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## A Comprehensive Multi-Sector Tool for Analysis of Systemic Risk and Interconnectedness (SyRIN)

By Fabio Cortes, Peter Lindner, Sheheryar Malik, and Miguel Angel Segoviano



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Monetary and Capital Markets Department

**A Comprehensive Multi-Sector Tool For Analysis of Systemic Risk and Interconnectedness (SyRIN)**

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**Abstract**

This paper presents the Systemic Risk and Interconnectedness (SyRIN) tool. SyRIN allows a comprehensive assessment of systemic risk via quantification of the impact of risk amplification mechanisms, due to interconnectedness structures across banks and other financial intermediaries—insurance, pension fund, hedge fund and investment fund sectors, which cannot be captured when analyzing sectors independently. The tool produces various metrics to evaluate systemic risk from complementary perspectives, including tail risk, cross-entity interconnectedness and the contribution to systemic risk by different entities and sectors. SyRIN is easily implementable with publicly available data and can be adapted to cater to different degrees of institutional granularity and data availability. The framework is designed to be a tool to identify vulnerabilities from a top-down perspective that can lead to deeper analysis in specific sectors for policy formulation.

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## GLOSSARY

| | |
|---|---|
| CDS | Credit Default Swap |
| CIMDO | Consistent Information Multivariate Density Optimizing |
| DB | Defined Benefit |
| DC | Defined Contribution (DC) |
| DiDe | Distress Dependence Matrix |
| EF | Equity Funds |
| ETFs | Exchange-traded funds |
| FSB | Financial Stability Board |
| FSI | Financial Stability Index |
| FSMD | Financial system multivariate density |
| HF | Hedge Funds |
| LTCM | Long-term capital management |
| MCSR | Marginal contribution to systemic risk |
| MMFs | Money market funds |
| NAV | Net asset value |
| PoD | Probabilities of Distress |
| PRA | Prudential Regulatory Authority |
| SRMs | Systemic risk metrics |
| SyRIN | Systemic Risk and Interconnectedness |
| VaR | Value at Risk |
| VI | Vulnerability Index |

## I. INTRODUCTION

The global financial crisis demonstrated the speed and magnitude by which financial losses can propagate through multiple corners of financial systems. The crisis showed that initial losses in specific firms and markets can be magnified and transmitted across other financial intermediaries and markets through systemic risk amplification mechanisms with dire consequences for financial and economic stability.[2] Therefore, proper measurement of systemic risk requires accounting for interconnectedness across financial entities and markets beyond the banking system in order to incorporate the effects of systemic risk amplification mechanisms that lead to financial contagion.[3]

The proposed tool allows for a comprehensive assessment of systemic risk. The framework derives metrics for assessing systemic risk from complementary perspectives and spans banks and nonbanks. In comparison to the empirical financial risk literature that limits its focus to the banking sector, or a much narrower definition of the financial system and specific metrics of systemic risk, the SyRIN tool proposed in this paper allows for the quantification of the impact of systemic risk amplification mechanisms due to interconnectedness across banks and other financial intermediaries, including the insurance, pension fund, hedge fund, and investment fund sectors, which cannot be captured when analyzing sectors independently.[4] The impact of systemic risk amplification mechanisms is embedded in various systemic risk metrics (SRMs) that make it possible to evaluate systemic risk from complementary perspectives, including the monitoring of tail (extreme) risk, interconnectedness across different entities, and the contributions made to systemic risk by different entities and sectors. While SyRIN is designed to be a tool for performing a comprehensive top-down analysis that can lead to deeper scrutiny of sectors identified as vulnerable, the tool is a reduced form approach; hence it cannot be used to identify the particular causal channels that impact such sectors.[5]

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[2] Systemic risk is defined as "the risk of widespread disruption to the provision of financial services that is caused by an impairment of all or parts of the financial system, which can cause serious negative consequences for the real economy" (BIS and others 2016, IMF 2013).

[3] Financial externalities that have the potential to amplify shocks up to the point of disrupting financial intermediation cause systemic risk. Such externalities may themselves be impelled by cyclical and structural vulnerabilities (Adrian and others 2014), which drive the interconected structures among diverse financial intermediaries and markets, and pave the way for financial contagion.

[4] An alternative framework is proposed by Duffie (2011), who recommends incorporating the largest banks, the largest asset classes, and the largest counterparties into the monitoring of systemic risk.

[5] For an overview of other methods considering interconnectedness and systemic risk measurement, please refer to Malik and Xu (2017). However, most methods usually focus on a few sectors, commonly the banking or the banking and insurance sectors.

As structural changes in financial intermediation are shifting the focus of risk to the nonbank financial sector, a comprehensive assessment of systemic risk is of key importance. In the aftermath of the global financial crisis, structural changes in financial systems are creating different types of risks and joint vulnerabilities across sectors in the system, which cannot be identified when scrutinizing intermediaries and sectors independently. Furthermore, banks interact with other intermediaries, which might respond to stress in different ways, acting as amplifiers and/or dampeners, depending on the state of their cycles. Hence, a proper policy response requires a comprehensive measurement of systemic risk and interconnectedness across sectors.[6]

SyRIN characterizes financial systems as portfolios of financial entities/sectors. Under this characterization, the expected implied asset values of the entities making up the system and the association across entities' asset values (interconnectedness structure) can be represented by a financial system's multivariate density (FSMD).[7] It is this multivariate dimension of SyRIN that allows analysis to estimate complementary and consistent SRMs that account for interconnectedness across the asset values of the financial entities that make up the system. SRMs can be estimated from various statistical moments of the FSMD. Importantly, because such metrics are all derived from a common FSMD, the proposed metrics are consistent across each other.

Interconnectedness across financial entities' asset values is marked by direct and indirect interlinkages across financial intermediaries and markets. While the business models of different intermediaries expose them to multiple and diverse vulnerabilities, the transmission of shocks across financial systems happens through two types of interlinkages, or channels of contagion: direct and indirect.[8] Direct interlinkages primarily stem from contractual obligations between financial entities. Indirect interlinkages can be caused by exposures to common risk factors and market price channels, including asset fire sales (triggered by stressed entities) and asset sell-offs (due to information asymmetries across agents). These

[6] This is highly relevant for macroprudential policy, which aims to contain risks across the financial system as a whole (BIS and others 2016). Since banks are usually the key providers of credit to the economy, macroprudential policy has typically applied its policy levers to the banking system. However, as activity can migrate into non-banks, macroprudential policy also needs to consider the systemic risk that can build up from activities outside the banking system and develop policy responses to contain such risk (FSB 2011 and IMF 2013).

[7] Such density characterizes (i) information of the individual firm's value distributions, in its marginal densities; and (ii) information of the function that describes the association across firm values (interconnectedness structure), in its copula function. In contrast to correlation, which only captures linear dependence, copula functions characterize linear and non-linear dependence structures embedded in multivariate densities.

[8] These channels of contagion are also referred to as the direct exposure channel and the asset liquidation channel, and have been highlighted in reports by the FSB and the Office of Financial Research as the main transmitters of systemic risk across different sectors of financial systems. (FSB 2014).

can become self-reinforcing, possibly giving rise to non-linear increases in the magnitude and speed of propagation of losses observed during financial crises. Indirect interconnectedness might not be apparent during calm periods, but can take on greater relevance in periods of high volatility. Hence, interconnectedness is complex and likely unstable in periods of financial distress. Thus, the understanding of the intricacies of interconnectedness between financial intermediaries and data constraints imposes significant impediments to modelers for the estimation of FSMDs.

We model the FSMD using the Consistent Information Multivariate Density Optimizing (CIMDO) approach.[9] Rather than relying on calibration of parametric multivariate densities, which can be problematic under the data restrictions available for systemic risk measurement, the CIMDO approach allows the inference of multivariate densities and interconnectedness structures across financial entities that are consistent with empirically observed probabilities of distress (PoDs). Thus, when PoDs are estimated with market-based information, SRMs estimated from the CIMDO-density incorporate changes in interconnectedness structures (for example, direct and indirect interconnectedness) that are consistent with markets' perceptions of risk; hence, SRMs embed realistic market reactions, an important feature for properly quantifying the non-linear increases in contagion usually observed in crisis times.[10]

SyRIN is easily implementable and can be adapted to cater to a high degree of institutional granularity and data availability. The portfolio assumption provides for the easy incorporation of multiple sectors into the analysis. Moreover, implementation can be done with market-based data or with publicly available supervisory data. This feature allows an assessment of vulnerabilities developing in sectors where data may be scarce and which are undergoing structural changes. We discuss how implementation can be performed under different types of data.

SyRIN is an informative tool that, through top-down analysis, identifies specific entities and sectors that may require closer scrutiny.[11] To showcase the use of SyRIN, we present a case

[9] The CIMDO methodology is based on the minimum cross-entropy approach (Kullback 1959). Under this approach, a posterior multivariate distribution—the CIMDO density— is recovered using an optimization procedure by which a prior density function is updated with empirical information via a set of constraints. In this implementation, the empirical estimates of the PoD of individual banks act as the constraints, and the derived CIMDO density is the posterior density that is the *closest* to the prior distribution and *consistent* with these constraints. This methodology and its advantages relative to other parametric multivariate densities are presented in detail in Segoviano (2006) and Segoviano and Espinoza (2017). CIMDO approach estimations are robust under the probability integral transformation criteria (Diebold and others 1998).

[10] While in most cases PoDs are estimated with market-based information, when such information does not exist, PoDs can also be estimated with supervisory information. Section IV.A discusses these cases.

[11] While the framework is reduced-form and cannot disentangle specific systemic risk amplification mechanisms, SyRIN can help to identify sectors that might be highly vulnerable to such mechanisms. Thus, it is a tool that can guide further analysis in specific vulnerable sectors, supporting efforts of authorities to define adequate policy responses.

study that focused on the US financial system from 2007 to mid-2014. In this example, we first used SyRIN as a tool for "top-down" analysis, which helped to identify the high yield mutual fund sector as vulnerable by the end of the analysis period. Based on these findings, we performed deeper analysis that found evidence of rising fragilities in the sector that made the sector more vulnerable to large asset price movements. We then discuss structural changes in capital markets that are currently ongoing and have the potential to increase interconnectedness across specific sectors, hence possibly increasing systemic risk amplification within such sectors. We argue that SyRIN could be used to assess the potential implications of such structural changes. Nevertheless, the tool cannot be used to identify the causes of such changes, since SyRIN is a reduced form approach.

The paper proceeds as follows. Section II describes the direct and indirect interlinkages across financial entities and sectors that define their channels of asset value interconnectedness. Section III describes the SyRIN. It presents its theoretical underpinnings and defines the various measures of systemic risk and interconnectedness that can be produced by the tool. Section IV discusses implementation aspects and presents analysis performed on the US financial system to showcase the use of SyRIN. Section V concludes.

## II. Channels of Interconnectedness

Structural changes in financial systems are creating sources of joint vulnerabilities across various sectors in the system, vulnerabilities that cannot be captured when analyzing sectors independently. These changes have led to greater sensitivity and synchronization (interconnectedness) of asset price movements across sectors, increasing overall market and liquidity risk. In this section, we briefly describe the generic characteristics of relevant sectors in financial systems, comment on key structural changes in these sectors and describe direct and indirect channels of interconnectedness and spillovers across sectors.

### A. Investment Funds

While different types of investment funds are subject to diverse risk factors, these intermediaries can transmit shocks to the financial system through two common channels. These are the asset liquidation channel and the direct exposure channel. Those two channels have been highlighted by the Financial Stability Board (FSB) and the Office of Financial Research as the main transmitters of systemic risk arising from funds.

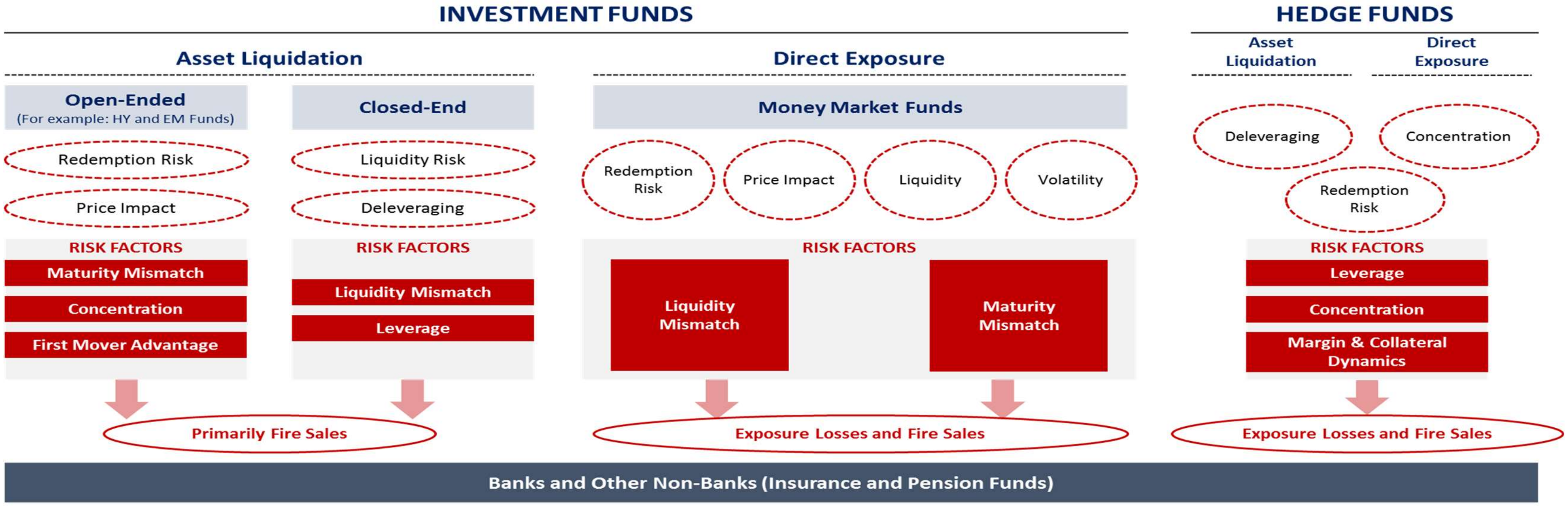
However, despite similar transmission channels, different investment fund sectors face diverse vulnerabilities, since they are affected by different risk factors. Open-end funds (also known as mutual funds) face a redemption risk that closed-end funds are not subject to, because for the latter, investors cannot redeem shares in the short run due to long lock-up periods. However, closed-end funds are subject to other vulnerabilities. The reason for this is that, due to lack of redemption risk, closed-end funds can and often do hold more illiquid assets, and more derivatives, and have more leverage than open-end funds. This implies that they face higher liquidity risk, higher volatility risk and risk from deleveraging. Moreover, closed-end funds exhibit discount as measured by the difference between the net asset value (NAV) and the share prices. In crisis times the share prices of a closed end fund can therefore fall significantly further than the value of an equivalent open-end portfolio. This may cause fund managers to sell assets even if there is no redemption risk from investors. Figure 1 provides a summary of channels of contagion, risks, and risk factors affecting different types of funds.

Open-end funds are exposed to redemption risk, as investors can redeem their shares (usually daily) while the funds may have invested in illiquid securities. This exposes the fund to a maturity and liquidity mismatch. Market stress can lead to losses on the funds' assets, which can provoke a run by investors due to the poor performance of the fund.[12] This run can be exacerbated by the fact that fund flows follow performance and that there is a first mover advantage incentive for investors to redeem ahead of others (Feroli and others 2014). Faced with significant redemptions, asset managers are compelled to liquidate funds' assets to meet these demands, which could trigger fire sales. Some of the assets of the funds may be illiquid, implying large discounts for investors and holders of those assets. Thus, fire sales can impact the entire market through the asset liquidation channel, and further increase the losses because of adverse price shocks (Figure 2). Nevertheless, open-end mutual funds currently dwarf closed-end funds globally.[13]

[12] The suspension of redemptions by several U.K. retail property funds in July 2016 highlights the risks of liquidity mismatches in certain open-ended funds. The temporary suspensions came after outflows accelerated following the U.K. referendum to leave the EU. The funds that suspended redemptions eventually reopened, but only after cutting valuations significantly and selling properties under adverse conditions.

[13] For example, by end-2015, the number of assets under management of closed-end funds was less than 2 percent of the U.S. fund industry.

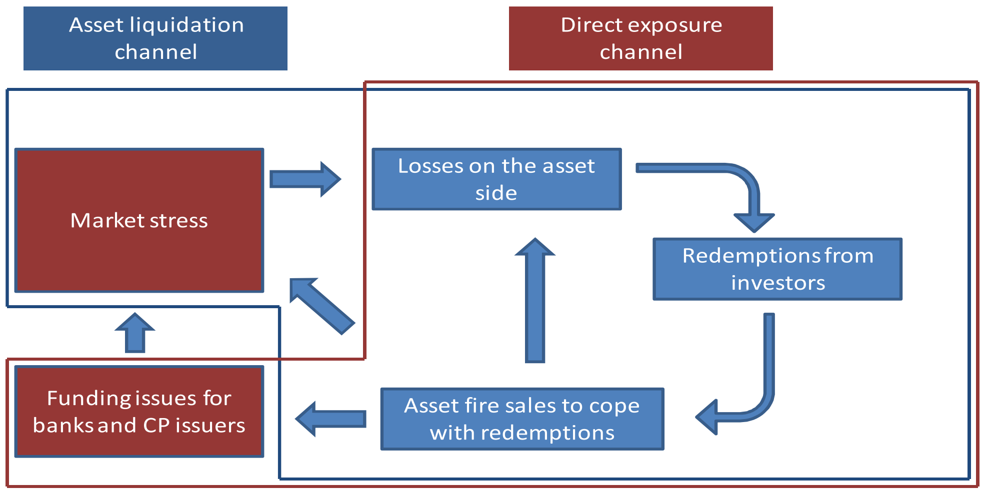
Figure 1. Asset Liquidation and Direct Exposure Channels




Source: Authors' calculations.

Note: While different investment funds are subject to diverse vulnerabilities and risk factors, these sectors can transmit shocks to the financial system through two common channels: the asset liquidation channel and the direct exposure channel. While the channels can broadly be defined into these two categories, it is noted that the notion of market sentiment –as a potential risk/volatility amplifier – is implicit within the former. By definition, *open-end funds* face a redemption risk that closed-end funds are not subject to, as the latter involve share sales and purchases between other shareholders on an exchange, while in the former, units are bought from and sold to the fund. There is evidence of price impact from open-end mutual funds to asset markets, especially in bond markets, less liquid assets, markets with herding, and emerging markets. This is particularly likely to be the case when there is a liquidity mismatch between assets and more liquid liabilities. *Money market funds* can affect other financial institutions through the direct exposure/funding channel. When faced with market stress that results in losses and outflows, funds are likely to reduce their exposures to risky issuers, thereby spreading risk in the system. *Closed-end funds*, due to lack of redemption risk, can and often do hold more illiquid assets, more derivatives, and have more leverage than open-end funds. This implies that they face higher liquidity risk, and risk from deleveraging as well as higher volatility risk. Moreover, closed-end funds often trade at a discount as measured by the difference between NAVs and share prices. In crisis times the share prices of a closed-end fund can therefore fall significantly further than the value of an equivalent open-end portfolio. This may cause the fund manager to sell assets, even if there is no redemption risk from investors. *Hedge funds'* ability to invest in derivatives, engage in buying on margin, and employ short-selling strategies and the use of leverage, as well as invest in illiquid assets, makes them potentially more vulnerable to downward asset price spirals than traditional mutual funds. It is important to note that transactions involving margin and collateral can exacerbate vulnerabilities. A short sale and a futures position involve a margin payment, and it is possible that an adverse price coincides with (i) an increase in the margin requirement and (ii) a decrease in the value of collateral. This makes the margin call worse compared to a situation where the margin does not change. The dynamics of asset prices must be considered together with the dynamics of margin requirements over time, as the two move together.

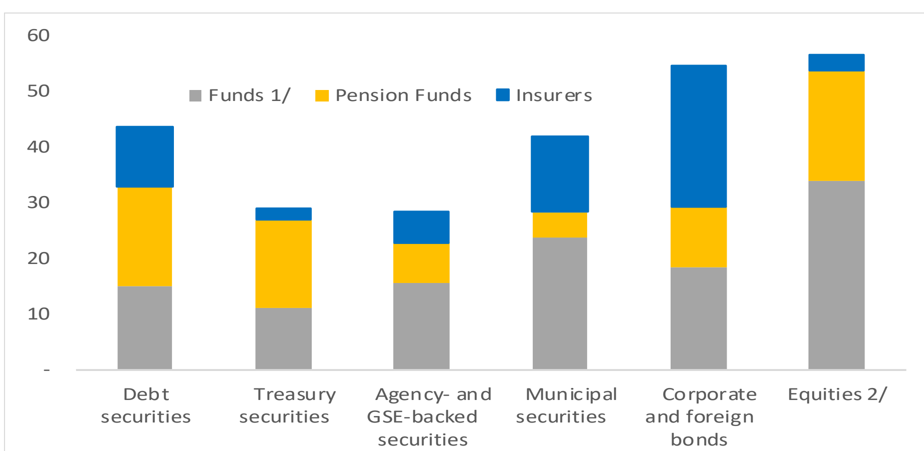
Figure 2. Asset Liquidation and Direct Exposure Channels




Source: Authors' calculations.

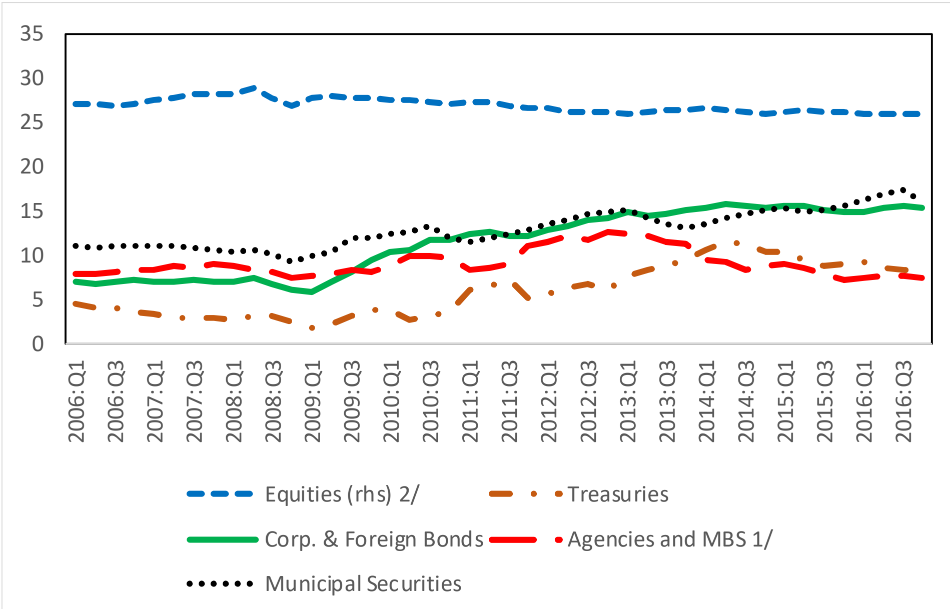
The asset liquidation channel of open-end funds is likely to be important given their significant market footprint. As of 2016Q4, these funds and exchange-traded funds (ETFs) held \$17.5 trillion of equities and fixed-income instruments (according to the Federal Reserve). Their share of the US equity market amounted to 34 percent, while their holdings of different debt market sectors ranged from 11 to 24 percent (Figure 3). They represented the largest group of holders in the markets for agency- and mortgage-backed securities, as well as for municipal bonds. The importance of mutual funds has been growing significantly since 2006, especially for corporate and municipal securities (Figure 4).

Figure 3: Holdings of Nonbank Financial Institutions as of 2016Q4
(in percent market size)




Source: Flow of Funds, authors' calculations.
Note: 1/ "Funds" include mutual funds, closed-end funds, and ETFs.
2/ Share of publicly traded US equities.

Figure 4. Holdings of US Funds as of 2016Q4
(in percent of each asset class)




Sources: Flow of Funds, authors' calculations.
Note: 1/ Debt and mortgaged-backed securities (MBS) issued by US agencies
2/ Share of publicly traded US equities.

Empirical studies have provided evidence of the significance of the asset liquidation channel stemming from open-end funds. Looking at equity funds (EF) from 1980 to 2004, Coval and Stafford (2007) show that widespread selling by distressed funds led to a surge in illiquidity and significant downward pressure on the individual stocks sold. Hau and Lai (2012) have analyzed the impact of distressed selling by mutual funds on the U.S. stock market during the global financial crisis (July 2007–June 2009). They show that stocks that were mostly owned by distressed funds experienced more negative returns during the crisis due to fire sales, and estimate that distressed selling by mutual funds accounted for 10 percent of the 52 percent crisis-related decline in the US stock market. They document two negative twin peaks due to fire sales' effects, in November 2008 and February 2009. Using quarterly data, Manconi and others (2012) show that during the first stage of the financial crisis (June–December 2007), funds that invested in securitized assets had to liquidate part of their portfolio because they faced liquidity needs. Mutual funds started by liquidating their corporate bonds (instead of their illiquid securitized bonds), thereby spreading the crisis. [14]Anand and others (2013) also report that during the peak of the financial crisis (September 2008–March 2009), institutional

[14] As the authors note: "… our findings show that mutual funds with high liquidity needs that were left with exposure to the now illiquid securitized bonds played a significant role in spreading the crisis from the securitized bond market to the seemingly unrelated corporate bond market."

investors such as pension funds and money managers reduced their liquidity provision, which resulted in a surge in illiquidity, especially for risky stocks.

Open-end funds, and especially money market funds, can also affect other financial institutions through the direct exposure/funding channel. When faced with market stress that results in losses and outflows, funds are likely to reduce their exposures to risky issuers, thereby spreading risk in the system. After the reforms to money market funds (MMFs) that came into effect in 2016, the commercial paper holdings of MMFs fell by 70 percent between 2016Q1 and 2016Q4. However, MMFs are still the main providers of repo funding in the US, accounting for around $800 billion as of 2016Q4 (23 percent of the repo market per US Flow of Funds). With broker-dealers receiving $1.3 trillion of repo funding as of end-2016, a run on MMFs similar to the one during the crisis could notably impair the capability of dealers to intermediate, potentially leading to significant problems throughout all sectors of the capital markets. Therefore, frictions in mutual fund lending can lead to the transmission of distress across borrowers, especially among banks and their broker-dealer subsidiaries.

Empirical studies have provided evidence of this direct exposure channel stemming from money market funds. During the European sovereign crisis, U.S. MMFs cut their exposures to European banks, which seemed to be an important factor to explain a severe dollar shortage for those banks, as documented by Correa and others (2012). This dollar shortage was also visible in the large increase in euro dollar basis swaps, until the ECB and the U.S. Federal Reserve reintroduced USDEUR swaps in November 2011. Chernenko and Sunderam (2014) show that U.S. funds exposed to European banks suffered large outflows in mid-2011, which led them to withdraw funding to non-European issuers, thereby spreading distress. During the financial crisis, European MMFs also suffered losses related to their exposure to securitized assets, and some had to suspend redemptions since their assets were too illiquid to be priced accurately (Bengtsson (2012). In the United States, MMFs experienced massive outflows in September 2008 after one MMF was not able to maintain its NAV close to one dollar (the fund "broke the buck"), which amplified further the financial instability arising from the Lehman collapse (Baba and others 2009).

Another potential transmission channel of risk from MMFs to other financial institutions could occur through sponsor support, by purchasing troubled assets or by providing liquidity. Even though sponsors of MMFs (asset managers or banks) do not have to step in to support their funds, some of them provided direct support by purchasing the portfolio. For example, Société Générale bought assets from its enhanced MMFs in the second half of 2007 and in 20081Q as investors sought redemptions and suffered losses in this portfolio. These purchases resulted in a EUR 552mn loss for Société Générale. Barclays chose to guarantee the par value of its MMFs, resulting in GBP 276mn in losses (Bengtsson 2012).

## B. Hedge Fund Sector

Hedge funds (HF) can be described as private investment vehicles for wealthy and financially sophisticated individuals and institutional investors. These primarily include pension funds, insurance companies, and sovereign wealth funds. Compared to mutual funds, HF are relatively unconstrained by regulatory oversight.[15] Hedge funds' ability to invest in derivatives, engage in buying on margin, short-selling and using leverage, as well as investing in illiquid assets, makes them potentially more vulnerable to downward asset price spirals than traditional mutual funds. The greater freedom from constraints regarding risk and leverage has provided HF with the ability to develop and use complex and proprietary investment strategies in a variety of instruments.[16]

Like mutual funds, HF can propagate risk through the asset liquidation channel. The collapse of a hedge fund (or group) leads to the liquidation of their position at fire sale prices. The impact on asset prices may be further magnified due to illiquidity and leverage. This would mean that if positions were large relative to the liquidity of the asset, any potential disorderly unwinding would result in losses for the holders of the assets, which can ultimately contribute to distress at a systemic level. HF can obtain leverage in several ways, including margin accounts, derivatives, repos, and short sales. It is important to note that transactions involving margin and collateral can exacerbate vulnerabilities. A short sale and futures position involves a margin payment, and it is possible that an adverse price coincides with (i) an increase in the margin requirement; and (ii) a decrease in the value of collateral. This makes the margin call worse compared to a situation where the margin does not change. The dynamics of asset prices must be considered together with the dynamics of margin requirements over time, as the two move together. This also implies that a hedge fund may have funding problems, even though markets are liquid.[17] As a result of the above, it is imperative for regulators and supervisors to be able to collect information not only on cash assets but also derivatives positions, short sales, repurchase agreements, margins and counter-parties. Two well-cited examples of hedge fund illiquidity problems were long-term capital management (LTCM) and Amaranth Advisors. These funds had asset positions with positive mark to market value, but were unable to meet margin calls. Figure 5 provides a

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[15] Some examples of regulation affecting mutual funds could be: (i) shares may be redeemable at any time (for open ended-funds); (ii) NAV needs to be calculated daily; (iii) investment policies must be disclosed; and (iv) the use of leverage is limited.

[16] Trading strategies are typically dynamic, as compared to mutual funds, which usually deploy buy-and-hold strategies.

[17] Illiquidity encompasses market liquidity and funding liquidity. Market (asset) liquidity refers to the ability of unwinding positions quickly with minimal price impact. Market liquidity is *systemic,* in that it may be reduced during a financial disturbance. Funding liquidity, on the other hand, is the ability of an investor to obtain cash to meet obligations. Funding liquidity is typically *idiosyncratic* to the firm.

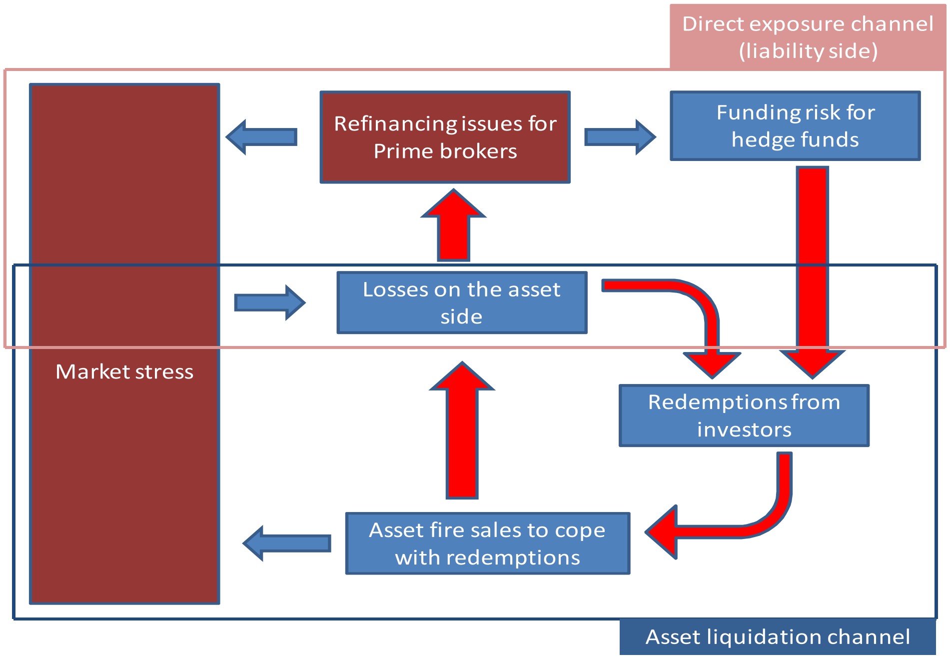
stylized representation of the channels for distress transmission between HF and the rest of financial system.

Overall, losses from HF during the financial crisis in 2008 were compounded by leverage and the illiquidity of underlying holdings in certain asset classes. This was particularly the case in credit and other fixed income markets, including syndicated loans, high yield bonds, convertible bonds, emerging market debt, and credit derivatives. Several funds in these asset classes, namely those primarily focused on relative value strategies that deploy material amounts of leverage, suffered significant losses[18]. These losses were quickly followed by a material increase in redemptions from their investors, which led to various hedge fund managers having to apply gates[19] and suspend redemptions due to their inability to liquidate the necessary number of assets to fully meet these outflows, while also protecting the interests of those investors who remained in the fund. Therefore, hedge fund liquidation can exacerbate market volatility and reduce liquidity in different sectors of financial markets. In addition, HF are exposed to common market risk factors along with other sectors in the financial system. Khandani and Lo (2011) report that in August 2007, long/short equity HF experienced large losses due to the sudden liquidation of a fund that led to fire sales by funds implementing the same types of strategy.

[18] Credit strategies, such as distressed and convertible bond arbitrage, lost 19 percent and 26 percent, respectively, while emerging markets HF lost 30 percent in 2008 (Le Sourd 2009). Per the authors, investors were "given a painful reminder that HF are exposed to a variety of risk factors, such as credit risk, liquidity risk, and several equity risk factors."

[19] Gates are measures to stop a specific amount of redemptions from a fund vehicle. Gates can take two forms: (i) at the fund-level and (ii) at the investor level.

Figure 5. Channels for Hedge Fund Distress Transmission




Source: Authors' calculations.
Note: Red arrows indicate that the effects are amplified by the use of leverage by hedge funds.

The direct exposure channel is also relevant for HF because of their relationship to banks through prime brokerage services. Hedge funds have a symbiotic relationship with the banking sector. Banks are exposed to hedge fund risk via prime brokerage services. Prime brokers are banks that offer services to hedge funds. The bank handles the hedge fund's trades, and determines the collateral the hedge fund has to provide, in addition to borrowing securities for short positions and providing loans.[20] Prime brokerage in the United States is *very concentrated*. As of end-2006, the top 10 prime brokers serviced 84 percent of hedge fund assets under management (King and Maier 2009). Prime brokers offer margin lending to HF and in return can re-pledge the funds' assets in the repo market to refinance the loan (re-hypothecation). Therefore, losses faced by the HF on their assets reduce their ability to repay the loan to the prime broker and thereby increase the refinancing risk for the prime broker, as they must post margin calls to account for the decrease in value of the collateral they posted. An additional channel can develop through exposure to common risk factors causing simultaneous distress in all sectors. In such cases, HF may not be the source of the shock but contribute to *shock amplification,* given their institutional structures. The dynamic and highly competitive nature of hedge fund investment strategies implies that such entities will shift their assets tactically and quickly, moving into markets when profit opportunities arise, and moving out very quickly at the first sign of distress, which can amplify market gyrations.[21]

[20] Hedge funds are not directly regulated, but do need to report to prime brokers.

[21] The fees charged by HF are dependent on performance and are, in general, higher than mutual funds. The fee structure gives hedge fund managers the incentive to make profit, but also encourages risk-taking.

Although such tactics may benefit hedge fund investors in many cases, they can also cause market dislocation in crowded markets, particularly if large asset shifts happen unexpectedly.

### C. Insurance Sector

It is useful to think of the insurance business model as a sophisticated swap, in which insurers receive fixed payments from policyholders and pay floating benefits. Indeed, insurers raise premiums (from individuals, households, workers, and employers), which can then be invested to earn a return, and pay benefits contingent on different event occurrences (mortality, morbidity, casualty, and liability events). As insurance risks are largely idiosyncratic and weakly correlated with the economic cycle, insurers can reap pooling and diversification benefits and earn a spread between the fixed and the floating leg of the swap.[22] The insurance business model is different from that of banks: insurance companies hold long term assets funded by short term liabilities, and should be more insulated from wider market dislocations than the banking sector. This is because the prepaid funding model (implemented via insurance premiums paid upfront and with penalties for discontinuing a policy) offers a cushion to mitigate short-term liquidity needs. Moreover, the need to meet future obligations tilts insurers' asset allocation toward liability-driven investment, which reduces the potential mismatch between assets and liabilities in periods of distress.

Insurance companies are subjected to various types of financial risk. Interest rate risk is particularly material for long-term contracts with minimum guarantees. The nature of insurance liabilities means that life insurers' duration gap is typically negative. The gap is managed and reduced by investing in fixed-income instruments, including government bonds and fixed-income derivatives (for example, swaps and swaptions), as well as corporate bonds and securitized products offering a more rewarding risk-return trade-off. Credit risk is material for all the previous asset classes, and takes the form of counterparty risk in reinsurance and derivative transactions. Depending on the business mix, life insurers can also have exposure to the equity market, as well as to property and infrastructure assets offering a good hedge against inflation. Inflation hedging is important for both life and non-life insurers, due to indexation of benefits and the relationship of claims handling and settlement processes to expense inflation. Foreign exchange risk can be material for insurers, but is often mitigated by regulatory requirements that match foreign currency exposures with suitable assets or hedging instruments on the asset side. Concentration risk typically affects both the asset and the liability side, as insurers' holdings may be concentrated in particular asset classes, while liabilities may originate from a narrow range of exposures or

[22] Insurance is characterized by an inverted production model: insurance premiums are received upfront and used to build reserves (technical provisions) to meet future obligations (insurance benefits). The latter are typically long term in life insurance, and short term in non-life insurance, although there are lines of business (for example, professional liability) that are "long tail" due to the longer duration of the claims reporting/settlement process.

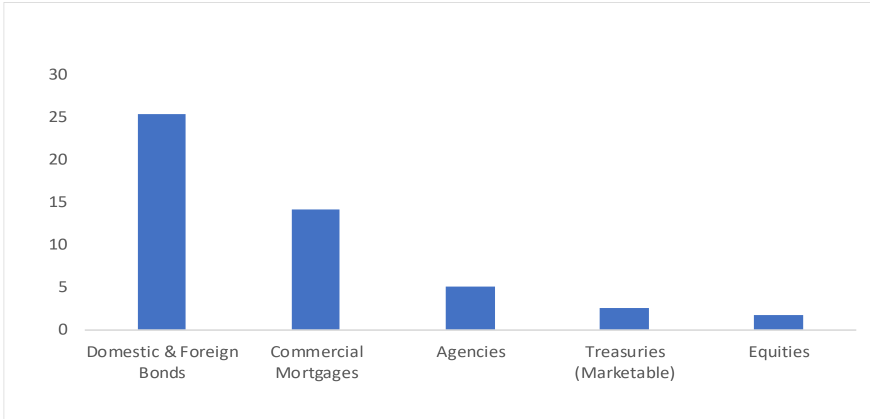
sales/underwriting channels. Liquidity risk is material for insurers when unexpected claims occurrences (for example, catastrophic events, waves of surrenders/lapses) cause immediate liquidity needs that cannot be supported by the regular cash flow provided by insurers' long-term investments.

Technical risks faced by insurers are related to underwriting performance and claims experience. These risks hinge on the nature (for example, life versus non-life) and mix (for example, mortality protection versus annuities) of the business. Claims experience can be higher than anticipated due to random fluctuations in claims occurrence or the emergence of systematic patterns of occurrence. The latter are particularly important for reserving risk, meaning that loss provisions become inadequate to cover expected future claims. Systematic risks that are typically stress tested are demographic and catastrophic risk occurrences (for example, natural hazards and pandemics), which by their nature cut across several different policies and lines of business and undermine the risk pooling model on which the insurance business model is based.

Non-traditional activities undertaken by insurance companies may give rise to relevant contagion channels to other financial intermediaries and markets. The insurance sector has become increasingly non-traditional over time, by providing a variety of "bank-like" functions such as corporate financing, or by engaging in securities financing transactions, securities lending, derivatives writing, and collateral management. Such activities are associated with the emergence of new risks, which may give rise to direct exposure and asset liquidation channels in distress episodes.

The insurance sector has emerged as a vital source of financing for other sectors; hence, the direct exposure channel may spread distress to such sectors. Insurance sector financing has been channeled by either holding corporate bonds and commercial mortgages securities, or, more recently, by providing direct loans to the corporate sector. Insurance companies have become an important buyer of securitized product. This has contributed to the insurance sector's expanded role in the financial intermediation process. As of end-2016, life insurance companies held almost $6.8 trillion in total assets, and property and casualty firms another $1.9 trillion. This made them the largest U.S.-based corporate bond investor, with 25 percent of total holdings, and a significant player in the illiquid municipal bond market, holding 13.5 percent of that market (Figure 6). Large-scale distress of insurance firms would inhibit their ability to continue playing a "bank-like" role and provide financing to the corporate sector.

Figure 6. Holdings of US Insurance Companies as of 2016Q4
(in percent)




Sources: Flow of Funds, authors' calculations.

The asset liquidation channel can become an issue if insurers are exposed to liquidity needs resulting in fire sales. Such situations may occur as the result of margin calls, due to non-traditional insurance operations, and, to a lesser extent, due to major catastrophes and waves of lapses/surrenders of policies.[23, 24] Margin calls can be related to insurers' use of derivatives, which is typically heavy when the business mix includes investments and participating products linked with long-term guarantees. During the past decade, however, insurers have increasingly dominated the supply side of the derivative market. Given the long-term nature of their investments and the inventory of risk exposures they hold, they can write non-standardized, long-term derivatives that are too costly for other financial institutions to intermediate in the current regulatory environment. These activities have extended to bank-like activities, such as liquidity provision in the form of liquidity or collateral swaps. The liquidity needs arising from such transactions could pressure some insurers, leading them to sell assets and thus create an important contagion channel, especially if non-traditional insurance activities are significant.

[23] Large aggregate claim amounts resulting from event occurrences affecting several policies simultaneously (for example, pandemics, earthquakes) can deplete standard reserves and extra provisions (such as resilience reserves), as well as eat into the regulatory capital buffer, forcing an insurer to sell illiquid, long-term assets at a significant discount.

[24] A policyholder can lapse by walking away from a contract (for example, a term assurance policy with no cash value) or surrender a policy by partially or fully withdrawing the policy cash value (exit or surrender value). In both cases, the insurer is exposed to losses resulting from lower business volume (for example, initial expenses, overheads, asset management charges). In the case of cash values, minimum guarantees offered on surrender benefits can be costly in a deflationary environment. An expansionary environment induces policyholders to surrender policies to take advantage of more advantageously priced policies or alternative investment opportunities. Waves of lapses or surrenders could lead to asset fire sales by insurers. The empirical evidence on such bank-run-like behavior is limited.

Insurers may leverage capital via intragroup loans and the use of off-balance sheet instruments. Such leverage can amplify shocks and spread contagion across sectors. These concerns are shared by international regulators, who are actively working on these issues.[25]

Additional indirect channels of contagion might be induced by insurance companies. For example, the banking and insurance sectors seem to be connected via a "flow of funds nexus," between the corporate bond market and lines of credit. Acharya and Richardson (2010) provide the following example: Suppose AA and AAA-rated firms find it punitively expensive to issue corporate bonds, given the inability of insurance companies to play corporate financing roles; they may then be forced to draw on their bank lines of credit. This type of last-resort financing will amplify liabilities in the banking sector, leading to distress. Acharya and Richardson suggest in their analysis that, whereas the banking sector has become better capitalized and less risky (due to conscious behavior or regulation), we have not witnessed a decline in systemic risk of the insurance sector.

## D. Pension Funds

Depending on the nature of the pension promises, pension plans can be classified as Defined Benefit (DB) or Defined Contribution (DC) plans. In DB plans, members pay regular contributions to acquire the right to receive post-retirement benefits, whose value is guaranteed and usually determined as a function of the number of years of contribution and the (average) level of salary before retirement. However, current and future pension liabilities can be supported by the contributions of active members. In other words, the plan does not need to be fully funded. On the other hand, if the funding level is inadequate, the sponsor must inject capital into the pension fund to ensure that future pension promises have proper financial backing. Corrective measures could include an increase in pension contributions by active members or the reduction in pension benefits to pensioners. In DC plans, the plan liability is limited to the value of each member's individual account into which he had contributed. The account balance will evolve depending on the performance of the assets in which the contributions are invested. The cumulative result of the contributions paid into the account and the investment returns generated during the working life of a member (accumulation period) will result in a cash balance that will be available at retirement to support the individual during the decumulation period. By definition, a DC plan is fully funded, and passes all the risk back to the participating members. Some pension plans may present features of both DB and DC types, in which case they are referred to as hybrid plans.

[25] Solvency II, for example, considers group supervision as an essential tool to supplement and complement the supervision of individual companies, and provides a range of governance and reporting requirements to facilitate group supervision.

Pension plans are in general unlikely to give rise to important contagion channels. DB plans hold long-term assets, limit the use of derivatives to hedging, are prevented from borrowing, and can rely on sponsors' contributions as well as benefit reductions in case of necessity. However, the extent to which DB plans can truly rely on additional sponsor contributions or benefit reductions in situations of wider market distress is unclear. In DC plans, individual members are the ultimate bearer of risk.

However, some contributions to systemic risk could materialize under certain conditions. Herd behavior may exacerbate asset price swings and contribute to downward price pressure in situations of market distress (for example, Impavido and Tower 2009, Broeders and others 2016).[26] Similarly, some asset-liability management strategies are inherently procyclical and may affect some asset classes, such as bond and equity markets. Waves of redemptions or drops in contributions in response to poor investment performance may result in pension plans being forced to liquidate illiquid asset holdings at large discounts, thus depressing valuations and retention of members. The effects would be amplified in situations where any minimum guarantees end up in the money without adequate backing assets. This contagion channel is not typically material, as abrupt withdrawals before retirement from both DB and DC plans are typically prevented or discouraged by steep penalties.[27] Unlike other sectors, such as mutual funds and insurance companies, the holdings of riskier securities by pension funds, particularly equities, have decreased significantly since 2008, while their investments in risk-free assets such as US treasuries has increased moderately over the same period (Figure 7).[28]

Moreover, changes in the behavior of pension funds can also have an (indirect) impact on the overall risk of the financial system. This is because there is emerging evidence that pension funds (alongside insurance companies) may be playing less of a countercyclical role in financial markets, making it more difficult to provide liquidity in times of stress.[29] Increased regulatory emphasis on asset-liability matching can play a role in making institutional

[26] Broeders and others (2016), for example, document three types of herd behavior: (i) weak herding, whereby pension plans follow a similar rebalancing behavior; (ii) semi-strong herding, meaning that pension plans respond in the same way to exogenous shocks; and (iii) strong herding, whereby some plans intentionally replicate the strategy of other funds.

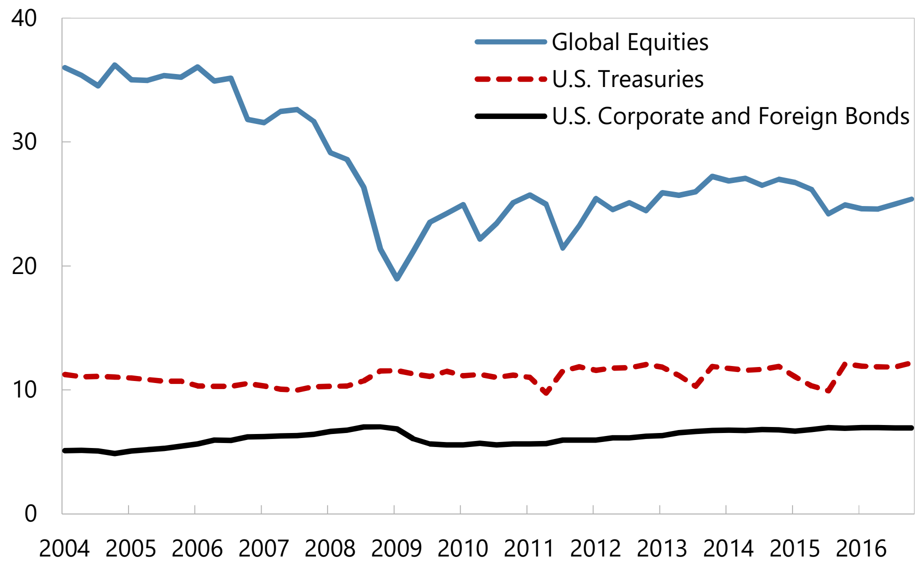
[27] There is evidence that changes to the regulatory framework, as well as to accounting standards, have increasingly limited the risk-taking capacity of pension funds (Franzen 2010). Also, there is anecdotal evidence that the lessons learned from the losses experienced by pension funds during the financial crisis in 2008 have made pension funds increasingly less tolerant of losses, while also strengthening their risk management processes.

[28] While this is likely the case in the aggregate, there is also evidence that some US public pension funds may have increased their risk taking over recent years. This may be related to the fact that US public funds face distinct regulations that link the rate at which they discount their liabilities to their expected return on assets. This contrasts with most other pension funds, which link the liability discount rate to the relative riskiness of their promised pension benefits (Andonov and others 2013).

[29] See discussion paper by the Bank of England and the Procyclicality Working Group: "Procyclicality and structural trends in investment allocation by insurance companies and pension funds" (July 2014).

investors more procyclical. If these investors are minimizing the liability shortfall, they may become increasingly risk averse during periods of stress, as their liability gap increases in down markets. Therefore, they are less likely to behave as shock absorbers and, on the contrary, more likely to sell securities during periods of stress, despite their overall reduction in risk-taking capacity in recent years.

Figure 7. US Pension Fund Holdings
(in $ bn), as of 2016Q4




Sources: Federal Reserve, authors' calculations.

## III. SyRIN: A Comprehensive Multi-sector Tool

Most empirical literature on systemic risk measurement has tended to focus on a single sector, typically the banking sector.[30] Upper (2007) provides a survey of work on contagion in the interbank market, within national banking systems. Segoviano and Goodhart (2009) proposed measures of systemic risk in the banking sector. Theoretical literature includes Allen and Gale (2000), who show that withdrawal of liquidity at one bank can affect the entire banking system, depending on the shape of the network. Freixas, Parigi, and Rochet (2000) discuss the resilience of a banking system to the insolvency of a single bank.

Research analyzing risks associated with nonbank financial institutions has recently started to emerge. A few studies provide evidence of contagion in the insurance sector. Fenn and Cole (1994) investigate the effects of contagion among life insurance companies. Fields and others

[30] In their survey or systemic risk analytics, Bisias and others (2012) note that "relatively few of the studies in our sample deal directly with pension funds or insurance companies despite the fact that the recent crisis actively involved these institutions."

(1998) show that news of large losses faced by Lloyd's in 1993 had negative effects on US insurers. Polonchek and Miller (1999) provide further evidence of contagion effects within the insurance industry by analyzing the impact of equity offerings on the sector.[31] Contagion in mutual funds has been considered by Chernenko and Sunderam (2014), and Hau and Lai (2012). These papers document how mutual funds can spread shocks to the entire financial system. Billio and others (2012) analyze systemic risk among banks, broker-dealers, hedge funds, and insurance companies.[32]

SyRIN conceptualizes the financial system as a portfolio of entities, spanning banks, and nonbanks. In providing a comprehensive treatment of both bank and nonbank financial institutions/sectors, the proposed tool is—to the best of our knowledge—the first of its kind in the literature on systemic risk analysis that attempts to incorporate banks and nonbanks in a consistent manner. The tool, illustrated in Figure 8, incorporates the largest banks and insurance companies operating in a country, as well as the pension sector, mutual fund sector, and hedge fund sectors.

By treating the financial system as a portfolio of entities, this tool incorporates asset value interconnectedness across banks and nonbanks within the measurement of systemic risk. The incorporation of interconnectedness is done thorough the inference of the FSMD, which in SyRIN is done with the CIMDO approach, a non-parametric method which enables robust inference of the FSMD (that is, the CIMDO-multivariate density) from minimum information on asset price returns and PoDs of the entities that make up the financial system (Box 1).

The FSMD allows us to estimate a set of systemic financial stability measures, permitting the assessment of financial stability from different yet complementary perspectives. These measures include financial stability indicators and systemic loss indicators. The financial stability indicators are estimated from joint and conditional probabilities from the FSMD and include (i) the Financial Stability Index (FSI)—a tail risk indicator, and (ii) the Distress Dependence Matrix (DiDe) and Vulnerability Index (VI)—both interconnectedness indicators (Segoviano and Goodhart 2009). [33] Additionally, this approach allows for the estimation (via simulation) of losses at the systemic level, from which we estimate the systemic loss indicators. These include (i) the marginal contribution to systemic risk (MCSR) and (ii) the Systemic Risk Index. These are indicators that simultaneously account for interconnectedness and the relative size of each entity in the system.

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[31] See Egginton and others (2010), who document how contagion effects arose during the collapse of AIG.

[32] They employ Principle Component Analysis to measure commonality in returns across institutions. Using Granger causality tests, the authors identify the direction of the relationships among institutions and show that during the global financial crisis, the number of interconnections between financial institutions soared, with banks and insurance companies being central to the transmission of shocks to other institutions.

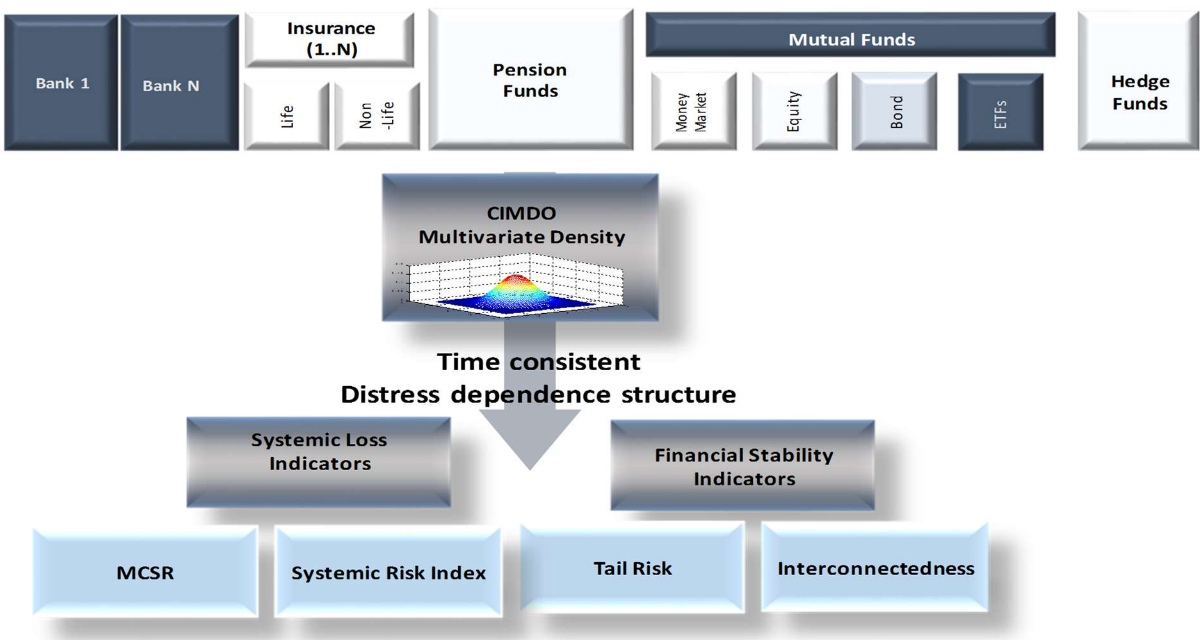
[33] In this paper, as an illustrative application, we implement the FSI, DiDe, and Vulnerability Index. The FSMD allows us to estimate additional indicators based on different conditional and joint probabilities.

For illustration purposes, we proceed by defining a financial system comprising three entities. The asset values of the portfolio of entities are characterized by the random variables $x$, $y$, and $r$. Hence, following the procedure described in Box 1, we infer the CIMDO-density function, which takes the form:

$$\widehat{p(x,y,r)} = q(x,y,r)\exp\left\{-\left[1+\hat{\mu}+\widehat{\lambda_1}\chi_{[x_d^x,\infty)}+\widehat{\lambda_2}\chi_{[x_d^y,\infty)}+\widehat{\lambda_3}\chi_{[x_d^r,\infty)}\right]\right\}, \tag{1}$$

where, $q(x,y,r)$ and $\widehat{p(x,y,r)} \in \mathbb{R}^3$ .

Figure 8. SyRIN: A Comprehensive Multi-Sector Tool




Source: Authors' calculations.

## A. Tail Risk Indicators

### The Financial Stability Index (FSI)

The FSI reflects the *expected number of entities becoming distressed* given that *at least one* entity has become distressed. The FSI represents a probability measure that predicates any entity becoming distressed, without indicating the entity.[34] A higher number signifies increased instability. The FSI embeds not only changes in the individual entities' PoDs, it also captures changes in the distress dependence among the entities in the system, which

[34] The FSI is based on the conditional expectation of a default probability measure developed by Huang (1992), who shows that this measure can also be interpreted as a relative measure of *banking linkage*. When the FSI=1.0 in the limit, banking linkage is weak (asymptotic independence). As the value of the FSI increases, banking linkage increases (asymptotic dependence). For empirical applications, see Hartmann and others (2001).

increases in times of financial distress; therefore, in such periods, the financial system's FSI may experience larger and non-linear increases. For example, for a system of two entities, the FSI is defined as follows:

$$FSI = \frac{P\left(X \geq x_d^x\right) + P\left(Y \geq x_d^y\right)}{1 - P\left(X < x_d^x, Y < x_d^y\right)}. \tag{2}$$

## B. Interconnectedness Indicators

### Distress Dependence Matrix (DiDe)

For each period under analysis, and for each pair of entities in the portfolio, we estimate the set of pairwise conditional probabilities of distress, which are presented in the *DiDe*. This matrix contains the PoD of *the entity specified in the row*, given that *the entity specified in the column* becomes distressed. While conditional probabilities do not imply causation, this set of pairwise conditional probabilities can provide important insights into interconnectedness and the likelihood of contagion between the entities in the system. For the hypothetical financial system defined in Eq. (1), at a given date, the DiDe is represented in Table 1.

**Table 1. Distress Dependence Matrix**

| | Financial Entity *X* | Financial Entity *Y* | Financial Entity *R* |
|---|---|---|---|
| Financial Entity *X* | 1 | *P(X/Y)* | *P(X/R)* |
| Financial Entity *Y* | *P(Y/X)* | 1 | *P(Y/R)* |
| Financial Entity *R* | *P(R/X)* | *P(R/Y)* | 1 |

Source: Authors' calculations.

Here, for example, the PoD of entity *X* conditional on entity *Y* becoming distressed is given by,

$$P\left(X \geq x_d^x \middle| Y \geq x_d^y\right) = \frac{P\left(X \geq x_d^x, Y \geq x_d^y\right)}{P\left(Y \geq x_d^y\right)}. \tag{3}$$

### Vulnerability Index

The Vulnerability Index (*VI*) is a measure constructed using information contained within the distress dependence. For example, the *VI* for entity *X* (given the above 3 entity example/ notation) is defined as sum of joint probabilities, i.e.

$$VI(X) = \quad P(X \geq x_d^x \mid Y \geq y_d^y) \cdot P(Y \geq y_d^y) + P(X \geq x_d^x \mid R \geq r_d^r) \cdot P(R \geq r_d^r) \tag{4}$$

The expression (4) would be computed at each point in time and similarly for the other entities in the system.[35] Typically the measure is normalized by the maximum over the monitoring horizon in order to map the measure in the space [0, 1].

[35] We are assuming that the three entities are in fact a subset of the entire universe of entities in the financial system. *VI(X)* would tend to $P(X)$ as we sum over joints vis-à-vis all entities in universe.

## Box 1. The CIMDO Framework to Model Multivariate Densities

The original formulation of CIMDO is presented in Segoviano (2006). Further methodological improvements and robustness proofs are presented in Segoviano and Espinoza (2017).* CIMDO is based on the Kullback (1959) minimum cross-entropy approach. For illustration purposes, we focus on a portfolio containing two different types of assets (financial system sectors in this application), whose logarithmic returns are characterized by the random variables *x* and *y*. Hence, we define the CIMDO-objective function as:

$C[p,q] = \iint p(x,y) \ln \frac{p(x,y)}{q(x,y)}\, dxdy$, where $q(x,y)$ and $p(x,y) \in \mathbb{R}^2$. (a)

The *prior* distribution follows a parametric form: $q(x,y)$; for example, a multivariate *t* distribution that is consistent with economic intuition (default is triggered by a drop in the firm's asset value below a threshold value) and with theoretical models (the structural approach to model risk). However, the parametric density $q(x,y)$ is usually inconsistent with the empirically observed measures of distress. Hence, the information provided by the empirical measures of distress of each bank in the system is of prime importance for the recovery of the *posterior* distribution. In order to incorporate this information into the *posterior* density, we formulate consistency-constraint equations that have to be fulfilled when optimizing the CIMDO-objective function. These constraints are imposed on the marginal densities of the multivariate *posterior* density, and are of the form:

$$\iint p(x,y)\chi_{[x_d^x,\infty)}\, dxdy = POD_t^x, \quad \iint p(x,y)\chi_{[x_d^y,\infty)}\, dydx = POD_t^y \qquad (b)$$

where $p(x,y)$ is the *posterior* multivariate distribution that represents the unknown to be solved. $POD_t^x$ and $POD_t^y$ are the empirically observed probabilities of distress (PoDs) of each of the sectors in the system, and $\chi_{[x_d^x,\infty)}$, $\chi_{[x_d^y,\infty)}$ are indicating functions defined with the distress thresholds $x_d^x, x_d^y$, estimated for each sector in the portfolio. In order to ensure that the solution for $p(x,y)$ represents a valid density, the conditions that $p(x,y) \geq 0$ and the probability additivity constraint $\iint p(x,y) = 1$ also need to be satisfied. Once the set of constraints is defined, the CIMDO-density is recovered by minimizing the functional:

$$\begin{aligned} L[p,q] = &\iint p(x,y) \ln p(x,y)\, dxdy - \iint p(x,y) \ln q(x,y)\, dxdy \\ &+ \lambda_1 \left[\iint p(x,y)\chi_{[x_d^x,\infty)}\, dxdy - POD_t^x\right] \qquad (c) \\ &+ \lambda_2 \left[\iint p(x,y)\chi_{[x_d^y,\infty)}\, dydx - POD_t^y\right] + \mu \left[\iint p(x,y)\, dxdy - 1\right] \end{aligned}$$

where $\lambda_1, \lambda_2$ represent the Lagrange multipliers of the consistency constraints and $\mu$ represents the Lagrange multiplier of the probability additivity constraint. By using the calculus of variations, the optimization procedure can be performed. Hence, the optimal solution is represented by a *posterior* multivariate density that takes the form

$$\widehat{p(x,y)} = q(x,y)\exp\left\{-\left[1 + \hat{\mu} + \widehat{\lambda_1}\chi_{[x_d^x,\infty)} + \widehat{\lambda_2}\chi_{[x_d^y,\infty)}\right]\right\} \qquad (d)$$

From the functional defined in equation (c), it is clear that the CIMDO recovers the distribution that minimizes the probabilistic divergence, that is, "entropy distance," from the prior distribution and that is consistent with the information embedded in the moment-consistency constraints. Thus, out of all the distributions satisfying the moment-consistency constraints, the proposed procedure provides a rationale by which we select the posterior that is closest to the prior (Kullback 1959), thereby, solving the under-identification problem faced when trying to determine the unknown multivariate distribution from partial information provided by the PoDs in its marginals. When we solve for the CIMDO-density, the problem is converted from one of deductive mathematics to one of inference involving an optimization procedure. This is because, instead of assuming that parametric probabilities characterize information contained in the data, the proposed approach uses this information to infer values for the unknown multivariate probability density.

* In comparison to the original version, the current version of the CIMDO approach employs a multivariate T density as a prior density, which improves robustness and includes a computational algorithm that allows estimation of CIMDO densities of large dimensions.

**Contributions to Distress Vulnerability**

While the *VI* is a useful summary measure to quantify distress dependence of an entity vis-à-vis other entities in the system, we suggest that the contributions of individual entities to the overall *VI* is even more informative. Percentage contributions to distress dependence of entity *X* from entity *Y*, for example, would simply be:

$$\frac{P(X \geq x_d^x \mid Y \geq y_d^y) \cdot P\left(Y \geq y_d^y\right)}{VI(X)} \text{ x } 100\% \qquad (5)$$

Monitoring these contributions over time provides a metric of how distress dependence of an entity in relation to different entities (or sectors) in the system has been evolving.

## C. Systemic Loss Indicators

**Marginal Contribution to Systemic Risk (MCSR*)***

The MCSR requires simulation of the distribution of losses at the system level. From this distribution, a systemic tail risk measure is delineated which, for this analysis, will be the "expected shortfall" (ES)[36]. The MCSR for each sector (or entity) is backed out from the systemic ES using a Shapley-value-based risk attribution methodology proposed by Tarashev, Borio, and Tsatsaronis (2010).

**Systemic Risk Index**

This is constructed using the systemic ES recorded at each point in time. The resulting series is bound between zero and unity by deflating by the max ES recorded over the period (or sub-period). We suggest that such a normalization is informative given that it illustrates the *relative* position of systemic risk with respect to a reference point.

These indicators allow the analysis of complex interlinkages and the quantification of vulnerability to distress risks between entities, both within and across sectors. Hence, this framework is a useful tool for addressing the following key questions: (i) How is systemic risk evolving and what is its current level? (ii) What are the institutions/sectors that contribute most to systemic risk? (iii) How vulnerable are specific institutions/sectors to distress in other institutions/sectors?

## IV. A Tool for Financial Analysis

In this section, we present a case study that focuses on the US financial system from 2007 to mid-2014 in order to showcase the use of SyRIN. We first show how the tool can be

[36] The ES represents the (average) extreme loss to the system that occurs with a probability of 1percent (or less).

implemented. Then we use SyRIN to assess (i) the evolution of systemic risk in the U.S. system; (ii) what are the institutions/sectors that contribute most to systemic risk; and (iii) how vulnerable are specific sectors to distress in other sectors. The tool indicates that at the time of analysis, the high yield mutual fund sector showed high systemic risk impact; hence, we performed further scrutiny in this sector to try to understand why amplification mechanisms could develop in this sector. [37]

## A. Implementation

As described above, the portfolio approach used in SyRIN allows for the easy incorporation of various entities and sectors into the analysis. Each entity or sector in the portfolio is characterized by a marginal density, which is an integral part of the multivariate density that represents the system. SyRIN requires the following steps for implementation:

- Key inputs for implementation are the determination of the asset sizes, recovery rates, and PoD of the financial intermediaries and sectors to be included in the analysis. We discuss below important aspects related to aggregation and probabilities of distress.

- The PoDs are used as an input in the CIMDO approach to infer the FSMD, which is the multivariate density describing the interconnectedness structures across the entities and sectors in the system.

- Two different types of measures are obtained from the FSMD (Figure 8): the financial stability measures and the loss metrics. The first are estimated by "sliding" the FSM into different joint and conditional probabilities. The latter are obtained by Monte Carlo simulations based on the FSMD. Note that since these metrics can be estimated from various statistical moments of a common FSMD, the proposed measures are consistent across each other.

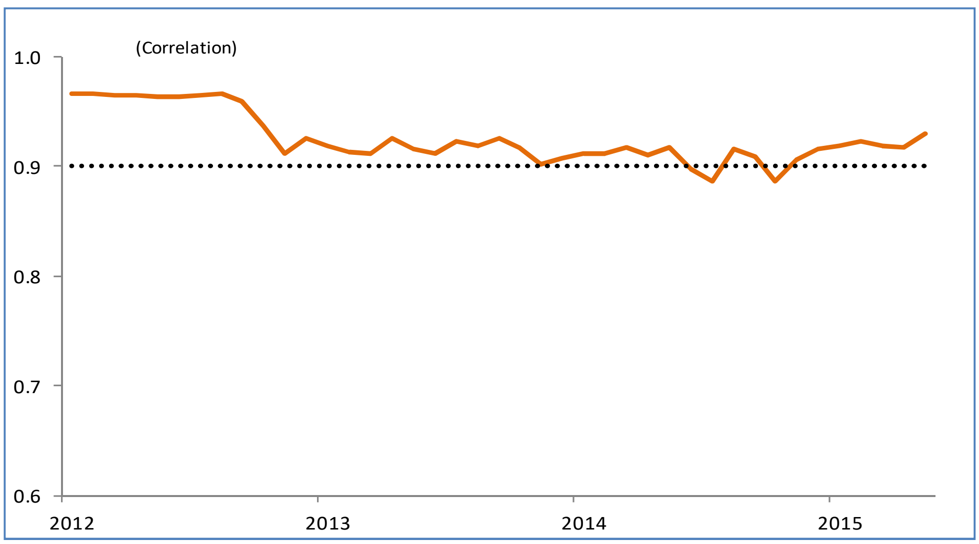
### Aggregation

We recommend inclusion, at the individual level, major banks and insurance companies, and at the sector level, different types of investment and pension funds. This is justified by the fact that individual banks and insurance companies usually undertake a significant proportion of financial intermediation (measured by asset size) in financial systems. Moreover, these entities might follow different business strategies, and hence, might be subjected to different risk factors that should be accounted for when assessing systemic risk. Data are also a consideration, since it is usually possible to get data at the entity level for banks and insurance companies.

[37] We adopt the following convention for certain sectors: HY = High yield bond mutual fund, IG = Investment grade bond mutual fund, and Sov = Sovereign bond fund sector. Bond = (Sovereign + HY + IG) bond fund, unless otherwise stated.

In contrast, we recommend inclusion of mutual funds, hedge funds, and pension funds at a sector level, aggregating them by common categories. This is because performance for such funds is usually benchmarked within their own sector; hence, their business strategies and therefore the risk factors affecting the funds within a sector are usually common. Essentially, this suggests that there is little benefit to be gained from incorporating fund-by-fund level information. An example of such benchmarking is illustrated for the case of the US High Yield sector. Figure 9 shows the consistently high correlation between the average return of the 10 largest US High Yield Mutual Funds and ETFs (by assets under management), and the US High Yield Index. [38] Additionally, data at the sectoral level for this these types of funds are more readily available. Therefore, we recommend including relevant sectors, for example HF, pension funds (PF), money market funds (MMF), EF, high yield funds (HY), Sovereign bond funds (Sov), and investment grade bond funds (IG). However, this taxonomy can easily be adapted to specific country circumstances and data availability.

Figure 9. Correlation of Returns: High Yield Mutual Funds and ETFs vs. the High Yield Index




Sources: Bank of America Merrill Lynch, Bloomberg L.P., EPFR Global, and IMF staff calculations.
Note: Twelve-month rolling correlation of the returns of the top 10 global high yield mutual funds as measured by assets under management. ETF = exchange-traded fund. The average correlation over the entire period was 0.93.

[38] Another point to consider is that an analysis that incorporated thousands of funds within a sector would likely become cumbersome.

**Probabilities of Distress**

The SyRIN is a structural risk model based on the notion of firms' distress. PoDs can be estimated using different models and types of data (market-based and supervisory information). Hence, the tool can be easily adapted to cater to a high degree of institutional granularity and data availability in different jurisdictions. The meaning of distress depends on the type of entity and data employed. Distress events usually include default; however, distress event effects can be broader than default and comprise, among others, debt restructuring, government intervention, recapitalization, credit agencies' downgrades, and so on. An observed common feature of these distress events is that financial entities' asset values decrease significantly.

PoDs for banks and insurance companies. These can be estimated using market-based information and supervisory information.

- **Market-based information:** The most common models are the following:

    - **Merton type.** In this case, distress is equivalent to default, as articulated in Merton's model (1974), which focuses on the capability of a bank to service its debt obligations, that is, credit risk.
    - ***CDS spreads.*** PoDs can be estimated using credit default swap (CDS) spreads. In these cases, distress is defined by the event that triggers the payment of a CDS.
    - ***Bond spreads.*** PoDs can be estimated using the no-arbitrage theorem since the yield of a bond that is subject to credit risk is a function of the probability of default (in this case distress refers to default of the bond).

- **Supervisory information:** PoDs can be constructed from supervisory information when market-based data is not available or not adequate. For example, in countries where subsidiaries of foreign banks operate, it might not be possible to get market-based indicators on the subsidiary (such indicators might exist for the consolidated bank, but this is not adequate). In these cases, we have employed supervisory information to estimate a bank's PoD, which indicates the probability that losses experienced by a bank would violate a supervisory-defined capital buffer (Segoviano and Padilla 2006).[39]

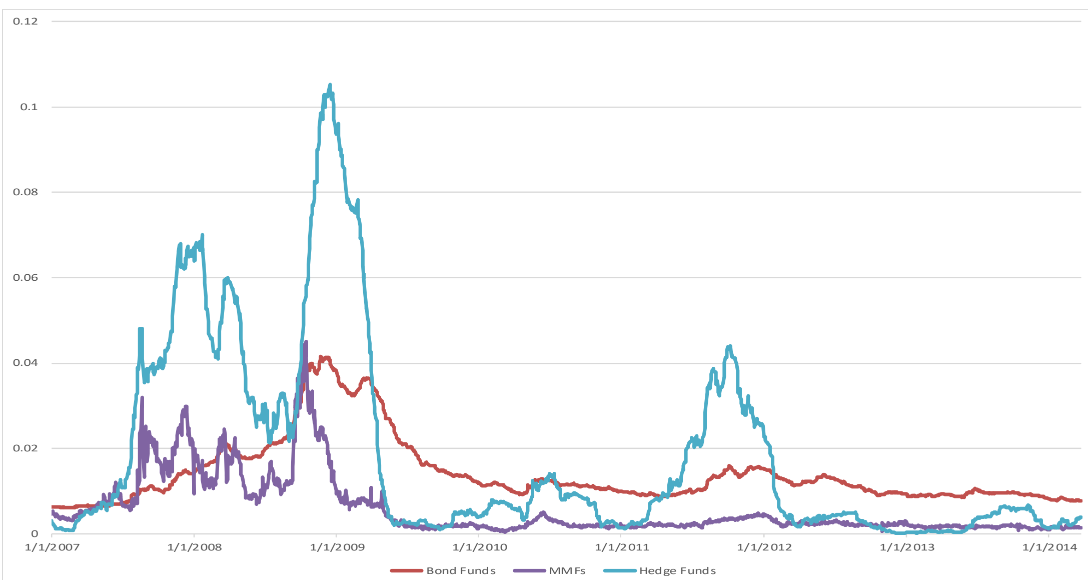
Probabilities of distress for investment funds. Based on the discussion presented in Section II, we define the PoD for investment funds as the probability of events that would require funds to liquidate assets to meet redemption demands. Thus, when funds experience

[39] Risk parameters of banks' loan portfolios (loans' probabilities of default, exposures, and loss-given default) are used to estimate banks' loss distributions (PLD). Supervisory information is used to define thresholds of capital buffers that, if violated, would indicate a distress event; for example, supervisory intervention. PLDs and thresholds are then used to estimate the banks' PoD; that is, the probability of violating the supervisory threshold.

strong outflows, they are likely to sell their assets to meet such demands, transmitting shocks to other financial entities in a system via the direct exposure and asset liquidation channels (Figure 1). In order to estimate such probabilities, we follow a Value at Risk (VaR) approach. With this approach, it is necessary to get asset returns information for the types of funds under analysis (taking account of aggregation aspects discussed above). With the distribution of asset returns for each type of fund, a threshold related to periods of significant outflows is defined. Once such a threshold is defined, it is possible to define the PoD as the probability that returns would be lower than the level indicated by the threshold (see Appendix 1 for technical details).

Probabilities of distress should be consistent with differences in risk factors faced by different types of financial entities. Business models of different financial intermediaries usually expose those entities to different levels of leverage, liquidity, and maturity mismatches. Therefore, PoDs should be consistent with differences in risk factors. Hence, while it is not always possible to explicitly identify such risk factors, PoD measures should be expected to be higher for entities with high leverage, liquidity, and/or maturity mismatches. Figure 10 shows that PoDs for different types of funds estimated under the described approach are consistent with differences across business lines.

Figure 10. PoDs Funds



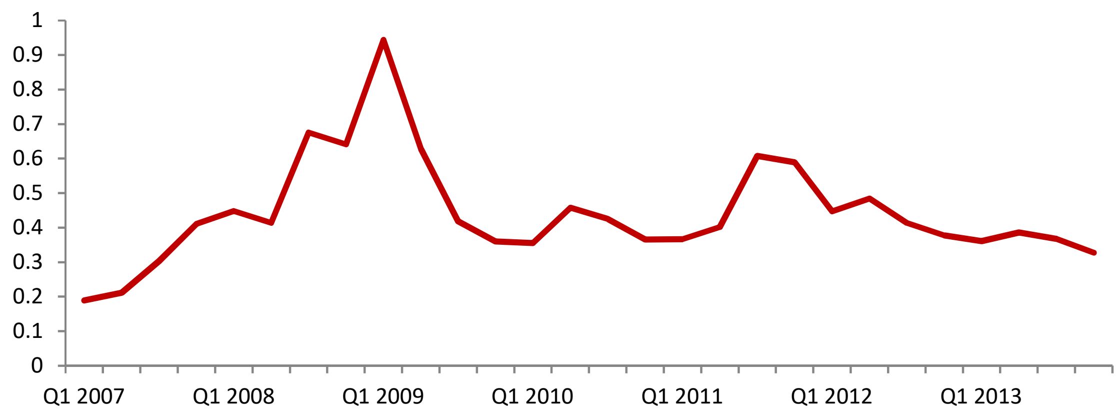

Source: Author's calculations.
Note: As described in Section II, hedge funds' ability to invest in derivatives, engage in buying on margin, short-selling, and using leverage, as well as invest in illiquid assets, makes them potentially more vulnerable to downward asset price spirals than traditional mutual funds. These vulnerabilities are reflected in hedge funds' higher PoDs (versus MMFs and bond funds), which became significantly higher in periods of distress. Open-end funds, especially bond funds that invest in less liquid assets (for example, high yield), showed larger PoDs than MMFs.

## B. Tool for Comprehensive Analysis

How is systemic risk evolving?

- The level of systemic risk at the time of analysis was contained. As is evident from two measures of systemic risk—the Systemic Risk Index (Figure 11) and the FSI Index (Figure 12)—the level of systemic risk is currently lower than it was historically around the peaks of the financial crisis and the European sovereign crisis. These two measures reveal similar readings (in broad terms) on the evolution of, and current state of, systemic risk.

Figure 11. Systemic Risk Index




Source: Authors' calculations.
Note: This measure displays peaks at well-documented systemic episodes: Lehman collapse (September 2008); initial stages of the European sovereign debt crisis (May–June 2010); and subsequent intensification of the crisis after spreading to Italy and Spain

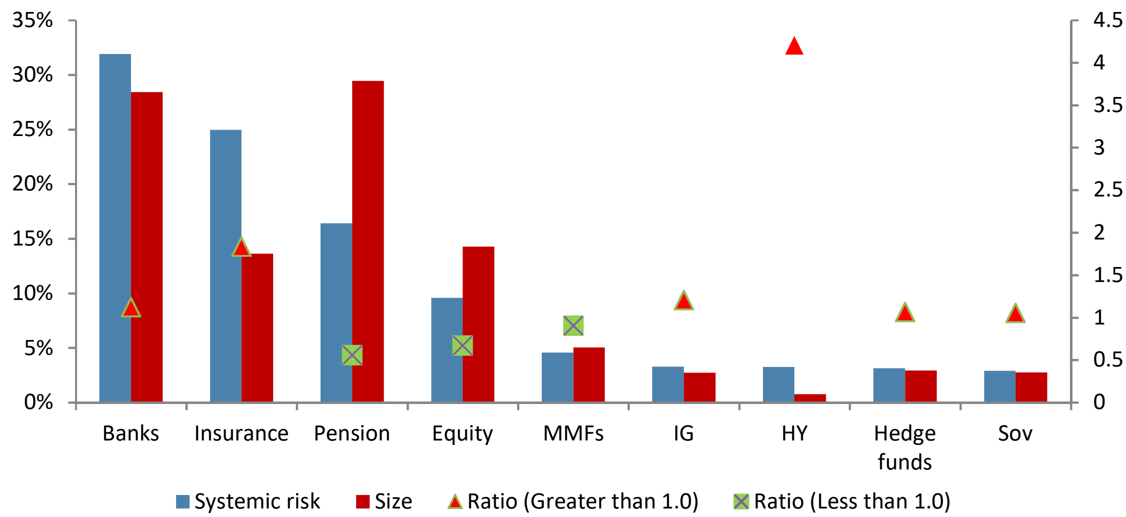
Figure 12. Financial Stability Index


Source: Authors' calculations
Note: This measure displays peaks at well-documented systemic episodes: Lehman collapse (September 2008); initial stages of the European sovereign debt crisis (May–June 2010); and subsequent intensification of the crisis after spreading to Italy and Spain.

What are the institutions/sectors that contribute most to systemic risk?

- The banking sector has the highest systemic impact in the US, followed by the insurance sector and pension funds. Systemic risk contribution is assessed in two dimensions: interlinkages and size. As of 2013Q4, these three sectors' marginal contributions to systemic risk (MCSR) amounted to 73 percent, with 32 percent for banks, 25 percent for insurance sector, and 16 percent for pension funds (Figure 13). It is also the case that for certain sectors—such as HY and IG—their interconnectedness measure dominates their relative size in the financial system; as reflected in a Ratio (= MCSR/Size) greater than unity.

Figure 13. Marginal Contribution to Systemic Risk as of 2013Q4



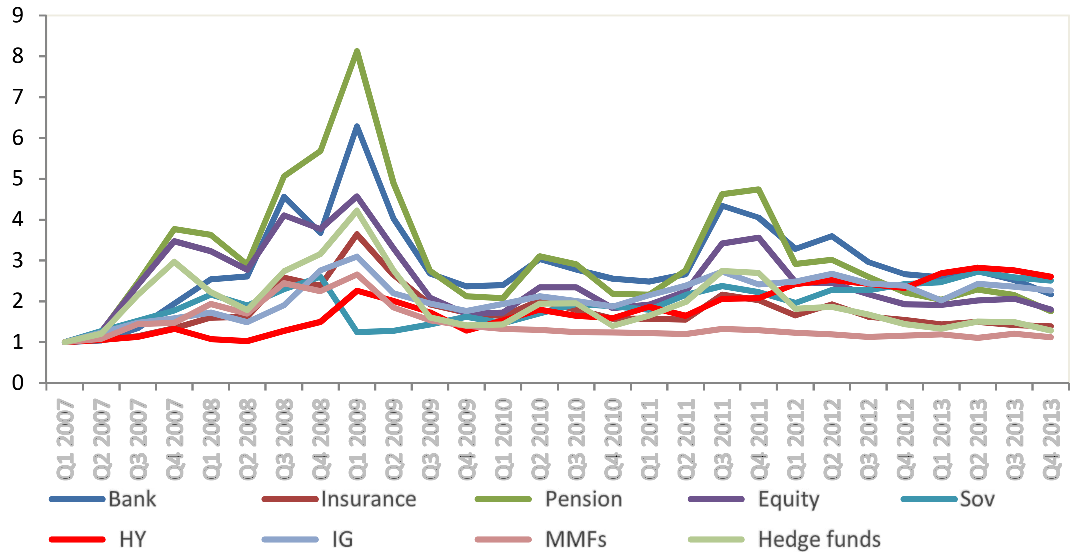

Source: Authors' calculations.
Note: Ratio is measured on the right axis.

We proceed to track the MCSR measured in absolute terms over time. This can be done for each of the considered sectors. The increase in absolute MCSR relative to 2007Q1 is reported in Figure 14. Findings using this measure further reiterate the increasing trend of interconnectedness of HY funds. As of 2013Q4, this sector had witnessed the steepest increase in MCSR relative to the base period.

How vulnerable are specific institutions/sectors to distress in other institutions or sectors?

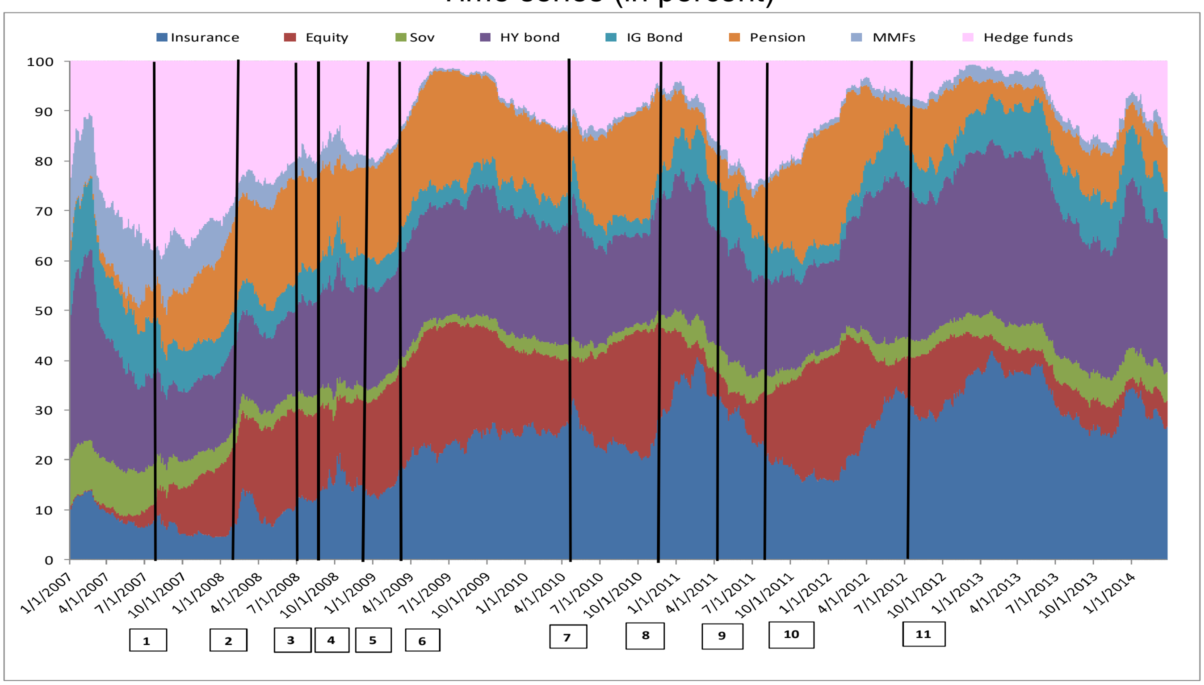
- Contributions to distress vulnerability of the banking sector from the hedge fund and insurance sectors tend to increase prior to periods heightened distress. Contributions from the insurance sector have been steadily increasing over time. Vulnerability to distress brought about by distress dependence can come as a result of direct linkages (due to cross exposures) or of indirect linkages (due to exposures to common factors), or both. Figure 15 plots the evolution of percentage contributions of different entities to banking system distress vulnerability along with well-documented periods of elevated distress.

Figure 14. Increase in MCSR
Index: 2007Q1 = 1




Source: Authors' calculations.

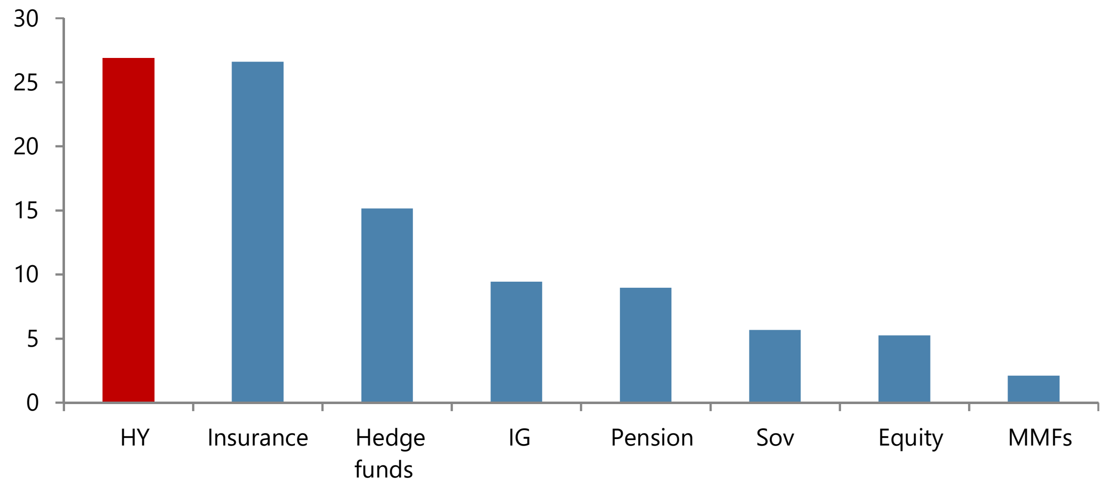
Figure 15. Contributions to Distress Vulnerability of the Banking Sector
Time series (in percent)




Source: Authors' calculations.
Notes: [1] August 9, 2007: BNP halts redemptions, [2] March 14, 2008: Bear Sterns collapse, [3] July 15, 2008: Short selling ban on GSE credit line, [4] September 15, 2008: Lehman collapse, [5] December 12, 2008: NBER announces US recession, [6] March 15, 2009: Fed announces Treasuries purchases, [7] May 2, 2010: Greek package, [8] November 21, 2010: Ireland package, [9] April 6, 2011: Portugal package, [10] July 10, 2011: ECB buys Italian and Spanish bonds, [11] July 26, 2011: Draghi's "Whatever It Takes" speech.

The analysis revealed that by 1Q2014, the HY sector was the most important sector for banking sector distress vulnerability, followed by insurance and hedge funds. This finding is based on a comparison of percentage contributions to banking sector distress vulnerability from each of the entities at the final point of the given time span. HY sector dominates, followed closely by insurance (Figure 16).

Figure 16. Contributions to Banking Sector Distress Vulnerability as of 1Q2014
(in percent)




Source: Authors' calculations.

Contributions to insurance sector vulnerability to distress from the banking sector have shown a steady increase over time. Importantly, the evolution of this contribution closely tracks the evolution of contribution to distress vulnerability of the banking sector from the insurance sector. In contrast, hedge fund sector contribution to insurance sector distress is much less cyclical and appears fairly stable since early 2011.

The analysis reveals the banking sector to be the most important contributor to insurance sector distress vulnerability, followed by HY and HF. For the case of the insurance sector, comparing contributions from each of the entities at the final point of the time span considered (that is, 3/24/2014) indicates that the banking sector's contribution dominates, followed by HY and HF sectors (Figure 17).

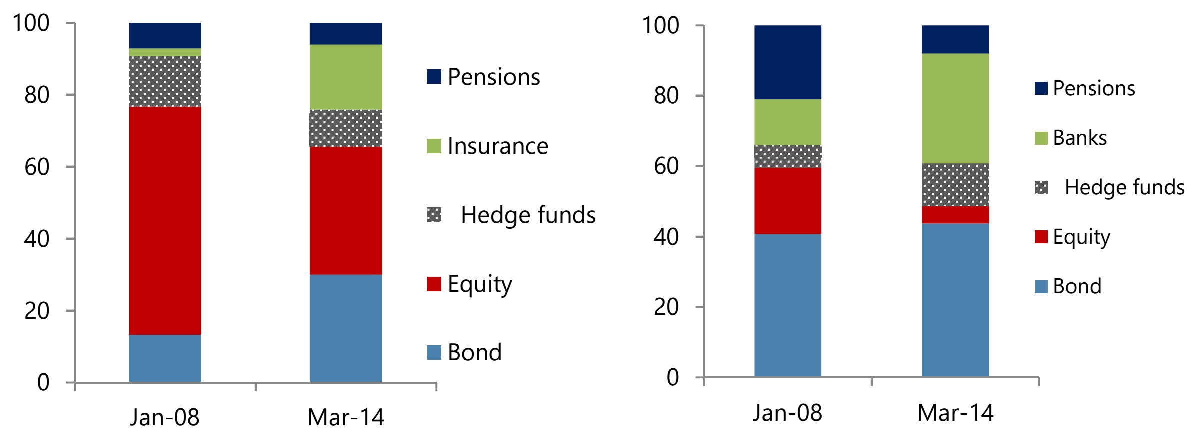
Figure 17. Contributions to Insurance Sector Distress Vulnerability
(in percent)


Source: Authors' calculations.

Linkages between the banking, insurance, and bond mutual fund sectors have increased in recent years. The analysis documents increasing interconnectedness of mutual funds and other sectors, for example, banking and insurance. Therefore, any potential distress in, for example, the bond fund sector, will have a greater impact on these sectors—through both direct (balance sheet) exposures to these markets as well as through indirect exposures, for example, through second order intermediation channels and mark-to-market exposures. In order to illustrate broad trends, between January 2008 and March 2014 the percentage contribution by bond[40] mutual funds to the vulnerability to distress of the banking and insurance sectors has increased (Figure 18). The upward trend in this particular sector's contribution is steeper for banking sector distress vulnerability, as compared to the insurance sector. We find that the contributions to vulnerability to distress of the banking and insurance sectors to each other have increased significantly. This is consistent with the evidence of convergence on business models of these sectors, that is, the insurance sector becoming more "bank-like" over time.

[40] 'This refers to the aggregate of Sov, HY and IG bond mutual fund sectors.

Figure 18. Contributions to Distress Vulnerability of the Banking (left) and Insurance (right) Sectors as at January 2008 and March 2014 (in percent)




Source: Authors' calculations.

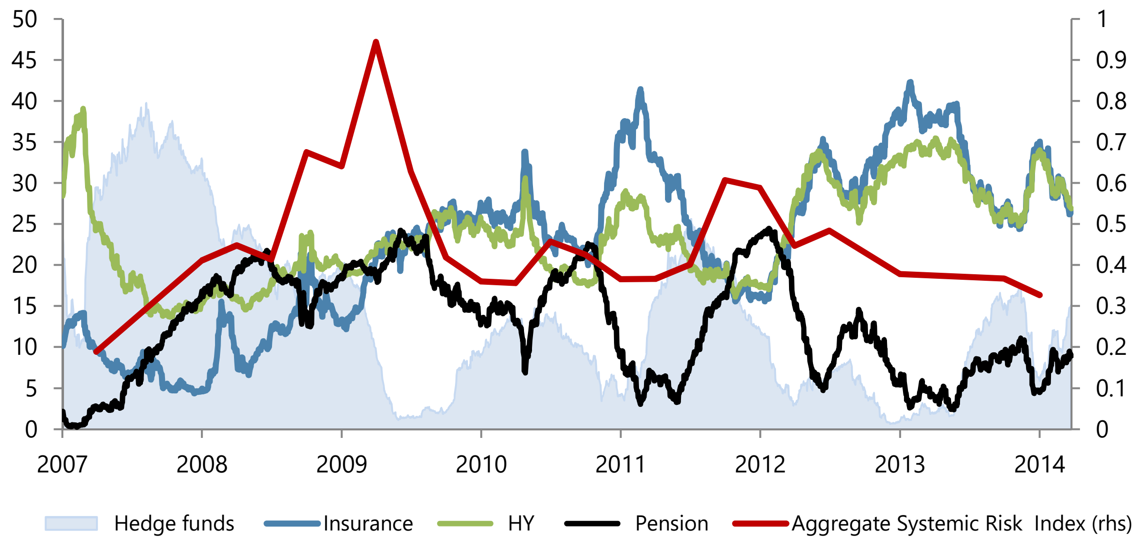
How does the level of systemic risk relate to the distress vulnerability?

- While the level of aggregate systemic risk was contained during the period covered by the analysis, the contributions to distress vulnerability from certain sectors had increased. In assessing measures of systemic risk level in conjunction with distress vulnerability, it is shown that, for the case of the banking (Figure 19) and insurance (Figure 20) sectors, since early 2012, and in spite of aggregate systemic risk falling to a low level (comparable to its level around 2007Q1), vulnerability to distress from shocks from certain sectors has increased sizably.

- Specifically, contributions to banking sector distress vulnerability from insurance and HY sectors had been trending upward over most of the sample, and have increased fairly steeply since early 2012. This corresponds to the same period where the level of systemic risk has been witnessing a steady decline. We also see that the increase in systemic risk level is typically preceded by a buildup of distress vulnerability of the banking sector to shocks from the hedge fund sector. Considering results for the insurance sector, we find that contribution to insurance sector distress vulnerability from the banking sector has exhibited a general upward trend over the sample. This is consistent with the observation of the convergence in business models of banking and insurance sectors.

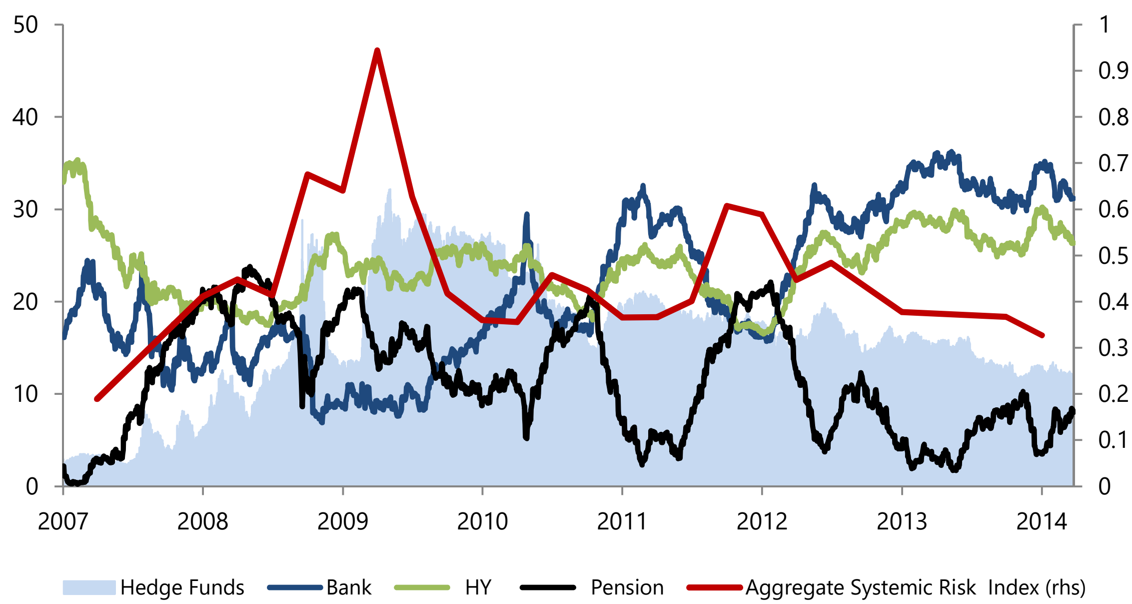
- Furthermore, we note that, whereas there is an accumulation of the hedge fund sector's contribution to banking sector distress *prior* to a rise in the level of overall systemic risk, this leading relationship of the hedge fund sector vis-à-vis the insurance sector is far less compelling. The contribution of the hedge fund sector to the insurance sector distress is generally stable (see figures 19 and 20), while in contrast, its impact on banking sector distress is characterized by relatively more pronounced cyclicality.

Figure 19. Comparison of Systemic Risk Level with Contribution to Banking Sector Distress Vulnerability




Source: Authors' calculations.
Note: LHS axis denotes percent.

Figure 20. Comparing Aggregate Systemic Risk level with Contribution to Insurance Sector Distress Vulnerability




Source: Authors' calculations.
Note: LHS axis denotes percent.

### C. SyRIN: A Tool for Guiding Deeper Analysis, and Related Policy Recommendations

In this paper, we have shown SyRIN to be a useful tool for analyzing problematic sectors. For example, based on publicly available data, the tool identified the high yield mutual fund sector as having potentially high systemic risk impact. Key conclusions of the previous section are:

- The level of interconnectedness of HY sector relative to size (that is, ratio) exceeds unity and has been on an upward trajectory since early 2012. This ratio currently stands at close to its level leading up to the financial crisis.

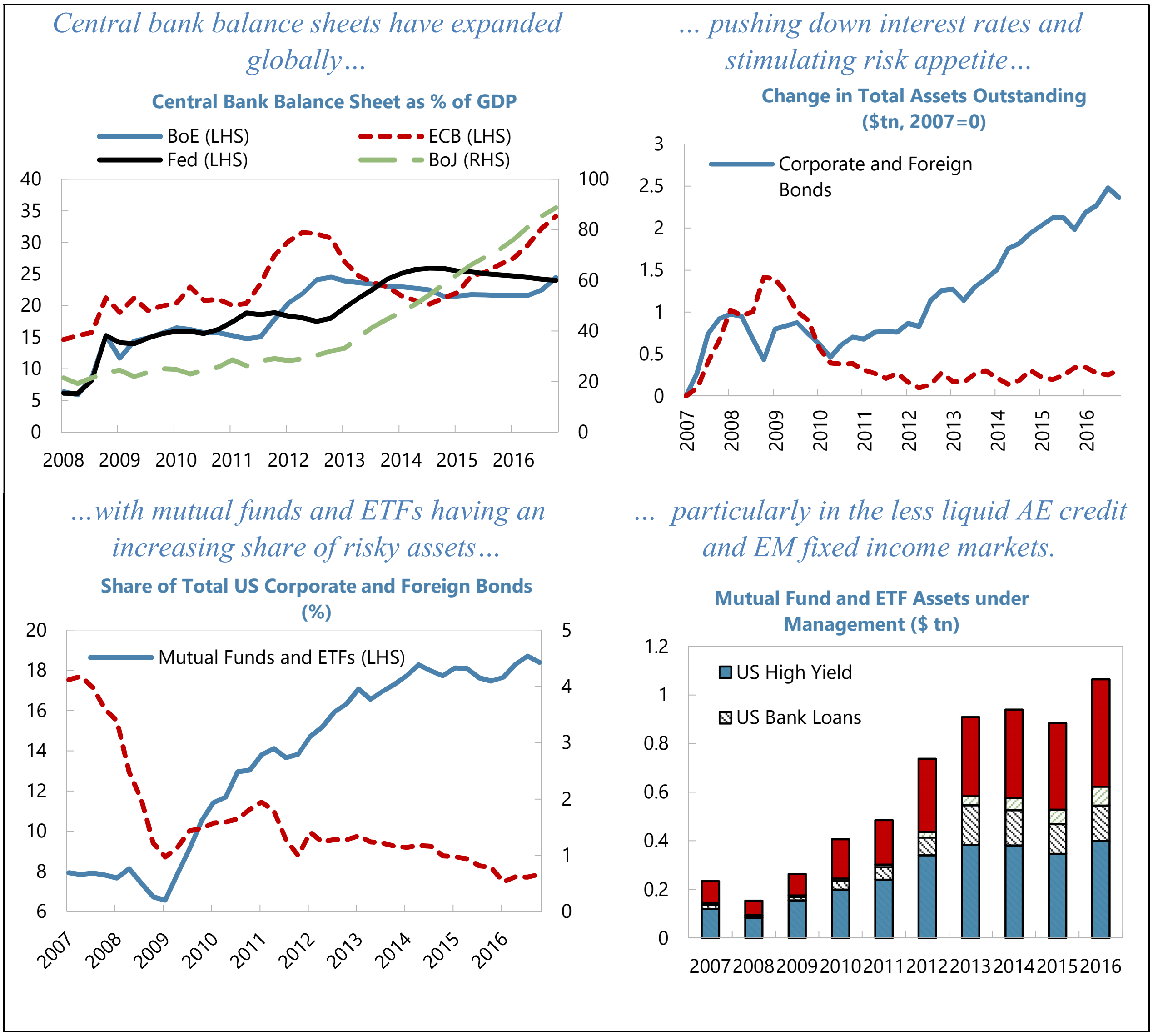
- The vulnerability to distress of the banking and insurance sectors to shocks from the HY sector has been increasing dramatically in recent years.

Focus on the HY sector revealed the underlying structural reasons responsible for the trends uncovered:

- Increasing flows into mutual fund and ETF investments, particularly into riskier, less liquid asset classes such as high yield, have taken place. In response to the crisis, authorities took bold and coordinated action that helped mitigate what could have potentially been another global depression. However, there is a tension between the following two types of policies pursued during the recovery. On the one hand, monetary authorities have deliberately sought to stimulate demand though near-zero short-term interest rates and unconventional monetary policy, removing low-risk, longer-duration assets from the market (Figure 21) and impelling investors to reallocate into riskier asset classes. At the same time, U.S. (and also European) regulatory authorities took steps to make banks safer by raising regulatory capital standards and drawing stricter limits on trading activities. By simultaneously pursuing unconventional accommodative monetary policies and tightening regulatory and capital standards on banks, authorities have spurred an appetite for risk that cannot be fully met by the regulated bank sector. This has contributed to the nonbank financial sector becoming a substantial holder of risk, with increasing ownership of corporate and riskier foreign debt. This has happened at a time when the average holdings of these securities by market makers (that is, broker-dealers) have decreased sharply. This growth has been particularly strong in the less liquid fixed income markets, such as high yield,[41] as low rates prevailing during the period of quantitative easing have also led to an increased supply of bonds by riskier companies.

[41] In addition to leveraged loans and emerging markets debt.

Figure 21. Accommodative Monetary Policies Have Encouraged Greater Risk-Taking

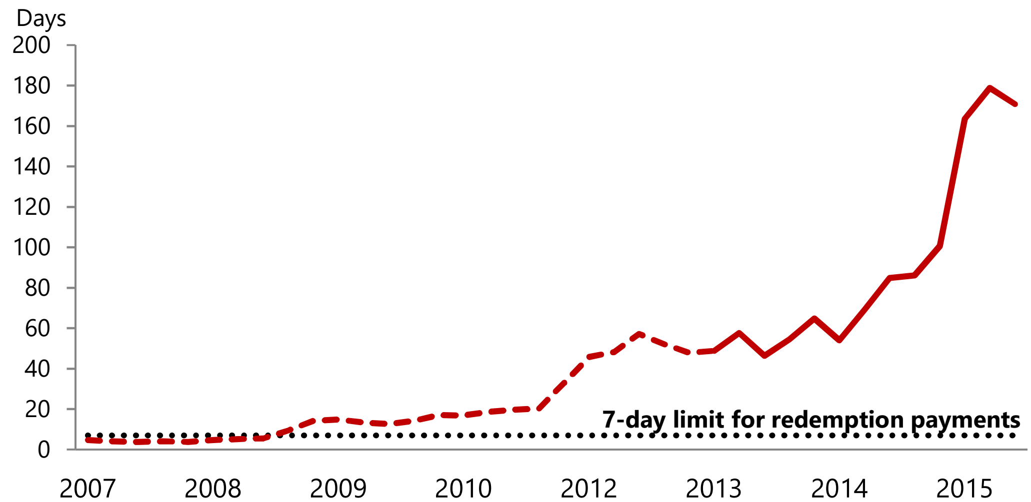



Sources: Bloomberg, Federal Reserve, EPFR Global, and Authors' calculations.

- HY mutual funds face rising redemption risks. While institutional investors, such as pension funds and insurance companies, have relatively stable funding structures, mutual funds and ETFs are vulnerable to investor withdrawals. The liquidity provided by funds can quickly reverse, with fund inflows historically reversing during times of stress, particularly for funds that invest in riskier, less liquid, fixed-income products. This risk is compounded by the fact that mutual funds and ETF vehicles engage in liquidity transformation, offering demandable equity in substantially less liquid underlying investments, and therefore may make the liquidation of a significant amount of their holdings very problematic within short periods of time, particularly during episodes of turmoil.[42]

- Redemption risks increase, due to mutual fund growth and declining inventories in the less liquid markets, as represented by the number of days it will take to fully liquidate all holdings should all investors decide to redeem at once (Figure 22). This is a concern as, for example, the current SEC regulations only permit funds to delay paying redemptions to their investors for a maximum of seven days.[43]

Figure 22. Days Required for Full Liquidation




Source: EPFR Global, Federal Reserve, and authors' calculations.
Note: The number of days to liquidate is the ratio of assets of US high-yield mutual funds and ETFs per daily dealer inventories. Under the Investment Company Act of 1940, US open-end mutual funds may not postpone the payment of redemption proceeds for more than seven days following receipt of a redemption request. Because there are no data for US high-yield bond-dealer inventories before April 2013, the dashed red line assumes a constant ratio of this amount to total corporate bonds before this date.

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[42] Most mutual funds in the less liquid fixed income markets offer the promise of daily liquidity to their investors, while ETFs offer continuous intraday liquidity given that they trade at exchanges.

[43] Under section 23(e) of the Investment Company Act of 1940 Provisions: "Open-end funds may not suspend the right of redemption, and open-end funds may not postpone the payment of redemption proceeds for more than seven days following receipt of a redemption request." Under exceptional circumstances, mutual funds may be allowed to suspend redemptions temporarily should (i) the disposal of securities by a mutual fund is not "reasonably practicable" or (ii) it is not reasonably practicable for such fund fairly to determine its NAV. In theory, there is a mechanism in which the SEC has the authority to authorize asset managers to suspend when facing large redemptions. See, for example, the case of the Third Avenue Focused Credit Fund, which announced the suspension of redemptions on December 9, 2015, and blocked future investor redemptions following a period of large losses and investor outflows. However, it remains to be seen how effective this mechanism would be on a large scale, as it has never been tested before in a period of significant distress across financial markets.

The observed growth in mutual fund and ETF holdings means that they have become key players in credit intermediation, and are, therefore, becoming increasingly interconnected with the rest of the financial system. For instance, the increase in the percentage contributions of HY mutual funds to the vulnerability of the banking and the insurance sectors reflects the fact that market and liquidity pressures in mutual fund holdings of HY bonds may negatively impact the banking and insurance sectors, both directly through balance sheet exposures as well as indirectly through common mark-to-market exposures and contagion through the asset liquidation channel.

Policy recommendations to mitigate these risks have been discussed in recent IMF Global Financial Stability Reports.[44] To address the contagion risk stemming from the liquidity mismatch posed by high yield mutual funds, policy should consider measures to limit the incentives for mutual fund investors to run, enhancing the accuracy of NAV calculations, and improving the liquidity and transparency of secondary markets. Specifically:

- Regulators should consider a tailored approach when assessing the relative liquidity of specific asset classes compared to the redemption terms offered by comingled investment vehicles such as mutual funds. For example, in markets with frequently observed transactions and substantial depth, such as advanced economy money markets and sovereign debt, the current practice of striking a daily NAV and redemption terms may be appropriate. In less frequently traded markets in which bid-ask spreads can be large, such as HY bonds, lower frequency redemption terms are more appropriate. In this regard, the seven-day maximum limit to pay for redemptions in US mutual funds (under the Investment Company Act of 1940, Section 22e) may not be enough during stress periods, given the existing liquidity mismatches stemming from the rise in mutual fund assets invested in the less liquid fixed-income markets and the low level of dealer inventories in these markets.
- While the oversight of liquidity risk management has intensified and new rules have been adopted,[45] liquidity mismatch vulnerabilities remain prevalent in certain investment vehicles and warrant further improvements to mitigate the risk. Recent initiatives such as the IOSCO consultation on liquidity risk management recommendations (July 2017) and the UK FCA's discussion paper on possible approaches to improve liquidity risk management (February 2017) have suggested possible methods to address these vulnerabilities. There is room for improvement in different areas including greater

[44] See Chapter 1 of the October 2014 and May 2015 IMF's Global Financial Stability reports.

[45] The SEC adopted a new liquidity risk management rules in October 2016 and the FSB published a series of policy recommendations to address structural vulnerabilities associated with asset management (including liquidity risk management) in January 2017.

flexibility in redemptions and dealing frequencies[46], the treatment of institutional investors, better guidance on the use of specific risk management tools and enhanced disclosure requirements.

- Improving the accuracy of NAV calculations should also reduce stability risks associated with HY mutual funds. The SEC rules for US mutual funds state (under the Investment Company Act of 1940, Rule 22c-1) that "an open-end fund generally must compute its NAV at least once daily, Monday through Friday." This may not be appropriate for funds invested in the less liquid assets, where the computation of a daily NAV often relies upon third-party "matrix-pricing" services that use algorithms and assumptions to generate estimates of fair value. Analysis in the GFSR shows how only a quarter of the bonds in the Barclays High Yield Index trade every day, and therefore setting a daily NAV for these securities poses challenges. The necessary use of matrix pricing can be misleading (See pp. 33 of Chapter 1 Oct 14 GFSR). This can lead to large price drops during volatile markets, and potentially to further redemptions from end-investors unaware of the limited liquidity of the underlying investments. Therefore, where transactions are infrequent, it is recommended that mutual funds change to less frequent NAV pricings, in line with lower frequency redemption terms that better match the liquidity of the underlying investments.
- Regarding ETFs, the regulatory authorities, which can withhold permission from particular fund types, should make the liquidity—or illiquidity—of the underlying assets a major criterion in the approval process of new ETFs.
- Insurance products which incorporate significant elements of protection against market moves should only be allowed if they are fully hedged with derivatives traded on exchanges or trading platforms. Insurance products that are subject to adverse moves in single factors (mortgage or bond insurance) should also only be provided if hedged with exchange- or platform-traded derivatives.
- Greater emphasis should be placed on asset managers' communication with investors about the risks inherent in mutual funds invested in certain markets that may be subject to greater liquidity risks and volatility, particularly during periods of distress.
- Finally, given the complexity of these issues, it is crucial that regulators pursue a harmonized and coordinated global effort to examine the universe of mutual funds when considering prudential policies, and to develop best practices for addressing redemption risks as well as the supervision of liquidity and pricing of illiquid securities.

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[46] Greater flexibility in redemption and dealing frequency under the European Union's UCITS Directive is a step in the right direction. The directive allows funds to have redemption frequencies of up to twice a month, which may help minimize the risk of liquidity mismatches. However, only a small proportion of funds invested in illiquid assets, such as high yield bond funds, offer redemption terms at a lower than daily frequency under UCITS, which has been related, amongst other reasons, to the inability of fund distribution platforms to accommodate any other fund dealing pattern than daily.

Going forward, SyRIN can be of use in assessing the impact of ongoing structural changes in financial markets. Hence, we hope that SyRIN represents a useful tool in the process of policy formulation, with the objective of minimizing vulnerabilities due to:

- Increased sensitivity of capital markets to the exit from unconventional monetary policies. The vulnerability of markets to asset price movements and the increased cross-market interconnectedness experience in recent years could make the exit from unconventional monetary policies more volatile, potentially undermining the ability of the financial system to support the recovery.
- The rise of passive investment and financial market participants becoming increasingly marked-to-market and benchmark-centric. This contributes to increases in sensitivity to changes in asset prices and the interconnectedness between them. There has been a substantial increase in the share of risky assets held by passive investment vehicles such as index funds and mutual funds.[47] For example, the share of total U.S. public equities held by index funds and ETFs rose from 6 percent in 2007 to 16 percent by end-2016 (Figure 23). At the same time, there is evidence of increased procyclicality of pension funds and insurance companies at a time of significant reduction in bank dealer market making activities.[48]
- Changing cross-country financial interlinkages. The globalization of financial services has increased financial interconnectedness, not only across sectors but also across borders.
- Higher vulnerabilities for emerging markets to shocks originating in advanced economies. Financial links between advanced markets and emerging markets are now stronger, reflecting portfolio concentration and the changing nature of asset price volatility, exposing emerging markets to shocks emanating from advanced economies.

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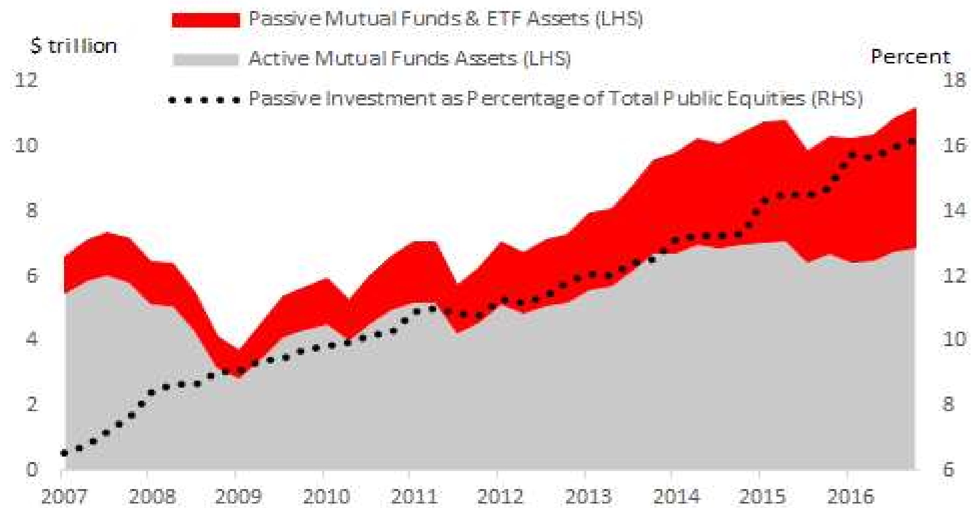
[47] There is a growing body of academic work warning about the risks related to the growth of passive investing. Wurgler (2011) argues that the increase in passive investment inhibits the ability of active managers to beat benchmarks and can also lead to greater risk of asset price bubbles followed by crashes as it may encourage trading activity that exacerbates those risks. Wermers and Yao (2010) find that stocks with "excessive" levels of passive fund ownership exhibit more long-term pricing anomalies as well as a larger price reversal following trades. Sullivan and Xiong (2012) also find that the growing popularity of passive investing contributes to higher systemic market risk.

[48] See Bank of England and the Procyclicality Working Group, 2014.

Figure 23. The Rise of Passive Investment in US Equity Markets




Sources: Federal Reserve, ICI, and authors' calculations.

## V. Conclusions

Systemic risk can be amplified across various financial intermediaries and markets. Therefore, a proper measurement of systemic risk requires an assessment of risk beyond the banking system that also accounts for interconnectedness across financial entities and markets which could pave the road for financial contagion. SyRIN allows a comprehensive assessment of systemic risk by quantifying the impact of systemic risk amplification mechanisms due to interconnectedness structures across banks and other financial intermediaries, including the insurance, pension fund, hedge fund, and investment fund sectors—risk that cannot be captured when analyzing sectors independently. The tool produces various metrics that serve to evaluate systemic risk from complementary perspectives, including tail risk, interconnectedness across different entities, and the contribution to systemic risk by multiple entities and sectors.

SyRIN is easily implementable with publicly available data and can be straightforwardly adapted to cater to different degrees of institutional granularity and data availability. SyRIN is designed to be a tool to identify vulnerabilities from a top-down perspective that can lead to deeper scrutiny in specific sectors and that can provide information to authorities to assist their policy formulation process.

SyRIN's contributions are increasingly relevant, as structural changes in financial intermediation are shifting the locus of risk to the non-financial sector, and involve increasing interlinkages across sectors. Going forward, SyRIN can be useful for assessing the impact of emerging vulnerabilities due to increased sensitivity of financial markets to the exit of unconventional monetary policies, higher vulnerabilities of EMs to shocks originating in AEs, and increased procyclicality arising from structural changes in markets.

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## APPENDIX I. INPUTS FOR IMPLEMENTATION

The implementation of SyRIN requires as inputs PoDs and total assets of the entities and sectors under analysis. Our dataset includes PoDs at the individual entity level (banks and insurance companies) and sectors (mutual funds, pension funds, and hedge funds). This appendix describes the method employed to estimate the PoDs for each of those entities and sectors.

### PoDs: Banks and Insurance Companies

For banks and insurance companies in the sample, PoDs are estimated using CDS spreads[49], following Segoviano and Goodhart (2009). Based on the no-arbitrage theorem and assuming a recovery rate ($R$) of 40 percent, PoDs are defined by the following formula:

$$PoD_t = \frac{CDS_t}{1-R}.$$

The entities included in the banking and insurance sectors are as follows:

- Banking: Bank of America, Capital One Financial, Citigroup, Goldman Sachs, JPMorgan, Morgan Stanley, and Wells Fargo. These entities cover approximately 67 percent of total US banks' assets.

- Insurance: AIG, Allstate, Berkshire Hathaway, Hartford Financial Services, MetLife, Prudential, and Travelers Companies. These entities cover approximately 50 percent of total U.S. insurance sector assets.

### PoDs: Investment Funds

We follow a VaR approach. As discussed in Section IV.A, this approach requires an estimation of the distribution of asset returns for each type of fund under analysis, and a threshold related to periods of significant outflows. Once such a threshold is defined, it is possible to define the PoD as the probability that returns would be lower than the level indicated by the threshold. The steps in this estimation were the following:

1. Compile daily stock price: $P_t$
2. Compute daily stock price return: $r_t = \log(P_t) - \log(P_{t-1})$
3. Standardize $r_t$ by subtracting full sample mean $\bar{r}$ and dividing by full sample standard deviation σ.
4. Standardized returns are thus given by: $r_t' = \frac{r_t - \bar{r}}{\sigma}$
5. Compute distress threshold for the full-time series such that 1 percent of returns fall below this threshold. This is analogous to 99 percent VaR and is consistent with periods of high outflows.

[49] We use five-year CDS spreads from CMA retrieved through Datastream (or Bloomberg).

- Re-order $r_t'$ series in ascending order—lowest to highest; i.e. $\widetilde{r_{t,R}}$.
- Delineate the 1st percentile of $\widetilde{r_{t,R}}$ series. Call this $\gamma$.

6. Compute time series of PoDs.

- Corresponding to each point in time $\widetilde{r_t}$—compute rolling sample mean and standard deviation for six months prior (trailing window).
- Using these sample moments for $\widetilde{r_t}$ and assuming a Normal distribution—at each point in time compute the probability that returns fall below $\gamma$.

Returns can be estimated using mark-to-market asset value data, noting that, depending on how data are presented, the estimation of returns might need to be adjusted by redemptions and subscriptions to ensure that returns reflect adequately the impact of price changes.

In cases when mark-to-market asset value data are not available, it is possible to proxy mark-to-market data by reconstructing funds' asset portfolios and estimate their market value based on individual asset prices. Input series for this procedure are described in Table Appendix Table 1.

**Appendix Table 1. Input Series for Portfolio Reconstruction**

| | |
|---|---|
| **Equity funds** | 75% MSCI US index, 25% MSCI World index. Weights derived from ICI data. |
| Ticker | MSUSAM$ (US), MSWRLD$ (World) |
| Field | MSRI |
| **Bond funds (incl. HY and IG)** | BofA Merrill Lynch US Corporate & Government Index, BofA Merrill Lynch US High Yield Index, and BofA Merrill Lynch US Corporate Index (Investment Grade) |
| Ticker | B0A0, C0A0 (Investment Grade), and H0A0 (High Yield) |
| Field | ML: RIUSD (Price), ML: OAS (Spread) |
| **MMF** | 40% 3M Certificate of Deposits, 20% O/N repo, 20% 3M Commercial Paper, 10% Asset-Backed Commercial Paper, and 10% T-Bills |
| Ticker | FRCDW3M (CDs), USORGCP (O/N repo), FRCPN3M (CP), USCPA3M (ABCP), and FRTBS3M (T-Bills) |
| Field | Price (Yield) |
| **Pension funds** | 50% domestic equities (MSCI US index), 25 % foreign equities (MSCI World index), and 25% bonds (BofA Merrill Lynch US Corporate & Government Index). Weights derived from ICI data [1]. |
| Ticker | MSUSAM$ (US), MSWRLD$ (World), and B0A0 |
| Fields | MSRI, ML: RIUSD (Price), ML: OAS (Spread) |
| **Hedge funds** | HFR index |
| Ticker | HFRXHF$ |
| Field | RI |

**Data on Total Assets per Sector**

We employ bank and insurance sector data from the US Flow of Funds (FoF).
Data by fund type, that is, equity, bond funds, and MMFs, come from the ICI.
The size of each fund is estimated by applying the relative weights derived from ICI to the FoF data.

Data are retrieved using Datastream or Bloomberg at a quarterly frequency. When data are annual, a linear interpolation to obtain the quarterly data is used.

For HF we use Barclayhedge data[50] on global HF and apply a 75 percent weight for the US, where the weight is derived from the 2013 IOSCO survey.[51] Total asset data sources are provided in Appendix Table 2.

**Appendix Table 2. Input Series for Total Asset Data**

| | |
|---|---|
| **Banks** | Private depository institutions (Table L.109) |
| Ticker | US70PDTAA |
| **Insurance** | Life insurance (L.115) + other insurance Corporations (L.114) |
| Ticker | US54XXXAA, US51XXXAA |
| **Equity funds** | ICI—all equity funds |
| Ticker | USFANEQ.A |
| **Bond funds** (Incl. HY and IG) | ICI—All bond and income funds TNA [2]. IG and HY bond funds are a subset of bond funds (that is, three subsectors: Investment Grade, High Yield, and Sovereign). Their relative shares are derived using ICI yearly figures. [3] |
| Ticker | USFANBI.A |
| **MMF** | ICI MMFs TNA |
| Ticker | USFANMM.A |
| **Pension funds** | Private and public pension funds (L.116) |
| Ticker | US59TOFAA |
| **Hedge funds** | AuM of hedge funds—weight 75% |
| Ticker | Barclayhedge website |

Notes:
[1] http://www.ici.org/research/stats/retirement
[2] TNA refers to total net assets.
[3] We used Table 4, available at http://www.icifactbook.org/2013/fb_data.html#section5.

[50] http://www.barclayhedge.com/research/indices/ghs/mum/HF_Money_Under_Management.html
[51] http://www.iosco.org/library/pubdocs/pdf/IOSCOPD427.pdf