the correlation-contribution started to decrease after a period of continuous growth. Against this background, it can be concluded that the financial turbulence which intensified from mid-July 2011 and was driven mainly by international processes in the light of the available data (February 1, 2005–September 16, 2011) is more serious than the foreign exchange swap market turmoil in December 2010 and less serious than the problems experienced at the time of the Lehman bankruptcy.

3.2 EVALUATION OF THE SYSTEM-WIDE FINANCIAL STRESS INDEX

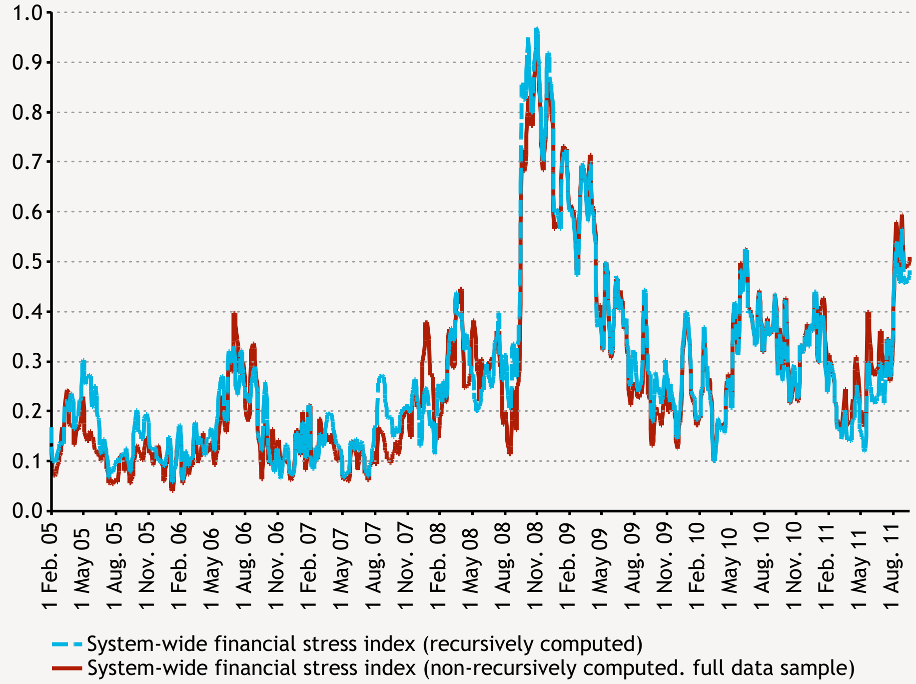
As stated above, the rationale behind correlation-based weighting of the segment stress indicators in a system-wide financial stress index was that with this weighting methodology the systemic risk relevance of distinct events and time periods can be captured (i.e. during periods of significant financial turbulence, risks in financial markets co-move strongly; therefore, the system-wide indicator puts more weight on events and periods when stress prevails on various segments of the financial system at the same time). Without this weighting scheme, one cannot properly distinguish periods characterised by severe financial stress from those marked by less heavy financial strains (i.e. the signaled stress level for the latter period might be "overestimated"). From a portfolio-theoretic perspective, the unweighted version of a system-wide stress index can be considered as a special case of the correlation-weighted indicator, namely when there is perfect correlation among the segment stress indices. This happens either during extremely tranquil or exceptionally turbulent times (i.e. the segment stress indicators are either at their historically high or low levels). This characteristic is well captured by Chart 5 below, which depicts the correlation-weighted and unweighted versions of the system-wide financial stress index. As is obvious from the chart, in normal or less turbulent times the signaled stress levels of the unweighted SWFSI are considerably higher than warranted by the gravity of the situation (i.e. the co-movement among the segment-stress indices as suggested by the correlation-contribution is not intense). However, the reverse is true during periods characterised by extreme

Chart 5
Correlation-weighted system-wide financial stress index (marked in black) versus arithmetic average of subindices (marked in blue)



Note: the numbers shown in figure 5 indicate the financial stress events listed above.

Chart 6
Recursive and non-recursive (i.e. full-sample) computation of the system-wide financial stress indicator



financial stress. In these periods (e.g. aftermath of the collapse of Lehman Brothers) – that is, when correlations among the segment-specific stress indicators are very high or almost perfect – the correlation-weighted and unweighted system-wide stress indicators closely approach each other or overlap perfectly. Hence, the correlation-contribution, which is the difference between the correlation-weighted and unweighted versions of the SWFSI, approaches zero.

A financial stress indicator has to have not only the ability to separate systemic from non-systemic events, but another required property is that the signaled level of stress by a financial stress index has to be stable over time. If this condition is not met, because past values of the SWFSI may change as a result of the arrival of new information, the real-time monitoring of financial stress may not be informative. Hence, users of stress indicators may have to reconsider their past judgements about financial stress developments [e.g. no robust historical comparison of past stress episodes can be made (event reclassification problem)]. Furthermore, calculation of critical threshold levels for the stress index would not make sense.

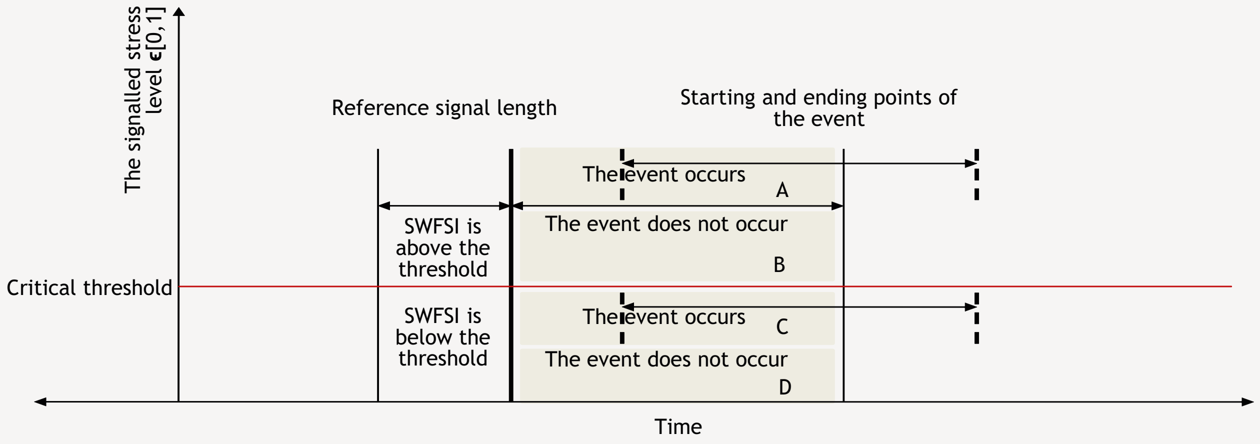
To check whether the employed percentile-based transformation of the raw input variables is robust to the arrival of new information two variants of the SWFSI were computed: a recursive one and a non-recursive one. First, the "raw" input variables were percentile-transformed in a recursive way over expanding samples[25] (recursion began in December 31, 2007); the SWFSI was then computed, using these recursively transformed variables to arrive at the recursive system-wide stress index. Chart 6 suggests the robustness of the employed variable transformation method to the arrival of new information, i.e. the recursively and non-recursively computed stress indicators coincide strongly, as affirmed by the mean absolute error of 0.032 and the mean error of −0.01.

3.3 THE CRITICAL STRESS LEVEL OF THE FINANCIAL SYSTEM

Decision-makers responsible for financial stability must not only monitor the evolution of a financial system's stress, but also need to decide what level of stress is regarded as critical from the perspective of systemic stability (i.e. at what level

[25] To introduce the "real-time character" of the system-wide financial stress index, the percentile transformation was applied recursively over expanding samples. The non-recursive percentile transformation was applied to all observations for the "raw" input variables from the pre-recursion period running from 1 February 2005 to 31 December 2007. All subsequent observations were transformed recursively by adding one new observation to the pre-recursion sample.

Chart 7
Graphical illustration of the signalling approach



Note: values of the system-wide financial stress indicator (SWFSI) can assume values within the (0,1), due to the percentile-based transformation of the "raw" input variables.

of stress extraordinary turbulence-mitigating measures may be required to prevent the materialisation of systemic risk).[26] The critical threshold is considered the level of stress where, if it is **permanently** exceeded by the system-wide stress index, there is significant likelihood that systemic risk will materialise (i.e. serious adverse consequences for the real economy will ensue). This occurs when the signaled stress levels of the segment stress indices are consistently high and, consequently, cross-correlations between them are strong and positive. To compute the critical stress threshold, we rely on the work of Alessi and Detken (2009). A graphic illustration of their approach is shown in Chart 7 below.

The logic behind the method is that if an analysed indicator (in our case, the system-wide financial stress index) exceeds its critical threshold over a predetermined time period (the reference signal length),[27] then following the signal there is significant likelihood that the event (in our case, the materialisation of systemic risk) will occur. In Chart 7, three major time intervals are marked: the reference signal length ("SWFSI is above the threshold" label in Chart 7), the post-signal reference period ("The event occurs" label in Chart 7) that describes the time period in which the event is expected to occur, and the event's starting and ending points ("Starting and ending points of the event" label in Chart 7). There are four possibilities:

1. the SWFSI permanently exceeds the critical stress threshold and the event occurs (A)

2. the SWFSI permanently exceeds the critical stress threshold, but the event does not occur (B) → ["Type two" error]

3. the SWFSI is permanently below the critical stress threshold, but the event occurs (C) → ["Type one" error]

4. the SWFSI is permanently below the critical stress threshold and the event does not occur (D)

For example, "A" is the number of months, quarters, etc. when the signal was correct, while "B" is the number of months, quarters, etc. when the indicator gave a false alarm. Cases "C" and "D" can be interpreted similarly. Namely, "C" and "D" denote "Type one" and "Type two" errors respectively, and the ratios of these errors are determined by **C/(A+C)** [share of missed events] and **B/(B+D)** [share of false alarms]. We can assume that in the case of false signals (i.e. missed events and false alarms), the use of a system-wide financial stress indicator imposes costs. The question is how these costs relate to the costs resulting from the lack of the system-wide index (for the sake of simplicity, "costs" refers to real economic costs, arising from materialisation of systemic risk). If decision-makers are able to identify stress events with systemic

[26] By their nature, financial stress indices such as the SWFSI primarily support decision-making in the crisis management phase. The support of crisis prevention functions requires forward-looking analytical tools such as early warning systems and stress tests.

[27] The reference signal length represents the minimum time that the analysed risk metric must stay above the critical threshold in order for its signal to be considered relevant. International crisis experiences may help defining the length of this reference interval.

risk importance more effectively with the system-wide financial stress index than without it (i.e. relying only on past experience and intuition), then the existence of the indicator is justified and the costs of erroneous decisions stemming from the lack of the index can be mitigated significantly.

For decision-makers who are responsible for financial stability, the main problem is clearly the "Type one" error (i.e. when the event is important from a systemic risk perspective, but the stress index does not indicate this). This implies that decision-makers are not able to take the necessary actions in time to prevent the materialisation of systemic risk. The "Type two" error could result in the implementation of turbulence-mitigating measures which are unnecessary, as the financial turmoil does not actually require extraordinary intervention. The costs of "Type one" errors are obviously much higher than the costs of losses related to "Type two" errors. If under the category of "costs" only real economic costs are considered, then "Type two" error-related losses are virtually null. Based on this reasoning, risk-averse decision-makers – who are interested in avoiding financial distress with high real economic costs – prefer a low critical stress threshold. If the critical stress threshold is low, then the likelihood of a "Type one" error can be reduced considerably, as the signals of the system-wide indicator often exceed the critical threshold. In parallel with this, however, the frequency of false signals (the stress index almost always signals an event, but the event does not occur) increases substantially (i.e. the probability of a "Type two" error increases). Against this background, the magnitude of "Type one" and "Type two" errors can only be reduced at the expense of the other; the two cannot be curtailed simultaneously. From the decision-makers' perspective, the optimal critical stress threshold is one which, subject to the central bankers' risk preferences (relative weights associated with "Type one" and "Type two" errors), minimises the loss stemming from the two error types. The loss function to be minimised is defined in (3) as follows:

$$L = \theta \cdot \frac{C}{A+C} + (1-\theta) \cdot \frac{B}{B+D} \tag{3}$$

Parameter Θ expresses central bankers' relative risk preference towards "Type one" and "Type two" errors and measures which error types the decision-makers aim to reduce. The closer that Θ is to one, the more that central bankers are interested in avoiding losses due to "Type one" errors than losses due to "Type two" errors. The value of the loss function depends directly on the central bankers' relative risk preference and the size of the "Type one" [share of missed events] and "Type two" [share of false alarms] error ratios, while the latter hinges on the critical stress threshold and the assumed duration of the signal (reference signal length). During the calculations (baseline specification), there was considered to be a signal when the system-wide financial stress index **permanently exceeded the critical stress threshold for at least 20 working days (1 month)** and the event triggered by the signal (i.e. the materialisation of systemic risk) was a decline greater than 2 per cent of yearly real GDP (i.e. change over the same quarter of the previous year), lasting for at least one year and occurring within one year after the signal. The robustness of the "event assumption" on the calibrated critical stress threshold is checked and the related results are presented in sections 3.3.1 and 3.3.2 below.

In fact, the lack of a system-wide financial stress indicator is equivalent to as if the central bankers were to completely ignore its signals, both those above and below the critical threshold. The size of loss stemming from neglecting signals above the critical threshold (A=B=0) according to (3) is Θ (i.e. the degree of relative risk aversion). By contrast, the loss from neglecting the signals below the critical threshold (C=D=0) according to (3) is (1–Θ). Consequently, the system-wide financial stress index can be considered as informative in terms of identifying stress events with systemic risk importance when, subject to the decision-makers' relative risk preference (Θ), the loss computed according to (3) does not exceed the minimum of losses arising from complete ignorance of the financial stress indicator's signals (see equation 4 below). Hence, with the system-wide financial stress indicator being systemically relevant, stress events can be identified more accurately than if decision-makers relied simply on their past experience and intuition.

$$\min[\theta;1-\theta] - \theta \cdot \frac{C}{A+C} - (1-\theta) \cdot \frac{B}{B+D} > 0 \tag{4}$$

3.3.1 Computing the critical stress level of the financial system (with no available information about the decision-makers' risk preferences)

Since we are not aware of the decision-makers' exact risk preference, the function defined in (4) is conditionally optimised. The steps of this procedure are as follows:

1. Computing critical stress thresholds related to the different percentiles (1-99th) of the system-wide financial stress indicator's own distribution

2. Calculating the share of missed events and the share of false alarms subject to the different critical stress thresholds computed in the previous point (recall that in the baseline case the event triggered by the signal is a greater than 2 per cent of yearly real GDP decline)

3. Recovering the optimal critical stress threshold. An optimal critical threshold exists only conditionally on Θ (i.e. the risk preference level); that is, the critical stress level is "risk-preference" dependent. The closer Θ is to zero, the more central bankers are interested in avoiding losses due to "Type two" than due to "Type one" errors (i.e. they want to avoid false alarms) and, accordingly, prefer higher critical stress thresholds. Conversely, the closer is Θ to one (i.e. central bankers are interested in avoiding losses due to "Type one" than due to "Type two" errors), the lower the critical stress threshold preferred by the decision-maker. To recover the optimal critical stress threshold, the risk-preference level of the decision-makers is fixed at Θ=0.5 (i.e. "risk-neutral" decision-makers are assumed) and values of function 4 above are computed by using the share of false alarms and missed events belonging to the different critical stress thresholds calculated in the previous point. The optimal critical stress threshold is the one that maximizes function 4 at the fixed preference level (Θ=0.5). Also verified is how the "risk-preference" dependent optimal critical stress level varies if the event triggered by the signal of the stress index changes. The analysed triggered events are the following:

   a. higher than 3 per cent of yearly real GDP decline that lasts for at least one year and occurs within one year after the signal,

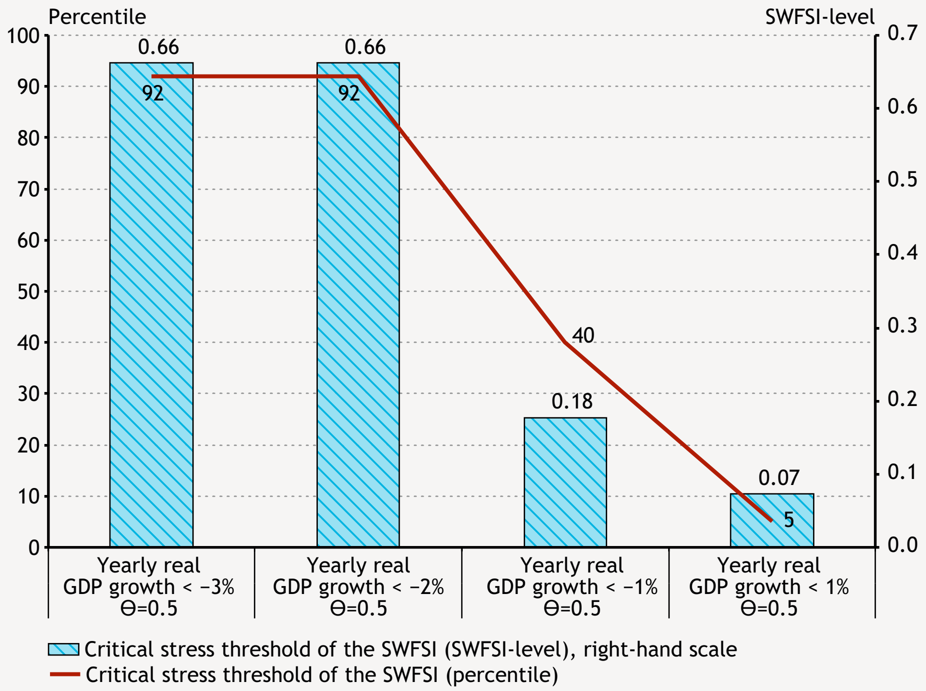
   b. higher than 2 per cent of yearly real GDP decline (baseline) that lasts for at least one year and occurs within one year after the signal,

   c. higher than 1 per cent of yearly real GDP decline that lasts for at least one year and occurs within one year after the signal,

   d. lower than 1 per cent of yearly real GDP growth that lasts for at least one year and occurs within one year after the signal.

Chart 8 below depicts the optimal critical stress thresholds in percentiles (numbers on the bars) and in SWFSI values (above the bars) as a function of distinct events triggered by the stress index signal (the SWFSI permanently exceeds the critical stress threshold for at least 20 working days). However, as emphasised by the definition of systemic risk (see footnote 4), it bears mentioning that the event triggered by the signal of the system-wide financial stress indicator has to be **serious in terms of real economic costs**. Hence, from this perspective, events "c" and "d" are strictly speaking irrelevant, and analysis of these events only makes sense in terms of understanding the sensitivity of the optimal critical stress threshold to the triggered event assumption. From Chart 8 below, two main conclusions can be drawn. First, if the triggered event is serious enough, then the optimal critical stress threshold shows stability. In our case, it is irrelevant from the threshold's stability point of view whether a higher than 2 per cent or higher than 3 per cent of yearly real GDP decline is assumed. Second, if decision-makers want to avoid even a moderate real economic contraction triggered by financial stress, they need to intervene in financial system processes at relatively low stress levels (i.e. the optimal critical stress threshold is relatively low).

Chart 8
Optimal critical stress thresholds as a function of the decision-makers subjective "risk-preference" level



In Table 3, by fixing the optimal percentile (92th) which belongs to the "risk-neutral" preference level of Θ=0.5, the values of function (4) are computed by assuming different preferences (Θ=0.2 ; Θ=0.3 ; Θ=0.4 ; Θ=0.5 ; Θ=0.6 ; Θ=0.8). As Table 3 below shows if risk aversion between "Type one" and "Type two" errors are unbalanced and "biased towards" the minimisation of losses due to "Type two" errors (Θ<0.5), then using the SWFSI would reduce preference-weighted errors by 7-16 percentage points compared to situations in which decision-makers would ignore the indicator. In contrast, if central bankers prefer to avoid losses due to "Type one" errors (Θ>0.5), then the use of the SWFSI would abate the preference-weighted errors up to a certain point (around Θ=0.6); above this risk preference level, the use of the stress indicator would increase preference-weighted errors.

Table 3
"Usefulness" of the system-wide financial stress indicator for distinct risk preference levels

Critical stress threshold percentile: 92th	
Θ	min(Θ;1−Θ)−Θ·C/(A+C)−(1−Θ)·B/(B+D)
0.2	0.07
0.3	0.12
0.4	0.16
0.5	0.21
0.6	0.05
0.8	−0.26

3.3.2 Computing the critical stress level of the financial system (information available about the decision-makers' risk preferences)

The critical stress threshold is calculated in another way as well, namely by utilising information related to the MNB's extraordinary measures to mitigate financial system distress (i.e. the typical stress levels in the financial system at which the central bank took operational measures to alleviate market turmoil). In recent years, the MNB has introduced the following extraordinary measures (listed in chronological order to mitigate strains in the Hungarian financial system:

Introduction dates of extraordinary measures:[28]

1. **October 13, 2008:** Two-way O/N FX swap tenders (providing euro and forint liquidity) under a competitive bidding scheme. **The target segment of the measure is the foreign exchange swap market;**

2. **October 16, 2008:** ECB and MNB agreement to support liquidity in the domestic foreign exchange swap market. Under the agreement, the MNB introduces an overnight foreign exchange swap facility providing euro liquidity from October 16, 2008 until countermanded. **The target segment of the measure is the foreign exchange swap market;**

3. **October 17, 2008:** Announcement of MNB's auctions for the purchase of government securities. **The target segment of the measure is the government bond market;**

4. **October 21, 2008:** Six-month, variable-rate collateralised loan tenders. **The target segment of the measure is the banking segment;**

5. **October 21, 2008:** Two-week, collateralised loan tenders with a fixed interest rate. **The target segment of the measure is the banking segment;**

6. **October 22, 2008:** Narrowing the interest rate corridor around the key policy rate to ±50 basis points from ±100 basis points. **The target segments of the measure are the banking segment and the interbank unsecured money market;**

7. **October 22, 2008:** Extraordinary, 300 basis point increase in the base rate. **The target segment of the measure is the spot foreign exchange market;**

8. **October 28, 2008:** Widening the range of eligible assets in a series of steps from 28 October 2008. **The target segment of the measure is the banking segment;**

9. **November 24, 2008:** Reducing the reserve ratio from 5% to 2%. **The target segment of the measure is the banking segment;**

10. **February 2, 2009:** The MNB introduces a Swiss franc liquidity facility, providing a one-week, fixed price EUR/CHF foreign exchange swap tender from February 2, 2009 until countermanded. **The target segment of the measure is the foreign exchange swap market;**

11. **March 2, 2009:** The MNB introduces a new euro liquidity facility, providing a 6-month EUR/HUF foreign exchange swap line from March 2, 2009 until countermanded, in order to boost corporate lending and stimulate banks' longer-term external borrowing. **The target segment of the measure is the foreign exchange swap market;**

12. **March 9, 2009:** The MNB introduces a new euro liquidity facility, providing a 3-month EUR/HUF foreign exchange swap tender from March 9, 2009 until countermanded. **The target segment of the measure is the foreign exchange swap market;**

13. **February 8, 2010:** The MNB's monetary council launches a mortgage-covered bond purchase program for both the long-term development of the domestic mortgage bond market and for increasing market liquidity and transparency. **The target segment of the measure is the banking segment.**

[28] Major interventions on the spot EUR/HUF foreign exchange market were also considered as extraordinary measures.

Dates of withdrawal of extraordinary tools:

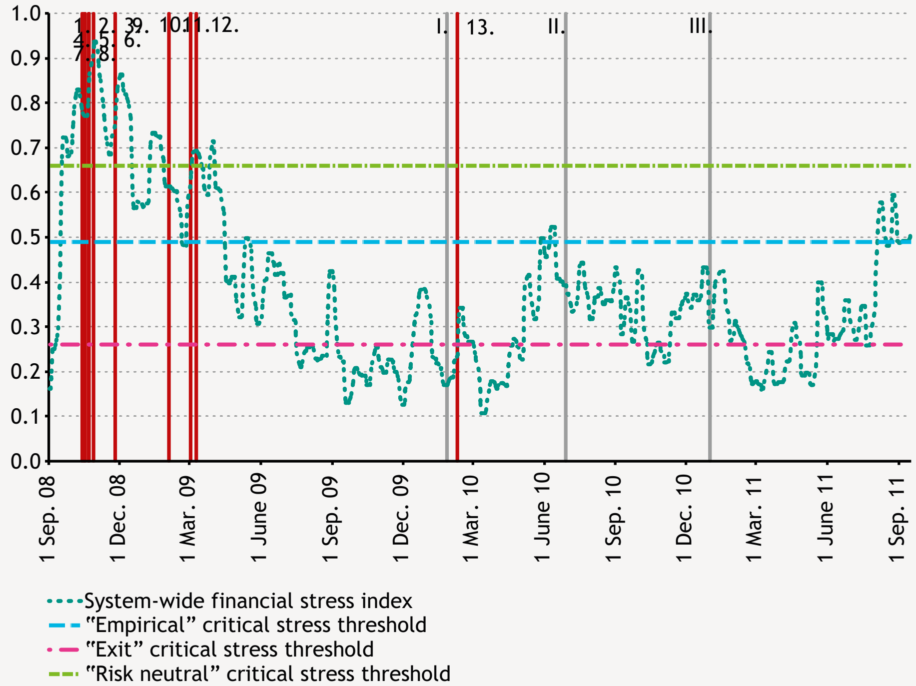
I. January 26, 2010: Suspension of the EUR/CHF foreign exchange swap tender announced on February 2, 2009.

II. June 28, 2010: Suspension of the EUR/HUF foreign exchange swap tender announced on March 2, 2009.

III. December 31, 2010: Mortgage-covered bond purchase program is closed.

Chart 9 below depicts the critical stress levels and extraordinary measures taken by the MNB. Chart 9 shows that during the intensive phase of financial turbulence (approximately 2-3 months following Lehman's bankruptcy), the central bank's policy-makers introduced several instruments within a short period of time that simultaneously affected several segments (foreign exchange swap market, government bond market, spot foreign exchange market)[29] of the financial system. The results of the decomposition exercise presented in Table 1 suggest that the extraordinary measures introduced immediately following Lehman's bankruptcy affected those segments of the financial system where the stress level increase was the highest. After this turbulent period, the frequency of introducing extraordinary tools declined and the time lag between measures gradually increased.

Chart 9
Critical stress level of the financial system and extraordinary financial turbulence-mitigating measures introduced by the MNB



Note: for the sake of clarity, the critical stress threshold levels, as well as the system-wide financial stress indicator, are plotted from September 1, 2008. The red vertical lines show the emergency measures introduced to mitigate financial system distress, while the vertical grey lines indicate the dates of the withdrawn emergency measures. The blue horizontal line depicts the empirical critical stress threshold calculated considering the extraordinary tools, while the pink horizontal line indicates the "exit" stress level related to the withdrawal of some emergency measures.

Based on the observed behaviour of the central bank, an "empirical" stress threshold is constructed. Since the decision about the introduction of extraordinary instruments is usually made after the materialisation of risks over a specified period (processing and evaluating information takes time), the critical stress level was computed by averaging the values of the system-wide financial stress indicator for ten working days prior to the introduction of the extraordinary tools.[30]

[29] Reducing turbulences on the spot foreign exchange market might directly mitigate tensions in the banking system.

[30] Critical stress threshold calculations were repeated by using 5, 15 and 20 working days as well. The resulting critical thresholds showed no significant difference from the benchmark of 10 working days.

According to this estimate, the "empirical" critical stress threshold lies at 0.55. Knowledge of the "empirical" critical stress threshold allows recovery of the corresponding risk-preference level of MNB decision-makers. As a first step, "Type one" and "Type two" errors – namely, the share of missed events [C/(A+C)] and false alarms [B/(B+D)] – are computed as belonging to the "empirical" critical stress threshold and an event triggered by a higher than 2 per cent of yearly real GDP decline. Function (4) is then maximised according to the risk-preference parameter (i.e. at which Θ function (4) reaches its maximum at the observed threshold). As a result of this exercise, a risk-preference parameter (Θ) of 0.53 occurred, indicating that decision-makers of the MNB prefer to avoid losses due to "Type one" errors (i.e. they do not want to miss events, important from a systemic risk perspective).

Since during the period under review the MNB not only deployed extraordinary instruments, but in less turbulent times withdrew some of them, similar to the empirical critical stress threshold an "exit" stress threshold could be determined: this threshold is found at 0.26 for the system-wide stress index. The "exit" stress threshold might support the planning and timing of the withdrawal of extraordinary measures. When decision-makers responsible for financial stability decide on the withdrawal of some extraordinary instruments, they take into account the utilisation of these measures by market participants over time. When utilisation of these measures is low, this may indicate that market participants no longer feel a substantial degree of financial market turbulence and consider that market funding can be smoothly ensured, suggesting the withdrawal of the extraordinary instruments. Hence, the "exit" stress threshold can be an indicator of the level of stress in which market participants can still smoothly perform their functions.

3.3.3 Computing the critical stress level of selected segments of the financial system (information available about the decision-makers' risk preferences)

The "empirical" critical stress threshold calculated in the previous section depicts the average stress level of the financial system at which any extraordinary turbulence-mitigating measure was introduced by the MNB. However, the resulting "empirical" critical stress threshold and the associated risk-preference parameter reflect an "average" behaviour. The "empirical" critical stress threshold and the related risk-preference level might differ substantially across market segments. Decision-makers may consider it more important to stabilise certain segments of the financial system than others in order to maintain stability of the system as a whole. As a result, turbulence-mitigating measures might be introduced more often for the preferred segments. By reviewing the emergency measures listed above, 10 out of 13 of them (77 per cent) introduced between 2008 and 2010 directly targeted the foreign exchange swap market and the banking segment. By following the approach described in the previous section (section 3.3.2), "empirical" critical stress thresholds and the related risk-preference levels are calibrated for these two segments by considering the segment-specific interventions. The "empirical" critical segment-specific stress levels are computed by averaging the ten working days values of the foreign exchange swap market and banking segment stress indicators respectively, prior to the introduction of the segment-specific interventions. The "empirical" critical stress thresholds for the foreign exchange swap and banking segments are 0.87 and 0.84 respectively, with a corresponding risk-preference level of 0.52 for both segments.

The reason for these higher segment-specific empirical critical stress thresholds can be explained by the differences between the calculation of the segment-indices and the system-wide indicator. Namely, the segment stress indicators are computed as a simple arithmetic average of the transformed segment input variables, whereas the system-wide index is calculated by taking into account the time-varying cross-correlations among the six segment indices. As a result the mean stress levels of the segments are higher, but their dispersion is lower, as suggested by the coefficient of variation measures, compared to statistics computed for the financial system as a whole by means of the SWFSI. The mean stress levels and coefficient of variations (cv) for the entire financial system and for its six segments are the following: SWFSI (mean: 0.27, cv: 0.66), spot foreign exchange market (mean: 0.49, cv: 0.51), equity market (mean: 0.53, cv: 0.44), secondary market of government bonds (mean: 0.53, cv: 0.34), interbank unsecured money market (mean: 0.48, cv: 0.33), foreign exchange swap market (mean: 0.53, cv: 0.33), banking segment (mean: 0.53, cv: 0.43).

It is important to emphasise that a number of simplifying assumptions were made when the above thresholds were computed. The impacts of the various tools to mitigate financial turbulence were treated equally. In addition, we did not expect the effect that the impact of two identical or nearly identical measures introduced under different stress levels at different times might produce different results in alleviating turbulence. Furthermore, the decision-makers' risk preferences may also vary over time. Hence, the estimated stress thresholds cannot be considered as an absolute benchmark, but rather a mere indication of possible levels.

4 Summary and conclusion

In this study, a system-wide financial stress index (SWFSI) was developed for the Hungarian financial system. The indicator measures the joint stress level of the Hungarian financial system's most important segments: the spot foreign exchange market, the foreign exchange swap market, the secondary market of government bonds, the interbank unsecured money market, the equity market and the banking segment.

In computing the system-wide financial stress index, the six segment-specific stress indicators are aggregated into a system-wide index by taking into account their time-varying cross-correlation structure, which can support the identification of stress events and periods relevant from a systemic risk perspective. Due to this aggregation method, the stress level indicated by the system-wide indicator is found to be higher in periods of more intense financial turbulence than less distressed times, because of the strong co-movement of the segment stress indices expressing segment-specific risks. Namely, the indicator puts more weight on those periods and events when stress prevails in several segments of the financial system at the same time. Accordingly, a stress event can be relevant from a systemic risk perspective if the values of the segment stress indices are permanently high and the cross-correlation between them is strong and positive.

Our results suggest that in terms of the stability of the Hungarian financial system after February 2005, the default of Lehman Brothers in September 2008 and its global consequences clearly constituted a systemic stress event. Finally, our results suggest that in the period under review (February 1, 2005–September 16, 2011) the foreign exchange swap market segment and the banking segment were the primary drivers of stress developments in the Hungarian financial system.

References

Alessi L. and C. Detken (2009), "Real Time Early Warning Indicators for Costly Asset Price Boom/Bust Cycles: A Role for Global Liquidity", *ECB Working Paper Series,* No. 1039.

Avesani R. (2005), "A market-based approach to evaluate financial system risk and stability", *IMF Working Paper,* 05/232, December

Balakrishnan R. , S. Danninger, S. Elekdag and I. Tyell (2009), "The Transmission of Financial Stress from Advanced to Emerging Economies", *IMF Working Paper,* No. 09/133.

Borio C. and I. Lowe (2002), "Asset Prices, Financial and Monetary Stability: Exploring the Nexus", *BIS Working Papers,* No. 114.

Borio C. and I. Lowe (2004), "Securing Sustainable Price Stability: Should Credit Come back from the Wilderness?", *BIS Working Papers,* No. 157.

Brunnermeier M., A. Crocket, C. Goodhart and H. Shin (2009), "The Fundamental Principles of Financial Regulation", *Geneva Reports on the World Economy* 11.

Csávás Cs., G. Kóczán and L. Varga (2006), A főbb hazai pénzügyi piacok meghatározó szereplői és jellemző kereskedési stratégiái", *MNB Occasional Papers,* No. 54.

Cardarelli R., S. Elekdag and S. Lall (2011), "Financial Stress and Economic Contractions", *Journal of Financial Stability,* Vol. 7.

De Bandt O. and P. Hartmann (2000), "Systemic Risk: A Survey", *ECB Working Paper Series,* No. 35.

De Bandt O., P. Hartmann and J.-L. Peydro (2009), "Systemic Risk in Banking: An Update", in A. Berger, P. Molyneux and J. Wilson (eds.), Oxford Handbook of Banking, Oxford University Press.

Demirguc-Kunt A., and E. Detragiache (2000), "Monitoring Banking Sector Fragility. A Multivariate Logit Approach", *World Bank Economic Review,* Vol 14. Issue 2.

Drehmann M. and K. Nikolaou (2009), "Funding Liquidity Risk Definition and Measurement", *ECB Working Papers,* No. 1024.

ECB (2010), Financial Stability Review, June 2010

Hakkio S. C. and W. R. Keeton (2009), "Financial Stress: What is it, how can it be measured, and why does it matter?", Federal Reserve Bank of Kansas City, Economic Review, 2009 Q2

Hatzius, J., P. Hooper, F. Mishkin, K. Shoenholz and M. Watson (2010): "Financial Condition Indexes: A Fresh Look after the Financial Crisis", *NBER Working Paper* No. 16150

Holló D., M. Kremer and M. Lo Duca (2012), "CISS – A Composite Indicator of Systemic Stress in the Financial System", *ECB Working Paper Series* No. 1426

Illing M. and Y. Liu (2006), "Measuring Financial Stress in a Developed Country: an Application to Canada", *Journal of Financial Stability,* Vol. 2, No. 4, pp. 243–265.

Jordá, O. (2005), Estimation and Inference of Impulse Responses by Local Projections, American Economic Review, Vol. 95, No. 1, pp. 161–182.

Kota, V. and A. Saqe (2011), *"A Financial Systemic Stress Index for Albania",* Bank of Albania mimeo.

Lo Duca, M. and T. A. Peltonen (2011), "Macro-Financial Vulnerabilities and Future Financial Stress Assessing Systemic Risk and Predicting Systemic Events", *ECB Working Paper Series,* No. 1311.

Merton, R. (1974), "On the Pricing of Corporate Debt: The Risk Structure of Interest Rates", *Journal of Finance,* Vol. 29 (2), pp. 449–470.

Páles, J. and L. Varga (2008), "Trends in the Liquidity of Hungarian Financial Markets – What does the MNB's New Liquidity Index Show?", *MNB Bulletin* April 2008.

Resti A. and A. Sironi (2007), "Risk Management and Shareholders' Value in Banking", Wiley.

Segoviano M. and C. Goodhart (2009), "Banking stability measures", *IMF Working Paper* 09/4, January.

Methodological annex

I. DESCRIPTION OF THE QUANTITATIVE VARIABLE-SELECTION METHODOLOGY

In order to be informative, a system-wide financial stress indicator has to produce robust signals. Three main stability criteria can be defined, which a system-wide financial stress indicator must include. The first is (ex-post) stability to the arrival of new information, denoting that past existing values of the stress index should not change when new data points arrive. The use of a robust "raw" input variable transformation methodology, such as the one employed in this study (i.e. percentile transformation) or the quantile transformation used by the ECB (Holló, Kremer and Lo Duca, 2012), may help alleviate "the event reclassification problem".

The second required property for a system-wide financial stress indicator is the ability to separate systemic from non-systemic events. Lacking this property, the calculation of a system-wide financial stress index could produce misleading signals regarding the "true" levels[31] of tensions and strains in the financial system, since the stress indicator might "overshoot" and signal slightly different stress levels for distinct stress events with varying degrees of gravity.

Finally, the third stability requirement is called component stability, meaning that a system-wide stress index should comprise a low number of components that possess utmost information content. Since the signaled stress levels by a system-wide stress index are not invariant to the number and type of its components (i.e. the transformed input variables), the stress levels indicated by a stress index with "unstable components" might deviate substantially from the "true" ones. However, component instability is of a different nature than the lack of ex-post stability in the sense that a "component unstable" financial stress indicator can be stable ex-post (i.e. "only" the index composition is non-optimal). If ex-post and component instability is present at the same time, it is difficult to judge whether the bias between the signaled and the "true" stress levels is due to both types of distortions or only one of them. A system-wide financial stress index can be treated as stable in the narrow sense if it fulfils both the ex-post and component stability criteria. Nevertheless, ensuring component stability is much less straightforward than finding a solution to the ex-post instability problem.

In the following, we present a method for quantitative variable selection to ensure component stability. It is important to emphasise that – regardless of the quantitative variable selection approach – an optimal variable composition exists only conditionally, subject to the risk factor content of the potential variable set; in other words, the optimal variable set may change if the composition of the potential risk factor set varies (selection bias). The qualitatively selected raw risk factors (potential variable sets) of the six segments are as follows:

Spot foreign exchange market:

- Average daily bid-ask spread calculated from firm quotations (EUR/HUF spot foreign exchange market)
- Daily change in exchange rate/daily turnover (EUR/HUF spot foreign exchange market)
- Daily turnover/daily number of transactions (EUR/HUF spot foreign exchange market)
- 1-month EUR/CHF implied volatility

[31] Regarding the so called "true" stress level one might ask what is it and how can it be measured? These questions are not a matter of course, but in our view a "true" stress level can be signaled by an index, which is ex post stable contain only a limited number of variables with utmost information content and able to differentiate between systemic and non-systemic financial stress episodes.

Secondary market of government bonds

- CEBI (Central European Bond Indices) bid-ask spread index of Hungarian government bonds
- Daily change in CEBI index of Hungarian government bonds/daily turnover
- Daily turnover/daily number of transactions
- 5-year Hungarian CDS spread

Interbank unsecured money market

- Average daily bid-ask spread calculated from indicative quotations, daily change in average overnight interest rate/daily turnover
- Daily change in average overnight interest rate/daily turnover
- Daily turnover/daily number of transaction
- Daily number of transactions

Foreign exchange swap market

- Average daily bid-ask spread approximated from implied yields (USD/HUF foreign exchange swap market)
- Daily change in average tom-next implied yield/daily turnover (USD/HUF foreign exchange swap market)
- Daily turnover/daily number of transactions (USD/HUF foreign exchange swap market)
- Daily number of transactions (USD/HUF foreign exchange swap market)

Equity market

- Realised volatility of the BUX-index
- CMAX[32] for the equity market index (BUX)
- CMAX for the equity market index of small-cap and mid-cap stocks (BUMIX)
- Stock-bond correlation: equity time-varying correlation between the BUX and 10-year German government bond indices

Banking segment

- Default probability of Bank "A"
- Distance to default of Bank "A"
- Default probability of Bank "B"
- Distance to default of Bank "B"
- CMAX of DataStream's Hungarian financial corporate index
- Realised volatility of DataStream's Hungarian financial corporate index
- CMAX of DataStream's Hungarian banking index
- Realised volatility of DataStream's Hungarian banking index

The goal of the quantitative variable selection approach is to select those risk factors from the qualitatively selected variable sets, which have the highest information content. The steps of the calculation are as follows:

First step:

The first step of quantitative variable selection is to compute all the possible stress indices for each segment, using different numbers and types of risk factors from the segment-specific variable set. If the number of potential (i.e. qualitatively chosen) segment-specific variables for the i^{th} segment *(i=1,2,…,6)* is x_i and the segment-specific stress indicator

[32] CMAX compares the value of a variable at time *t* to its maximum over a specified period, according to the following formulae: $CMAX_t = 1 - \frac{z_t}{\max\left[z \in \left(z_{t-j} \middle| j = 0,1,\ldots T\right)\right]}$, where *z* denotes the variable and *T* indicates the fixed size of the moving window. In computing CMAX, a 90-day moving window was employed.

can comprise any k_i $(k_i=1,2,3,..,x_i-1)$ variables, then the number of possible stress indicators in that segment is derived by the following formula (sum of combinations without repetition):

$$z_i = \sum_{k_i=1}^{x_i-1} \frac{x_i!}{(x_i - k_i)!k_i!} \tag{1}$$

where z_i is the number of stress indices in the i^{th} segment. Segment stress indices are defined as the arithmetic average of the selected percentile transformed input variables.

Second step:

At each point in time, the median values of the possible z_i segment indices are calculated. Formally, the median stress indicator (S_t^i) of segment i at time t $(t=1,2,..,v)$ can be computed as follows:

$$S_t^i = median\left\{s_{1,t}^i, s_{2,t}^i, s_{3,t}^i, \ldots\ldots, s_{j-1,t}^i, s_{j,t}^i\right\}, \tag{2}$$

where $s_{j,t}^i$ denotes the value of the j^{th} $\left(j = 1,\ldots,\sum_{k_i=1}^{x_i-1} \frac{x_i!}{(x_i - k_i)!k_i!} \right)$ segment-specific stress indicator at time t.

The computations of the segment-specific median stress indicators are indicated by the stability of the signaled stress levels of the median indices (the signals stable in time and invariant to variable composition).[33] Empirical evidence shows that the larger the information content of the segment-specific stress indicator (i.e. the more variables that cover distinct aspects of financial stress are included), the closer it is to the median stress index. This means that the dispersion range of the signaled stress levels by stress indices containing the same number but different type of variables is reduced if the number of variables that comprise the stress indices increases (i.e. the signaled stress levels converge in relation to the values of the median stress index).

Due to the stability of the stress levels signaled by the median stress indicators (ex-post stability of the signaled stress levels and variable composition invariance), the median indices can be considered as appropriate measures of segment-specific stress. However, the calculation of the median segment indicators can be computationally burdensome, especially when the number of variables selected on a qualitative basis is large. This makes it difficult to fluently update the system-wide financial stress index and to use it as an analytical toolkit for the regular monitoring of financial stress developments. Hence, the goal is to find a subset of variables for each segment that produces stress indices mimicking the median segment stress indicators.

Third step:

Computing the sum of squared deviation (SSD) of the possible segment-specific stress indicators from the median segment stress index in segment i:

$$SSD_j^i = \sum_{t=1}^{v} \left(S_t^i - s_{j,t}^i\right)^2,\ t = 1,2,\ldots,v\ ;\ j = 1,\ldots,\sum_{k_i=1}^{x_i-1} \frac{x_i!}{(x_i - k_i)!k_i!} \tag{3}$$

$$SSD^i = \min\left\{SSD_1^i, SSD_2^i, \ldots\ldots, SSD_j^i\right\} \tag{4}$$

The optimal risk-factor number and composition of a segment-specific stress indicator is given by the variable combination related to the least sum of squared deviation (SSD^i).

[33] The ex-post stability of the signaled stress levels of the system-wide financial stress index to the arrival of new information is ensured by the percentile-based transformation of the raw risk factors.

II. COMPUTATION OF SEGMENT WEIGHTS

The relative segment weights were derived from simple reduced form macro models. Bivariate vector autoregressions[34] (VARs) were estimated by following Jorda's method (2005) for all of the segments that the system-wide financial stress indicator comprises. The models include the Hungarian industrial production index as a proxy for real economic activity and the respective segment stress indices. In the calculation, we focus on the orthogonalised impulse-response functions, namely the responses of the industrial production index to an orthogonal shock in the segment stress indices. To identify the impulse-responses we used the Cholesky procedure, applying a particular ordering of the variables and allocating any correlation between the residuals of any two elements to the variable that comes first in the ordering. The segment indices are ordered at the end due to their immediate reaction to real shocks, whilst the industrial production index is ordered at the beginning due to its sluggish reaction to financial shocks.

To arrive at the market weights, first the absolute cumulative impact of a one standard deviation shock in each segment stress indicator on the industrial production index was computed on a 24-month horizon. Then, segment-specific weights were obtained by dividing each market-specific cumulative effect by the sum of the individual absolute cumulative impacts. The six models were estimated on monthly frequency data from February 2005 to December 2010. The time-invariant relative weights of the six segments of the system-wide financial stress indicator are the following:

Hungarian system-wide financial stress indicator	**Composite Indicator of Systemic Stress (EMU)**
Interbank unsecured money market: 13%	Money market: 15%
Equity market: 12%	Equity market: 25%
Spot foreign exchange market: 16%	Spot foreign exchange market: 15%
Foreign exchange swap market: 25%	
Secondary market of government bonds: 15%	Bond market (gov. and non-fin. corp.): 15%
Banking segment: 19%	Financial intermediaries: 30%

III. SKETCH OF MERTON'S DEFAULT PROBABILITY MODEL

The default risk measures of listed banks employed in this study are based on the structural valuation model of Merton (1974). Merton drew attention to the idea that corporate securities are contingent claims on the asset value of the issuing firm. Merton's assumptions:

One zero-coupon bond with face value *F* and maturity *T*

Firm value *V*, geometric Brownian motion

Equity, *E* is a call option on *V* with strike equal to *F* and maturity of *T*

Equity is given by the Black-Scholes-Merton

$$E = V \cdot N(d_1) - e^{-rT} \cdot F \cdot N(d_2) \tag{5}$$

$$d_1 = \frac{\ln(V/F) + \left(r + \frac{\sigma_v^2}{2}\right) \cdot T}{\sigma_v \sqrt{T}} \tag{6}$$

Debt value is given by the value of the risk-free bond, minus the value of a put written to equity. Equity volatility follows:

[34] In the case of bivariate VAR models, the identification of impulse-response functions is straightforward; however, in the seven-variable case (the industrial production index and the six segment stress indices), since the complex "lead-lag" relationships among the segment stress indices are unknown, identification is not straightforward. Lag-length selection of the various models was based on the Akaike information criterion.

$$\sigma_E = \frac{V}{E} N(d_1)\sigma_v \tag{7}$$

The system of equations 5 and 7 has to be solved for *V* and σ_V (we can observe *E, F, r, T*). The procedure of the KMV is to start with an initial σ_V and to solve equation 5 for *V*, given *E* each day for the previous year using the initial σ_V. Then, by taking the resulting time-series of *V*, new σ_V and μ are calculated. The iteration continues until σ_V converges. With *V* and σ_V the distance to default can be defined as a Z-score.

$$DD = \frac{\ln(V/F) + \left(\mu - 0.5 \cdot \sigma_v^2\right) \cdot T}{\sigma_v \sqrt{T}} \tag{8}$$

The corresponding default probability is:

$$pd^{Merton} = N(-DD) \tag{9}$$

However, we followed not the above described procedure, but Bharath and Shumway (2008) who have found[35] that one can construct a measure which is similar to the default probability derived from Merton's model without solving and iterating any equations. They call this measure "naive PD". Bharath and Shumway (2006) define:

$$V = E + F \tag{10}$$

$$\sigma_V = \left[E/(E+F)\right] \cdot \sigma_E + \left[F/(E+F)\right] \cdot \left(0.05 + 0.25 \cdot \sigma_E\right) \tag{11}$$

$$\mu = r_{it-1} \tag{12}$$

By substituting 10, 11 and 12 in equation 8, we arrive at the naive *DD* and the corresponding "naive" default probability, which captures the form and information of pd^{Merton}.

The value of equity corresponds to the market value of the firm, while equity volatility corresponds to historical equity volatility (or implied volatility from equity options) and can be calibrated from market data. The face value of debt *F* is usually assumed to be equal to the face value of short-term liabilities plus half of the face value of long-term liabilities. The time horizon *T* is usually fixed at one year (252 working days).

[35] Bharath S., and T. Shumway (2008) "Forecasting Default with the Merton Distance to Default Model", *The Review of Financial Studies,* Vol. 21, Issue 3, pp. 1339–1369.

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