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SYSTEMIC FINANCIAL SECTOR AND SOVEREIGN RISKS

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Systemic Financial Sector and Sovereign Risks

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Abstract

This study takes a comprehensive approach to systemic risk stemming from Luxembourg's Other Systemically Important Institutions (OSIIs), from the Global Systemically Important Banks (G-SIBs) to which they belong, from the investment funds sponsored by the OSIIs, from the housing market, from the non-financial corporate sector and from the sovereign. All sectoral balance sheets are integrated and the resulting systemic contingent claims are linked into a stochastic version of the general government balance sheet to gauge their impact on sovereign risk. Explicitly modeling default dependence and capturing the time-varying non-linearities and feedback effects typical of financial markets, the approach evaluates systemic losses and potential public sector costs from contingent liabilities stemming directly or indirectly from the financial sector. Various vulnerability and risk indicators suggest the sovereign is robust to a variety of shocks. The analysis highlights the key role of a sustainable fiscal position for financial stability.

JEL Classification: C1, E5, F3, G1

Keywords: financial stability; sovereign risk; macro-prudential policy; banking sector; investment funds; default probability; non-linearities; generalized dynamic factor model; dynamic copulas.

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Résumé non-technique

La présente étude utilise une approche permettant d'englober le risque systémique émanant des banques et des fonds d'investissement, ainsi que des secteurs des sociétés non financières et des ménages. Se basant sur la condition de parité call-put telle qu'énoncée dans le modèle de risque de crédit structurel de Merton (1974), cette étude intègre les créances éventuelles systémiques qui en résultent dans une version stochastique du bilan de l'Etat afin d'en évaluer l'impact sur le risque souverain. De surcroît, il y a lieu de noter que le risque systémique peut également provenir du secteur public. Par conséquent, des pertes systémiques peuvent résulter d'un risque systémique qui est commun à l'ensemble du secteur financier ; d'un effet de contagion au sein du secteur financier ; de l'accumulation de vulnérabilités du secteur financier au cours du temps ; du marché immobilier ; du secteur des sociétés non financières ou du secteur souverain.

Plus précisément, dans cette étude, le risque systémique ainsi que les passifs éventuels qui en découlent, pourraient provenir des 6 Autres Etablissements d'importance systémique luxembourgeois (Other Systemically Important Institutions (OSIIs)), des 4 Banques d'importance systémique mondiales (Global Systemically Important Banks (G-SIBs)) auxquelles ils appartiennent, des 17 fonds d'investissement parrainés par ces OSIIs, du marché immobilier, du secteur des sociétés non financières ainsi que du secteur souverain.

Le cadre conceptuel de cette étude est le même que celui proposé par Jin et Nadal De Simone (2014, 2015, et 2016). Premièrement, les probabilités de défaut (PD) sont estimées à partir du modèle de risque de crédit structurel de Merton. Deuxièmement, l'approche de Segoviano (2006) est utilisée afin de modéliser l'interdépendance linéaire et non-linéaire entre les banques, les OPC, les sociétés non financières, entre les ménages ainsi qu'entre ses secteurs et le souverain, ainsi que les effets de retour (feedback effects). Cette étude est, au meilleur de la connaissance des auteurs, la première application complète de l'analyse des créances éventuelles (à la Gray et Malone, 2008, et Gray et Jobst, 2011) à un pays entier.

Tous les bilans sectoriels stochastiques contiennent à la fois des éléments observés et non observés. L'élaboration des bilans des ménages et des sociétés non financières est basée sur les statistiques de flux de fonds telles que publiées par le STATEC (Institut national de la statistique et des études économiques). Les éléments non observés du secteur souverain, tels que les passifs éventuels, doivent être estimés. Afin de préserver la cohérence interne du présent cadre intégré, cette étude suit Gray and Malone (2008) et utilise la fonction de production agrégée de l'économie luxembourgeoise afin d'établir le lien avec les ménages et les sociétés non financières. En particulier, la valeur actuelle après impôts du revenu du travail est calibrée selon les projections de la Banque centrale du Luxembourg et la valeur du stock immobilier résidentiel des ménages provient des comptes nationaux. La fonction de production agrégée est aussi

utilisée pour calibrer la valeur actuelle après impôts des revenus de capitaux dans le secteur des sociétés non financières.

Un résultat général significatif de cette étude est que les différents indicateurs de vulnérabilité et de risque suggèrent que le secteur souverain est robuste par rapport à un éventail de chocs générant des passifs éventuels provenant directement ou indirectement du secteur financier. L'analyse souligne le rôle clé d'une situation budgétaire saine pour la stabilité financière.

D'autres résultats plus spécifiques peuvent être mentionnés. Premièrement, en ligne avec Jin and Nadal De Simone (2014a and 2014b), la baisse des taux d'intérêt mise en place afin de contrer les effets négatifs de la crise financière de 2008 sur l'économie réelle a contribué à réduire le niveau de fragilité des banques et des fonds d'investissement, bien qu'elle ait également augmenté l'interdépendance en matière de risque entre les établissements financiers.

Deuxièmement, les garanties implicites du gouvernement (c'est-à-dire les pertes éventuelles auxquelles le gouvernement pourrait devoir faire face) envers des Autres Etablissements d'importance systémique luxembourgeois ont connu une baisse en valeur durant la période suivant la crise financière, mais ont été très peu affectées par la crise des souverains.[1] Troisièmement, l'hétérogénéité des garanties conditionnelles implicites du gouvernement est moindre au sein des groupes bancaires européens que parmi les Autres Etablissements d'importance systémique luxembourgeois durant la période retenue, excepté lors de la crise de la dette souveraine. Quatrièmement, le risque systémique provenant des ménages et des sociétés non financières ne semble pas être particulièrement élevé.

Cinquièmement, en ce qui concerne le secteur souverain luxembourgeois, la distance par rapport à la défaillance (distance to distress) s'est améliorée de façon significative entre 2014 et la fin de cette étude, juin 2015, reflétant l'amélioration de l'excédent primaire des administrations publiques, la stabilisation de la dette publique et d'autres facteurs.

Sixièmement, la solidité du secteur souverain n'est pas considérablement affectée par le risque systémique provenant de chacune des sources considérées dans cette étude. Les garanties conditionnelles implicites du gouvernement ne s'écartent pas de façon significative du point de référence (« the no-shock benchmark») suite à une défaillance dans le secteur financier ou à des chocs, de grande ampleur mais plausibles, touchant les prêts hypothécaires des ménages ou les prêts des sociétés non financières. A l'inverse, le risque souverain serait significativement affecté par une augmentation

[1] Les garanties implicites du gouvernement sont calculées comme suit: la perte par défaut de l'OSII supposée en défaut est ajoutée aux pertes attendues conditionnelles d'au moins un autre OSII, pondéré soit par la part du gouvernement luxembourgeois dans les capitaux propres de l'OSII, soit par la part des actifs de l'OSII dans le total des actifs du groupe bancaire auquel il appartient.

présumée (exogène) de 40% de la volatilité de la valeur des actifs souverains associée à des chocs sur les Autres Etablissements d'importance systémique luxembourgeois, les groupes bancaires, les fonds d'investissement ou le secteur privé non financier. Bien que la solvabilité du secteur souverain luxembourgeois ne soit pas mise en danger, ce scénario illustre l'importance de la soutenabilité des finances publiques pour la stabilité financière.

Plusieurs enseignements pour la formulation de la politique macro-prudentielle peuvent être tirés de cette étude. Etant donné que le cadre conceptuel peut mesurer l'exposition des banques via leur soutien financier implicite aux fonds d'investissement qu'elles parrainent, ce cadre peut aider à calibrer la capacité d'absorption de pertes additionnelles requise par les banques afin de couvrir leur contribution directe et indirecte au risque systémique. L'étude contribue aussi à une mesure plus robuste du risque systémique, en permettant d'évaluer les passifs éventuels du souverain émanant du système financier et de déterminer ainsi les pertes éventuelles qui résulteraient dans l'hypothèse d'un cadre de politique économique inchangé. En outre, même si ceci n'est pas entrepris dans cette étude, l'approche contribue à l'élaboration de la politique macro-prudentielle, car elle offre un cadre pour la prévision des changements des risques systémiques financiers, permettant ainsi d'apporter une solution à la problématique selon laquelle la simple agrégation des PD marginales et leur projection dans le futur produit une mesure du risque systémique biaisée vers le bas (e.g., Jin et Nadal De Simone, 2012). Ainsi, ce cadre pourra être utile dans les tests d'endurance du système financier.

1. Introduction

In 2010, the sovereign debt crisis that erupted in Greece, Portugal, and Ireland spread as markets questioned debt sustainability. In April 2010, when some euro area countries were downgraded, markets pushed up Credit Default Swap (CDS) premia in most advanced countries, including the US and the UK (CGFS, 2011). In turn, higher sovereign risk pushed up banks' cost of funding and changed its composition. Also, banking sector systemic risk and "too-big-to-fail" global systemic institutions amplified the sovereign risk via large implicit contingent liabilities, as in Ireland. In addition, concerns arose about sovereign risk in Italy, Spain and even France with negative repercussions on market perceptions about the viability of the euro area.

Sovereign risk and systemic financial sector risk are clearly intertwined. The links are multiple and run in both directions. First, losses on banks' holdings of government debt weaken their balance sheets, increasing their riskiness and making bank funding more costly and difficult to obtain. Second, higher sovereign risk reduces the value of the collateral banks can use to raise wholesale funding and central bank liquidity. Third, sovereign downgrades generally flow through to domestic banks with lower ratings, increasing their wholesale funding costs and potentially impairing their market access. Fourth, a weakening of the sovereign reduces the funding benefits that banks derive from implicit and explicit government guarantees. Other risk transmission channels include international spillovers resulting from bank holdings of foreign sovereign debt or simply contagion; changes in risk aversion as a result of sovereign tensions and crowding out effects that raise the cost of funding for banks issuing securities. Financial sector reforms undertaken since 2008 have sought to reduce the links between the sovereign and the financial sector. However, some will remain such as those that stem from the impact of sovereign ratings on the value of banks' holdings of sovereign paper.

Standard economic analysis does not properly account for systemic risk interactions between the financial sector and the sovereign, limiting our understanding of the transmission and amplification of risk across different sectors of the economy or national borders. The Macro-prudential Research Network (MaRs) established in 2010 by the General Council of the European Central Bank aimed to develop core conceptual frameworks, models and/or tools that would provide research support to improve macro-prudential supervision in the European Union. MaRs undertook theoretical and empirical work in three areas: macro-financial models linking financial stability and the performance of the economy; early warning systems and systemic risk indicators; and originally, interbank contagion risks. However, the increase in sovereign bond spreads prompted MaRs to extend the latter area to include sovereign contagion. Different methodological approaches applied in several MaRs papers found that European sovereign credit spreads were highly correlated (e.g., Barbosa and Costa 2010, Broto and Perez-Quiros 2011, Lucas, Schwaab, and Zhang 2014). Before the onset of the sovereign crisis, much of the behavior of sovereign bond yields could be explained by measures of global risk aversion, but these global factors appear to have given way to more idiosyncratic developments. The study of the links between banks and the sovereign has since become one of the most rapidly growing areas of research in financial stability.

To the best of our knowledge, this is the first study to use a comprehensive approach that measures systemic risk in the banking and investment fund industries, the household and non-financial corporate sectors, and then integrates the resulting systemic contingent claims into a stochastic version of the general government balance sheet. In this integrated framework, systemic risk can originate in both the private and the public sector. Systemic losses can result from systemic risk that is common across the financial sector; from contagion within the financial sector; from a build-up of financial sector vulnerabilities over time; from the housing market or from the non-financial corporate sector and from the sovereign. The proposed approach evaluates systemic losses and potential public sector costs from contingent liabilities stemming from the financial sector by explicitly modeling default dependence within the financial sector and capturing the time-varying non-linearities and feedback effects typical of financial markets. In contrast to static or accounting-driven models, the approach captures potential losses via “price-mediated” contagion (Cont and Schaanning, 2015) which can expose a financial institution to asset classes that regulation prevents it from holding them. This can amplify the institution’s exposure to a given risk factor relative to what is apparent from its balance sheet. The approach can also measure bank exposure through implicit financial support for the investment funds they sponsor. Therefore, the framework can also help to calibrate the additional loss absorbing capacity required for banks to cover their direct and indirect contribution to systemic risk. Finally, it can also adjust measures of sovereign risk and vulnerability to account for all the above sources of systemic risk.

The main results follow:

First, indicators of systemic risk in each of the sectors correlate well with major macro-financial developments in Luxembourg and in the euro area. In particular, the decline in interest rates helped to reduce the fragility of banks and investment funds, although it also increased interdependence across financial institutions. These findings are consistent with results in Jin and Nadal De Simone (2014a and 2014b).

Second, the implicit government guarantees stemming from Luxembourg's Other Systemically Important Institutions (OSIIs) all fell in value during the financial crisis and were hardly affected by the sovereign crisis. The volatility of these guarantees was largely driven by changes in correlation rather than by changes in probabilities of distress. The conditional implicit government guarantees attached to investment funds and European banking groups tend to be between 1/2 to 1/3 of those attached to OSIIs. It should be noted that the investment funds sponsored by OSIIs represent less than 1% of total assets in Luxembourg investment funds.

Third, there has been less heterogeneity among European banking groups than among OSIIs over the sample period, except during the sovereign crisis. Following Lehmann's collapse, the highest conditional implicit government guarantee may have reached about 0.8bn euro. During the sovereign crisis, this number fell to between 0.4bn and 0.1bn euro. In the period of uncertainty preceding the Asset Quality Review and the start of the Single Supervisory Mechanism, the guarantee rose again to a maximum over 0.6bn euro.

Fourth, expected loss profiles among investment funds are broadly similar to those of OSIIs and banking groups. However, systemic risk stemming from distress among investment funds and banking groups is more concentrated than systemic risk stemming directly from distress among OSIIs.

Fifth, systemic risk emanating from households and non-financial corporations does not seem to be of immediate concern. The non-financial corporate sector is characterized by a volatile distance to distress due to large holding companies which finance their world operations in Luxembourg. Risk from the household sector, in contrast, has been quite stable over the sample period.

Sixth, for the Luxembourg sovereign, distance to distress improved significantly after 2013, reflecting notably the improved primary surplus of the general government and the stabilization of general government debt.

Seventh, the robustness of the sovereign is not drastically affected by systemic risk stemming from any of the sources considered. Implicit conditional government guarantees do not deviate significantly from the benchmark following distress in the financial sector or large and plausible shocks to household mortgages or non-financial corporate loans.

Finally, sovereign risk would be significantly affected by a 40% increase in the volatility of sovereign asset values combined with shocks to the OSIIs, banking groups, investment funds or the non-financial private sector, but the integrity of the Luxembourg sovereign would not be compromised. Nevertheless, this adverse scenario illustrates the need for a robust fiscal position over the cycle as it triggers wide deviations of sovereign risk from its benchmark.

The next section provides a selective review of the various strands of literature linked to this study. Section III presents the modeling framework and Section IV discusses the data. Section V presents the results on systemic risk and vulnerability measures. Section VI concludes.

2. Selective Literature Review

The literature linking sovereign and systemic risk in the financial sector can be said to be broadly concerned with two questions: first, how much financial sector systemic risk can a sovereign tolerate (can banks become “too-big-to-save”?) and second, how much of banks’ systemic risk is in fact sovereign risk? There are three approaches to these questions in the literature.

The first approach views systemic risk as running primarily from the sovereign to banks. Li and Zinna (2014) estimate that on average 45% of French and Spanish bank credit risk is actually sovereign risk, but the figure is only 30% in Italy and 23% in Germany. Banks’ exposure to “systemic risk”, understood as the joint default of systemically important European sovereigns, varies positively with their size, with sovereign debt holdings, and with expected government support. However, Li and Zinna assume that independent Brownian motion processes drive systemic intensity, country intensity and bank intensity, which unfortunately rules out the transmission of shocks between “systemic risk” and bank risk. To model contagion, Korte and Steffen (2014) suggest that the zero risk weight of government bond holdings increases the correlation between domestic sovereigns and the European sovereign CDS market index. They conclude that the subsidy provided by zero risk weights drives national debt above its optimal level. Gennaioli et al (2014) suggest that government default is costly because it destroys the balance sheet of domestic banks, as in Greece. Their model complements the Acharya et al (2012) model of the Irish crisis, where implicit guarantees to banks forced the government to tap funding markets in the short run. However, this analysis raises the question why governments repay their debts in the first place. Their model predicts that while public default raises available domestic resources, it reduces the liquidity of banks that hold domestic government bonds, cutting domestic credit, investment and output.

The second approach views systemic risk as running from banks to the sovereign. Ang and Longstaff (2013) study systemic sovereign credit risk using CDS spreads for the US Treasury, individual US states, and major euro area countries. Using a multifactor affine framework, they find that there is much less systemic risk among US states than among euro area sovereigns. They conclude that tighter macroeconomic links in the US do not lead to higher systemic risk than in Europe. Instead, they find that US and euro area systemic sovereign risk is strongly related to financial market returns. This is the first paper to estimate the systemic component of sovereign credit spreads from the cross section of CDS term structures. However, the links between the sovereign and the financial sector are not modeled, so contagion is not considered. In addition, the paper only takes into account common shocks as sources of systemic risk. Acharya and Steffen (2013) argue that the European banking crisis can in part be explained by the "carry trade" among banks. They use multifactor models to relate equity returns for Greece, Ireland, Portugal, Spain and Italy to German government bond returns. The results suggest that banks raised finance in short-term wholesale markets to invest in peripheral sovereign bonds. Marques et al (2013) provide international econometric evidence that government guarantees are positively related to risk-taking behavior by banks, and that market discipline declines after controlling for indicators of banks' systemic importance (size, leverage, and asset risk, but not necessarily interconnectedness).

Instead, the current study views the two previous approaches as complementary rather than mutually exclusive. An early paper in this vein is Acharya et al (2014) who argue that bank bailouts ignited the rise of sovereign credit risk in advanced economies. While a bailout alleviates a distortion in the provision of financial services, increased taxation to finance the bailout reduces gross fixed capital formation, impairing the sovereign's creditworthiness. However, the authors warn that higher sovereign credit risk also feeds back on to the financial sector through implicit and explicit government guarantees and through bank holdings of sovereign bonds. Acharya et al provide empirical evidence for the two-way feedback between financial and sovereign credit risk using euro area CDS data. While not explicitly addressing systemic risk, their paper addresses two of its basic elements: feedback effects and non-linearities.

Another paper in this tradition is Bolton and Jeanne (2011) who develop a theoretical open economy model in which financial markets interact with the sovereign, allowing for cross-country contagion. The ex ante benefits of risk diversification contrast with the ex post costs of contagion. Financial integration without fiscal integration results in an inefficient equilibrium supply of government debt, with safer governments inefficiently restricting the amount of high quality debt that could be used as collateral, and riskier governments issuing too much debt as they ignore contagion costs.

Correa et al (2014) explore how government support and changes in sovereign credit ratings affect bank stock returns. Using data for banks in 37 countries between 1995 and 2011, they find that downgrades of sovereign credit ratings have a large negative effect on stock returns for banks that are expected to receive stronger government support. This result is stronger for banks in advanced economies where governments are better positioned to provide support.

Black et al (2016) measure systemic risk as a hypothetical insurance premium to cover distressed losses in the European banking system using CDS spreads, equity return correlations, and total liabilities of individual banks. They convincingly argue that bank CDS contain not only banks' systemic risk, but also sovereign risk and liquidity risk.

Van der Kwaak and van Wijnbergen (2013) analyze the interaction between bank rescues, financial fragility and sovereign debt discounts. Interestingly, the possibility of default does not affect the equilibrium outcome under the assumption of short-term debt finance since interest rates on debt reflect higher default probabilities. When long-term government debt is introduced, the equilibrium outcome significantly deteriorates, with credit tightening increasing the output losses, recession duration and the fall in investment after a financial crisis. The maturity structure of government debt is a crucial element in the amplification process.

Giglio et al (2016) construct several systemic risk measures for the US and Europe. However, correlations among different measures are quite low, suggesting that they capture different aspects of the state of the financial system. While CoVaR may capture feedback and non-linearities typical of systemic risk, other measures do not. This may explain why many individual measures lack a robust statistical association with macroeconomic downside risk and may therefore fail to provide useful input in formulating macro-prudential policy. However, collectively the measures do a good job in predicting downturns, suggesting the information they contain needs to be aggregated.

Contagion between the sovereign and the financial sector can run in both directions, so measures of systemic risk must consider different possible channels of interaction. Jin and Nadal De Simone (2014a, 2014b) estimate systemic risk simultaneously in banks and investment funds. Their framework applies the Merton (1974) structural credit risk model based on contingent claims analysis (CCA) to estimate probabilities of distress. It then quantifies distress dependence among financial institutions to capture interconnectedness and contagion, non-linearities and feedback effects. Their measures of systemic risk combine the marginal probabilities of distress from Merton's model with the consistent information multivariate density optimization (CIMDO) methodology of Segoviano (2006). Jin and Nadal de Simone (2014a) extend this framework to generate out-of-sample projections of systemic risk.

Several authors use CCA to measure corporate default risk and public sector contingent liabilities. Gapen et al. (2004) apply the CCA approach to identify corporate sector and economy-wide vulnerabilities. Gapen et al. (2005) and Gray and Malone (2008) extend the CCA to estimate sovereign risk. Fisher and Gray (2006) use it to measure sovereign and banking sector risk in Indonesia and Keller, Kunzel, and Souto (2007) to track sovereign risk in Turkey. Gray and Walsh (2008) apply CCA to derive risk indicators for the Chilean banking system. Gray et al. (2008) use CCA to study public sector debt sustainability. Gapen (2009) applies CCA to evaluate the implicit guarantee to Fannie Mae and Freddie Mac during the global financial crisis. In addition, the IMF integrated CCA in the Stress Testing module of its Financial Sector Assessment Program for the United States (2010), Germany (2010) and the United Kingdom (2011).

Finally, Gray and Jobst (2011) developed the Systemic CCA framework to measure systemic risk in the financial sector. This approach applies CCA to individual financial institutions and then estimates a multivariate generalized extreme value distribution with a time-varying and non-linear dependence structure. Market information on equity and CDS is used to calculate individual contingent liabilities and provide a conditional and non-linear measure of systemic contingent liabilities. This approach was also used in the IMF stress testing exercise for the US mentioned above.

This paper's methodology is closely linked to the Systemic CCA in Gray and Jobst (2011). In contrast to the CoVaR of Adrian and Brunnermeier (2008), the Systemic Expected Shortfall (SES) of Acharya et al (2009), and the Distress Insurance Premium (DIP) of Huang et al (2010), the approach in this paper is based on a multivariate copula, allowing for the non-parametric estimation of both individual and joint default risk, and it captures the non-linearities and feedback effects typical of financial markets. The copula approach and quantile regressions have been extended to a dynamic environment (e.g., Patton, 2006a, Engle and Manganelli, 2004), and can both provide information about the degree and structure of dependence. However, quantile regressions (as in CoVar, SES and DIP) cannot model the joint or multivariate distribution (Baur, 2013). As a result, quantile estimation and prediction must rely heavily on unrealistic global distributional assumptions.

3. The Integrated Modeling Framework

This study uses the integrated modeling framework developed by Jin and Nadal De Simone (2014a) to measure systemic credit risk emanating from banks and investment funds. While the core methodology is the same, the sources of systemic risk are extended to cover the remaining sectors of the Luxembourg economy: households, the non-financial corporate sector and the sovereign. To the best of our knowledge, this is the first extension of the framework to build interlinked stochastic balance sheets of all the sectors of an economy. The Generalized Dynamic Factor Model (GDFM) module is not implemented in order to conserve space and to reduce complexity.

Only the main features of the framework are discussed below. The output part of the integrated framework, the CIMDO model, incorporates the prior dependence structure which is separately estimated using a rolling window on asset returns adjusted with Qi and Sun's (2006) nearest correlation matrix. The output is a set of systemic credit risk measures originally proposed for banks by Segoviano and Goodhart (2009) and by Radev (2012). These are applied here to both banks and investment funds.

The ECB (2009) Financial Stability Review distinguishes three forms of systemic risk: the first one arises from common distress in the financial sector, the second one arises from contagion and the last one is the result of the growth of vulnerabilities over time that unravel in a disorderly manner. The first form of systemic risk is measured below by the Financial System Fragility (FSF) indicator and the Financial System Index (FSI). The FSF measures the probability that at least two financial institutions get distressed and the FSI measures the *expected number* of financial institutions that will become distressed conditional on any one financial institution having become distressed as a result of a common shock. The second form of systemic risk, contagion, is measured by the Distress Dependence Matrix (DDM) measure, which displays pair-wise probabilities of distress of financial institutions, and the PAO measure, which captures the probability that at least one more financial institution will default given that one institution has already defaulted. The third one is not measured in this study.

The CIMDO approach has several important advantages. It can recover multivariate distributions from limited information (e.g., the marginal probabilities of default) in a relatively efficient manner. It does not need to explicitly choose and calibrate parametric density functions. It describes linear or non-linear dependencies among variables which are invariant under increasing and continuous transformations of the marginal distributions. The dependence structure is characterized over the entire domain of the multivariate density, but the CIMDO approach appears to be especially robust in the tail of the density, which is the relevant part for any operationally useful discussion of systemic risk.

3.1 Merton Credit Risk based on Book Value

Since only balance sheet data is available for banks and investment funds, the Merton model cannot be applied directly. Instead, probabilities of default (PDs) were calculated using an alternative approach. Souto *et al.* (2009) and Blavy and Souto (2009) find that book-based and market-based Merton credit risk measures are highly correlated.[2] In addition, Adrian *et al* (2013) forcefully argue that the ratio of total assets to book equity is a key measure of leverage in asset price modeling. Danielsson *et al* (2012) also argue that "… book equity is the appropriate notion when measuring leverage embedded in portfolio choice, and not market capitalization". This approach is followed here.

Adrian *et al* (2013) show that leverage in US investment banks fluctuates over the cycle, with balance sheets shifting with total debt, while equity remains constant. This also appears to be the case for Luxembourg banks. However, in the investment fund industry annual changes in assets and annual changes in equity move in tandem while debt changes are relatively small.[3]

Asset volatility based on book value is calculated by a rolling window as follows:[4]

$$\sigma_B = \sqrt{\sum_{t=1}^{N} (\ln(V_t^B / V_{t-1}^B))^2}$$

where V_t^B denotes the book value of total assets in quarter *t* and *N* is the width of a rolling window set at four consecutive quarters.[5] The book-value risk neutral PD[6] of the Merton model can be directly estimated by:

$$\pi_B = \Phi(-\frac{\ln(V^B / X) + (r - \frac{1}{2}\sigma_B^2)(T-t)}{\sigma_B \sqrt{T-t}}),$$

[2] See also Gray and Jones (2006) for an early application of this idea.
[3] Adrian et al (2013) note that in Merton's model leverage fluctuates with the value of assets and notional debt is fixed.
[4] Following usual practice, quarterly volatility is annualized.
[5] For tractability purposes, we assume that book-value assets follow a geometric Brownian motion. The mean of quarterly asset returns in a large sample is assumed to be zero to avoid the noise brought by the sample means to the volatility process (See Jin and Nadal De Simone, 2011). As empirically shown by Blavy and Souto (2009) and Souto et al (2009), book-based Merton's credit risk measures are highly correlated with market-based Merton's credit risk measures. This approach produces book-based asset volatility results that track events well and have been shown to produce PDs that also track CDS prices well.
[6] See Jin and Nadal De Simone (2011) for a detailed discussion of the difference between "actual" PDs and risk-neutral PDs and a discussion of the difference between levels and changes of the PDs.

where the implied book-value risk neutral distance-to-default (DD) is simply the number of standard deviations that the firm is away from default:

$$DD_B = \frac{\ln(V^B / X) + (r - \frac{1}{2}\sigma_B^2)(T-t)}{\sigma_B \sqrt{T-t}}.$$

In contrast to banks, assets on the sovereign balance sheet are measured less precisely.[7] However, total sovereign assets can be estimated using book values by simultaneously solving the optimal hedge equation and the call option equation:

$$\sigma_E = (\frac{V^B}{V^E}) \frac{\partial V^E}{\partial V^B} \sigma_B,$$

$$V^E = V^B N(d_1) - Xe^{-r(T-t)}\Phi(d_2).$$

where: $d_1 = \frac{\ln(\frac{V^B}{X}) + (r + \frac{1}{2}\sigma_B^2)(T-t)}{\sigma_B \sqrt{T-t}}$, $d_2 = d_1 - \sigma_B \sqrt{T-t}$, r is the risk-free interest rate, and $\Phi()$ is the cumulative density function of the standard normal distribution. Sovereign equity volatility is calculated using a rolling window as before: $\sigma_E = \sqrt{\sum_{t=1}^{N} (\ln(V_t^E / V_{t-1}^E))^2}$ where V_t^E denotes the book value of sovereign equity[8] at time *t*, N determines the width of the rolling window (four consecutive quarters). In this paper, the implied book-value risk neutral sovereign DD is used to track the full profile of sovereign systemic risk instead of the risk-neutral sovereign PDs, which are usually close to zero.

3.2 The CIMDO Approach

The CIMDO-approach developed by Segoviano (2006) is based on the cross-entropy concept introduced by Kullback (1959). This implies minimizing the cross-entropy objective function that links the prior and posterior distributions under a set of constraints on the posterior. For example, for two financial institutions X and Y, with logarithmic

[7] For example, foreign reserves, financial assets and the net present value of the general government primary surplus are either observable or can be approximated with relative ease. The value of government buildings, land and other sovereign assets can be difficult to estimate.
[8] See Section 3.3 for an explanation of the stochastic sovereign balance sheet and the meaning of "sovereign equity".

returns represented by random variables x and y , the following function can be minimized:

$$
\begin{aligned}
L(p,q) = & \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} p(x,y)\ln[\frac{p(x,y)}{q(x,y)}]dxdy \\
& + \lambda_1[\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} p(x,y)dxdy - 1] \\
& + \lambda_2[\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} p(x,y)I_{[x_d^x,\infty)}dxdy - PD_t^x] \\
& + \lambda_3[\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} p(x,y)I_{[x_d^y,\infty)}dxdy - PD_t^y],
\end{aligned}
$$

where PD_t^x and PD_t^y are empirically observed probabilities of distress for these two financial entities, and $p(x;y)$, $q(x;y) \in \Re^2$ are the posterior and the prior distributions, with λ_1 , λ_2 , and λ_3 being the Lagrange multipliers of the additivity constraint and the two consistency constraints (probabilities are non-negative). For each obligor, the region of distress PD_t is described by the part of the distribution over its distress threshold x_d^x or x_d^y . The optimal solution for the posterior density is of the form:

$$
p^*(p,q) = q(x,y)\exp\{-[1+\lambda_1 + (\lambda_2 I_{[x_d^x,\infty)}) + (\lambda_3 I_{[x_d^y,\infty)})]\} .
$$

This solution highlights the importance of distress thresholds and PDs in systemic risk analysis. The posterior joint density will diverge from its prior whenever one or both random variables take values above the specified cutoff values, e.g., in times of distress when more mass shifts toward the tails of the distribution. As proved by Segoviano (2006), the CIMDO-recovered distribution outperforms commonly used parametric multivariate densities under the Probability Integral Transformation Criterion. In this paper, the prior distribution is assumed to be a multivariate Normal distribution reflecting the parametric assumption behind the basic version of the structural approach (Merton, 1974). Importantly, the distress threshold is one of the central parameters of the CIMDO methodology. Following the intuition of Goodhart and Segoviano (2009), an average distress threshold is assumed for each financial institution, using the inverse standard Normal distribution of its average PDs.

Note that the CIMDO methodology is the "inverse" of the standard copula approach. The CIMDO density captures the dependence structure among the PDs. From the CIMDO density it is possible to extract the copula function that describes the dependence structure.[9] By construction, the CIMDO copula puts a greater emphasis on the distress region of the joint distribution. Therefore, this approach provides a robust and consistent method to estimate distress dependence in financial institutions.

As stated above, the general dependence measures calculated via the CIMDO approach are tightly related to the prior distribution for the correlation structure (Gorea and Radev, 2014). Assuming a joint Normal density function with zero correlation as prior could significantly understate PD dependence. This becomes particularly important in distress periods when cross-correlation values rise toward one. Therefore, this paper uses a simple rolling window approach for estimating the prior correlation input to the CIMDO, which is also consistent with the rolling window estimation of Merton's model. A Newton-type method is used to guarantee that the estimated correlation matrix of asset returns is symmetric and positive semi-definite (Qi and Sun, 2006).

3.3 Stochastic Balance Sheets of the Non-financial Private Sector and the Sovereign

The CCA balance sheets for households, non-financial corporations and the sovereign are constructed following Gray and Malone (2008) and Gray and Jobst (2011). Therefore, in line with the literature in this field, the sovereign comprises the general government and the monetary authority. The three sectoral stochastic balance sheets contain both observed and unobserved items.

The sovereign balance sheet raises several conceptual issues. The first regards the liability side of the monetary authority. Given that Luxembourg belongs to the euro area, the currency-in-circulation component of the monetary base has to be calibrated. This study uses Luxembourg's "capital allocation key" (as adjusted through time), which is public information available from the central bank balance sheet.

A second issue regards "other public assets" on the sovereign balance sheet. Sovereign assets can be broken down into three key components: reserves, "net fiscal assets" and "other public assets" from which implicit and explicit contingent liabilities from the financial sector are subtracted. The value of reserves can be observed and contingent

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[9] The converse of Sklar's theorem implies that it is possible to couple together any marginal distribution, of any family, with any copula function, and a valid joint density will be defined. The corollary of Sklar's theorem is that it is possible to extract the implied copula and marginal distributions from any joint distribution (Nelsen, 1999). This alleviates the bias associated with the unavoidable fact that PDs are generated regressors.

liabilities are estimated from the financial sector. “Net fiscal assets” are proxied by a five-year moving average of the present value of the general government primary fiscal surplus, where the projected primary surplus is taken from the Luxembourg Stability Program submitted to the European Commission and the discount rate is set at the average rate on general government debt. “Other public assets” are obtained by subtracting the above items from the implied total sovereign assets. Implied total sovereign assets are obtained by applying the book-value Merton model to sovereign equity and using short-term debt plus 50% of long term debt as threshold.[10]

Finally, the balance sheets of households and non-financial corporations are built using the flow-of-funds statistics published by the National Statistical Institute. However, as for the sovereign sector, there are some unobserved items that must be estimated. To preserve the internal coherence of the integrated framework proposed in Section III, this study follows Gray and Malone (2008) and uses the aggregate production function of the Luxembourg economy to link household and corporate assets (see Appendix I). The after-tax present value of labor income is calibrated using the central bank output projections and the value of households’ stock of residential property is taken from national accounts. The aggregate production function is also used to calibrate the present value of after-tax capital income in the non-financial corporate sector.

4. Data

This study considers the six Other Systemic Financial Institutions (OSIIs) in Luxembourg and the 17 investment funds sponsored by the OSIIs for which data is available over the sample period 2008Q4-2015Q2.

All the Luxembourg OSIIs are unlisted, so quarterly book value data is drawn from reporting data provided to the authorities.[11] For banks and investment funds, short-term debt includes deposits up to one-year maturity, short term funding, and repos, while long-term debt includes time deposits over one-year maturity and other long-term funding. For European banking groups, Bloomberg provides data on short-term borrowing (BS047) and long-term debt (BS051) at annual, semi-annual, and quarterly frequencies. To make the data consistent, four filtering rules are used (Appendix II). Market data for the major European banking groups include government bond yields and the number of outstanding shares, and book value data from Bloomberg.

[10] See Gray and Jobst (2011) application of the approach followed in this paper to Sweden. Like Luxembourg, Sweden only issues domestic-currency denominated debt.
[11] See Jin and Nadal De Simone, 2011a, for a detailed discussion of the estimation of credit risk models using balance sheet data when banks are not publicly listed.

The Basel Committee on Banking Supervision (BCBS) recently considered the "step-in" risk that a bank may provide financial support to an entity beyond or in absence of any contractual obligations (BCBS, 2015). As a primary indicator of step-in risk, the BCBS proposes the sponsorship concept.[12][13] Investment funds selected in this study are based on their sponsorship by the OSIIs.

For households, non-financial corporations and the sovereign sector, the financial part of the sectoral balance sheets is constructed using flow of funds data published by STATEC, the National Statistical Institute. The non-financial part is constructed calibrating the present value of after-tax salary income for households and the present value of after-tax profits for non-financial corporations as explained above. The balance sheet of the monetary authority and the general government budget are used for the sovereign balance sheet.

5. Vulnerability and Systemic Risk Exposures

This section uses PD to refer to both the probability of default and the probability of distress, since book value data are used for OSIIs and for investment funds but market data are used for banking groups. For the sovereign, both market data and the sovereign balance sheet are used. PDs and DDs reported below are always risk-neutral so the two concepts are interchangeable.

This first subsection below presents a set of vulnerability indicators for the six OSIIs in Luxembourg, the four Global Systemically Important Banks (G-SIBs) to which the OSIIs belong, and the largest investment funds sponsored by the six Luxembourg OSIIs. Systemic risk measures are also presented for the OSIIs, along with the probability of distress and the associated expected loss of an unconditional distress scenario. Subsection 2 discusses the conditional expected loss and the conditional implicit government guarantee stemming directly from distress of the OSIIs. Subsection 3 focuses on distress transmitted from the G-SIBs to their affiliated OSIIs in Luxembourg. Subsection 4 turns to distress among investment funds transmitted to their sponsor OSIIs. Subsection 5 considers distress in the household sector and the non-financial corporate sector transmitted to their creditor OSIIs. Finally, subsection 6 discusses the impact of implicit guarantees on standard measures of sovereign risk.

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[12] The definition of sponsor includes not only more or less explicit financial support, but also decision making and operations. The BCBS proposes these three elements as part of the list of indicators that banks will have to consider in assessing step-in risk.

[13] The starting period of Figure 1c is 2009 because the available database for investment funds starts in 2008Q4.

5.1 Vulnerability Indicators for Luxembourg's Financial Sector

This section provides vulnerability indicators for Luxembourg OSIIs, the G-SIBS to which they belong and the largest investment funds the OSIIs sponsor.

Figure 1a presents the simple mean, the 20th, the 50th and the 80th percentiles of the PD and the DD of the six OSIIs and the corresponding expected losses (EL). Together, the OSIIs represented about one third of total assets in the banking sector as of June 2015. The charts suggest a great deal of heterogeneity across OSIIs. The first observation is that the median Expected Loss, which peaked below 500 million euro after Lehman's collapse was less affected during the sovereign crisis and fell to very low values at the end of this study's sample period. In contrast, the 80th percentile of Expected Loss reached nearly 4bn euro in 2009. After declining, it rose again during the sovereign crisis to reach 1.5bn euro. The disparity between the mean and the median indicates an asymmetric distribution.

Figure 1b presents the PD and the DD of the four European banking groups to which the six OSIIs belong, and the corresponding Expected Loss. As in Figure 1a, the median Expected Loss was larger after Lehman's collapse than during the sovereign crisis, although it declined more rapidly than for Luxembourg's OSIIs. Similarly, the 80th percentile of EL was relatively limited after the sovereign crisis, compared to about 9.5bn at the height of the financial crisis. In contrast to their Luxembourg affiliates, the distribution of Expected Loss across international banking groups is more homogeneous as median and mean are much closer.

The book-value risk-neutral PD can be close to zero, so "synthetic" PDs are estimated by rescaling Merton's DD so that the lowest possible level of π_B is 1^{e-8}. Figure 1c focuses on the investment funds sponsored by the six Luxembourg OSIIs and reports synthetic PD, DD and synthetic Expected Loss. The median and mean of the synthetic PD correlate well with the PD of their sponsoring OSIIs, but for some investment funds the correlation was higher during the sovereign crisis. This suggests that step-in risk materialized in the sample, at least for some investment funds and their bank sponsors. More analysis is clearly needed on this matter. The median Expected Loss was negligible in economic terms.

Figure 2 reports 4-quarter rolling correlation of the log of asset returns among Luxembourg's OSIIs, European banking groups, and investment funds.[14] Two

[14] The Figure shows all pairwise correlations among the 6 OSIIs, 4 GSIBs and the 6 sponsored investment funds.

observations stand out. First, the distributions are pretty symmetric, except for the asset return correlations between banking groups and investment funds. Second, across the banking groups, asset return correlations were quite high until the start of the sovereign crisis and then declined until end-2014, when correlation increased sharply. This recent rise in correlation is also visible among OSIIs and, obviously, between OSIIs and their banking groups. The November 2015 ECB Financial Stability Review also identified a rise in correlation across asset classes. The narrowing gap between the 20th and the 80th percentiles may be linked to a rise in systemic risk. This can be seen in the measures in Figure 3 which show an increase in OSIIs interdependence (Banking Stability Index) and also in OSIIs fragility (Banking Fragility) (Jin and Nadal De Simone, 2014a and 2014b).[15] These measures support the ECB analysis.

Figure 3 also reports the unconditional PD and the corresponding EL of what is referred to as “all scenarii”. This is the result of the following addition of scenarii: summing one, two, three, up to six OSIIs defaulting. This resulting unconditional systemic risk measure peaked in the first quarter of 2010, when the crisis aggravated with high government deficits, rapidly increasing public debt-to-GDP ratios and rising contingent liabilities linked to government guarantees to banks. Luxembourg OSIIs reflected developments affecting their mother companies. Against this background, at an extraordinary meeting on 9/10 May, the European Council (Ecofin) agreed a comprehensive package of measures to preserve financial stability in Europe and established the European Financial Stabilization Mechanism. In May, the ECB Governing Council decided to intervene in the secondary markets for public and private debt securities through its Securities Markets Program. These measures led to a significant drop in market volatility reflected in the unconditional PD.

The unconditional PD peaked again during 2013, when many large euro area banking groups posted significant losses, especially in the second half of the year, reflecting high loan-loss provisioning. Several banks saw their return on equity fall below their cost of equity, indicating the need for further balance sheet adjustment (November 2013 and November 2014 ECB Financial Stability Review). Banks continued the much needed de-risking even as they struggled to raise profits. The pattern of OSIIs’ leverage during this period reflects this tension with leverage peaking at the same dates as the unconditional PD, although with some differences across banks.

[15] Banking Fragility measures the probability that at least two banks are distressed. Banking Stability Index is the expected number of banks that will become distressed given that any single bank in the sample is already in distress.

Table 1 reports a measure of pair-wise contagion, the distress dependence matrix (DDM), which is computed as the EL of each financial institution in the row conditional on distress on the financial institution in the column. It is computed for Luxembourg OSIIs, the banking groups to which they belong and the investment funds sponsored by the OSIIs.[16] The increase in fragility of OSIIs apparent in Figure 3 is also clear in the DDM. The average EL of OSIIs increased to 1.24bn at end-June 2015 from 1bn at end-June 2014. Given the rise in interdependence in the stability index (Figure 3), and despite significant deleveraging in the banking sector, “search for yield” may be driving up correlations across asset classes as indicated by the ECB. This is reflected in the rise in systemic risk measures (e.g., the Banking Fragility measure).

5.2 Systemic Risk and Conditional Contingent Liabilities Emanating from OSIIs

Another important measure of systemic risk is the probability that at least one bank is distressed given that one bank is already distressed, PAO. Figure 4 reports this conditional measure and its corresponding EL for Luxembourg OSIIs. There is a great deal of heterogeneity in terms of systemic risk across OSIIs. Given that asset correlations among OSIIs are high in general, the main reason for the dispersion across banks seem to be differences in their respective PDs. These result from both different business models and different leverage ratios.

Figure 4 also reports the conditional implicit government guarantees that result from the ELs. In the Merton model, EL can be expressed as the product of the risk-neutral PD and the implied risk-neutral loss-given-default (LGD), so the conditional implicit government guarantee is calculated as follows: the LGD of the OSII assumed to default is added to the conditional ELs of at least one other OSII, weighted either by the share of the Luxembourg government in the OSII’s equity, or by the OSII’s share in the total assets of the banking group to which it belongs.

Figure 4 raises three points. First, OSIIs are different in terms of their impact on conditional implicit government guarantees (divergence between the median and the mean). Second, conditional implicit government guarantees have fallen since the height of the financial crisis. They do not seem to have been much affected during the sovereign crisis. Finally, the volatility of the guarantees was largely driven by changes in correlation across OSIIs.

[16] This DDM is based on EL, not the conditional PD. See Jin and Nadal De Simone (2014a) for a thorough description of this measure.

5.3 Systemic Risk and Contingent Liabilities Emanating from G-SIBs Cross-border Contagion

The conditional systemic risk measure PAO can also be used to evaluate systemic risk emanating from the European banking groups to which Luxembourg OSIIs belong.[17] Figure 5 reports the PAO and the associated EL. Both assume that one banking group defaults, and measure the conditional PD of at least one Luxembourg OSII. In contrast to the PAO for Luxembourg OSIIs (Figure 4), Figure 5 displays less heterogeneity across the effects of each banking group distress on the Luxembourg OSIIs. Cross-border contagion is more homogeneous than contagion among OSIIs. However, regarding banking groups, markets seemed to distinguish among banking groups at the height of the sovereign crisis, with some remaining closer to the top of the left panel, indicating a larger systemic risk via cross-border contagion. The ECB Financial Stability Review (December 2011, pp. 82-84) used CDS-derived expected shortfall measures to assess systemic risk and found that prior to 2010 sovereign CDS and bank CDS were sensitive to tail events in other CDS in the same sectors, but after 2010 transmission channels among sovereign CDS became more heterogeneous. After 2010, a tail event in an Italian bank, for example, affected French sovereign CDS about twice as much as German sovereign CDS. This seems to be well captured by the PAO measure during the period 2010-2013.

Figure 5 also shows the conditional implicit government guarantees triggered by a theoretical bail out of OSIIs following default by their banking groups. Regulatory changes promoted by the Financial Stability Board and the European Commission (e.g., the Total Loss Absorbing Capacity, bail-in, capital surcharges, the Single Resolution Authority and the Single Resolution Fund) sought to prevent bailing out financial institutions with tax payer money. These results illustrate how much could be at stake. Differences across banking groups and across time are revealing. Following Lehmann's collapse, the highest percentile conditional implicit government guarantee was about 0.8bn euro. During the sovereign crisis, it fell by about half, and in the run up to the Asset Quality Review and the launch of the EU Single Supervisory Mechanism, it rose above 0.6bn euro.

According to the DDM in Table 1, three out of four banking groups experienced an increase in pair-wise vulnerabilities during the last part of the sample. Increased vulnerabilities stem from the rise in asset correlations as banking groups' PD actually dropped (Figure 5). This analysis confirms the need to consider several different

[17] This is what the ECB calls "the banking channel of sovereign risk" (Financial Stability Review, December 2011).

measures of systemic risk, including their components. While banks may reduce leverage and fragility, a rise in asset correlation may suggest future possible financial instability.

5.4 Systemic Risk and Contingent Liabilities Emanating from Investment Funds

As stated above, this paper uses bank sponsorship to proxy the BCBS's concept of "step-in" risk (defined as the risk that a bank may provide financial support to an entity beyond or in absence of any contractual obligations). Therefore, this section discusses the conditional implicit government guarantees that would result from distress in investment funds sponsored by Luxembourg OSIIs. During the sample period, the investment funds sponsored by Luxembourg OSIIs represented 0.1% of total assets managed by the Luxembourg investment fund industry at end-June 2015.

In Figure 6, synthetic PAO and synthetic PAO EL profiles are broadly similar to those of OSIIs and banking groups. However, there is less heterogeneity than for distress stemming directly from OSIIs (Figure 4).

Over the sample period, public guarantees associated with investment funds tend to be 1/2 to 1/3 times those emanating directly from OSIIs. However, the investment funds considered in this study represent a much smaller share of total assets than do the OSIIs. The panel of "synthetic" conditional implicit government guarantees reveals the potential cost of contagion risk. Table 1 indicates that toward the end of the sample period investment funds EL increased in all but two cases, although much less than for banking groups. Again, systemic risk measures need to be supplemented by an analysis of PDs and market-driven correlations.

5.5 Systemic Risk Emanating from the Household and Non-financial Corporate Sectors

Figure 7 reports the DD for both the non-financial corporate sector and the household sector.[18] According to the DDs, systemic risk was stable over the sample, but quite volatile in the non-financial corporate sector. This reflects the volatility in the financing needs of international holding companies located in Luxembourg. Recently, the fall in the DD of the non-financial corporate sector follows an acceleration of loan growth in a context of low interest rates. The drop from 45 at the beginning of the sample to 25 at the end may require further monitoring, but this should be evaluated in the context of the high volatile financial component of the sector's stochastic balance sheet.

[18] Both sectors PDs and ELs are basically zero and are not shown.

5.6 Systemic Risk and Sovereign Risk

5.6.1 Selected Statistics

Gray and Malone (2008) provide an internally consistent approach that is used in this paper to relate the Luxembourg sovereign risk to all sectors of the economy, with their implied non-linearities and feedback effects. This section brings together the financial sector, the non-financial corporate sector and the household sector, and discusses general supplementary indicators of systemic risk and sovereign risk.

Given the lack of CDS for the Luxembourg sovereign, the Luxembourg DD is calculated as follows. Houweling and Vorst (2005) propose a framework to value CDS. For a given default intensity process, the valuation of a CDS is well known. Following market practice, this paper specifies a simple annualized unconditional risk-neutral default intensity model, and inverts the closed-form expressions for CDS spreads to solve for the corresponding values of the constant annual intensity using a standard nonlinear optimization technique. German sovereign senior CDS with maturities of 1Y, 2Y, 3Y, 4Y, 5Y, 7Y, and 10Y are considered. Luxembourg CDS are constructed from German sovereign CDS through the following steps: first, credit spreads from German sovereign CDS are derived as in Houweling and Vorst (2005); second, credit spreads are adjusted proportionally using the ratios between Luxembourg and German government bond yields. As in Merton's model, the implied DD is the inverse of the standard normal cumulative distribution of the one-year PD derived from CDS.

Figure 8a compares the Luxembourg sovereign DD implied from German sovereign CDS to that of Germany's. Luxembourg and Germany share the same sovereign rating, and it is thus not surprising that their DDs are similar. Moreover, applying the Merton model to the sovereign balance sheet broadly confirms the picture (Figure 8b).[19] The noticeable improvement after 2013 reflects a combination of factors. These factors include the vanishing effect of the 2009 and 2010 primary deficits in the five-year moving average of the present value of the general government primary balance, buoyant tax revenues, and the stabilization of general government debt to GDP.[20]

[19] Gray and Jobst (2013) suggest to use the sovereign default barrier from the sovereign balance sheet and the full term structure of the sovereign credit curve (e.g., the sovereign CDS spreads at maturity of 1, 3, 5, 7, and 10 years) to estimate implied total sovereign assets and asset volatility using Merton's model. They applied it to Sweden. However, using the implied Luxembourg CDS following Houweling and Vorst, the application of Gray and Jobst's method produces an estimate of Luxembourg implied total sovereign assets that is too low when compared with the observed components of sovereign assets. Because of the limited volume and maturity of Luxembourg government bonds and their limited liquidity, the method to derive Luxembourg credit spreads may not precisely disclose the term structure of the sovereign credit curve.

[20] On 14 October 2016, Fitch Ratings confirmed Luxembourg's AAA rating with stable outlook. S&P and Moody's ratings for Luxembourg are also AAA, and Aaa, respectively.

Figure 8c displays the unconditional implicit government guarantees stemming from Luxembourg's OSIIs. Those guarantees reflect the EL consistent with the PDs of at least one OSII, of two OSIIs and so on, until all the six OSIIs are taken into account, while eliminating double counting. The corresponding PDs and EL were displayed in Figure 3.

Figure 8d separately reports the average conditional implicit government guarantees from the OSII, the banking groups, and the investment funds (Figures 4-6 reported above show the respective quantiles). The improvement in the EU banking sector since 2009Q2 is obvious in this panel, especially for Luxembourg OSIIs. As explained above, the de-leveraging process, the bad-loans provisions and the write-offs undertaken by major European banking groups amidst a morose economic environment in the run-up to the Single Supervisory Mechanism are reflected in the three sectors during 2014. Clearly, the conditional implicit government guarantees stemming directly from OSIIs are higher than those stemming indirectly from banking groups and investment funds.

Figures 8e and 8f illustrate the impact on conditional implicit government guarantees from shocks to household mortgages and to loans to non-financial corporations, respectively. The shocks assume that OSIIs write off 10% of their outstanding mortgage loans to households (Figure 8e), or 10% of their outstanding loans to non-financial corporations (Figure 8f). These shocks, significant by historical standards, only produce a minor deviation from the (no shock) benchmark, and do not seem to compromise the robustness of the fiscal position.

5.6.2 Systemic Risk Shocks and Sovereign Risk

In contrast to the assumption underlying the previous section, other things may not be equal. A short additional exercise is thus undertaken in this section.

Figure 9 shows the impact of various shocks on the sovereign stochastic balance sheet via the contingent implicit government guarantees. The figures report both the conditional DD of the sovereign (left-hand side) and its difference from the (no shock) benchmark DD (right-hand side). Clearly, systemic risk from Luxembourg OSIIs has a relatively small effect on sovereign DD given the strong fiscal position. This result holds despite feedback effects and nonlinearities typical of financial markets, an important feature captured by the multivariate CIMDO approach.

However, this exercise does not account for the likely increase in the volatility of sovereign assets following these shocks since this study is limited to a partial equilibrium approach. As an *ad* hoc attempt to capture this feedback channel, Figure 9 combines the shocks with an assumed increase in sovereign assets' volatility by 40%. This magnitude is consistent with the maximum implied sovereign asset volatility over 2009-2011. Only when contingent liabilities are combined with a large increase in sovereign asset volatility does the negative impact on sovereign risk become visible.

The main conclusion of this exercise is that even in the extreme but plausible scenario combining shocks with a 40% rise in sovereign assets volatility, the integrity of the Luxembourg sovereign remains robust. However, the severity of the shock also illustrates the fundamental importance of the fiscal position when the shock occurs given that the sovereign's DD falls 25 standard deviations.

Table 2 summarizes the transmission of systemic risk from each sector via each of the OSIIs as well as their impact on EL, conditional implicit government guarantees and the sovereign's DD (assuming a 40% rise in sovereign assets volatility). This table is based on the conditional PAO concept, but adds the EL of the institution assumed to be in distress. Two points warrant mention. First, contributions to EL and to the conditional implicit government guarantees vary over time. Second, the volatility of implied sovereign assets has a much stronger impact than systemic risk stemming from the OSIIs, their banking groups, their investment funds or the non-financial private sector.

6. Conclusions and Possible Extensions

To the best of our knowledge, this is the first study to apply an integrated framework to measure systemic risk and the build-up of systemic vulnerabilities from the financial sector or the real sector economy, as well as their interaction with the sovereign. The framework can be adapted to more sectors, more granularity or longer samples. In this study, systemic risk can arise directly from Luxembourg OSIIs, or indirectly from the European banking groups to which they belong or from the investment funds that the OSIIs sponsor, or from the non-financial private sector (via the loans the OSIIs make to them). The impact on sovereign risk and vulnerability via implicit contingent liabilities is found to be relatively contained. However, the study highlights the crucial role of fiscal sustainability in preserving financial stability.

This framework contributes to the macro-prudential literature with a methodology to monitor systemic risk at a national level while accounting for the non-linearities and feedback effects that characterize financial markets. It provides an internally coherent view of systemic risk in Luxembourg at an aggregate level. This approach delivers a first set of indicators of systemic risk so that policymakers, if deemed necessary, can deepen their analysis of vulnerabilities. It can also help in the calibration of macro-prudential instruments. In particular, the framework can help to determine banks' additional loss absorbing capacity to reflect their direct and indirect contribution to systemic risk.

Jin and Nadal De Simone (2014a and 2014b) showed how this framework can be used in conjunction with the Generalized Dynamic Factor Model to extract the driving forces of systemic risk, and contribute to the calibration of macro-prudential instruments. The framework can also generate robust out-of-sample forecasts of systemic risk measures, as in Jin and Nadal De Simone (2012). Incorporating the common and the idiosyncratic components of a broad set of macro-financial variables improves the analytical features and the out-of-sample forecasting performance of the framework. This adds to the value that this framework may bring to other areas where non-linearities and feedback effects matter such as when performing systemic macro-financial stress testing exercises.

Another possible application of the framework is to simulate the effects of changes in economic conditions and government policies on vulnerability indicators and on sovereign credit risk measures. For example, it is straightforward to study how changes in sovereign debt composition or the primary surplus will affect sovereign credit spreads and other risk indicators. Within the private sector, technological shocks or demographic change will affect the present value of the non-financial corporate sector and the household sector total assets. Those will interact with the sovereign balance sheet and different indicators of funding costs, and systemic financial and sovereign risk.

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Figure 1a: Luxembourg Other Systemically Important Institutions (OSIIs)

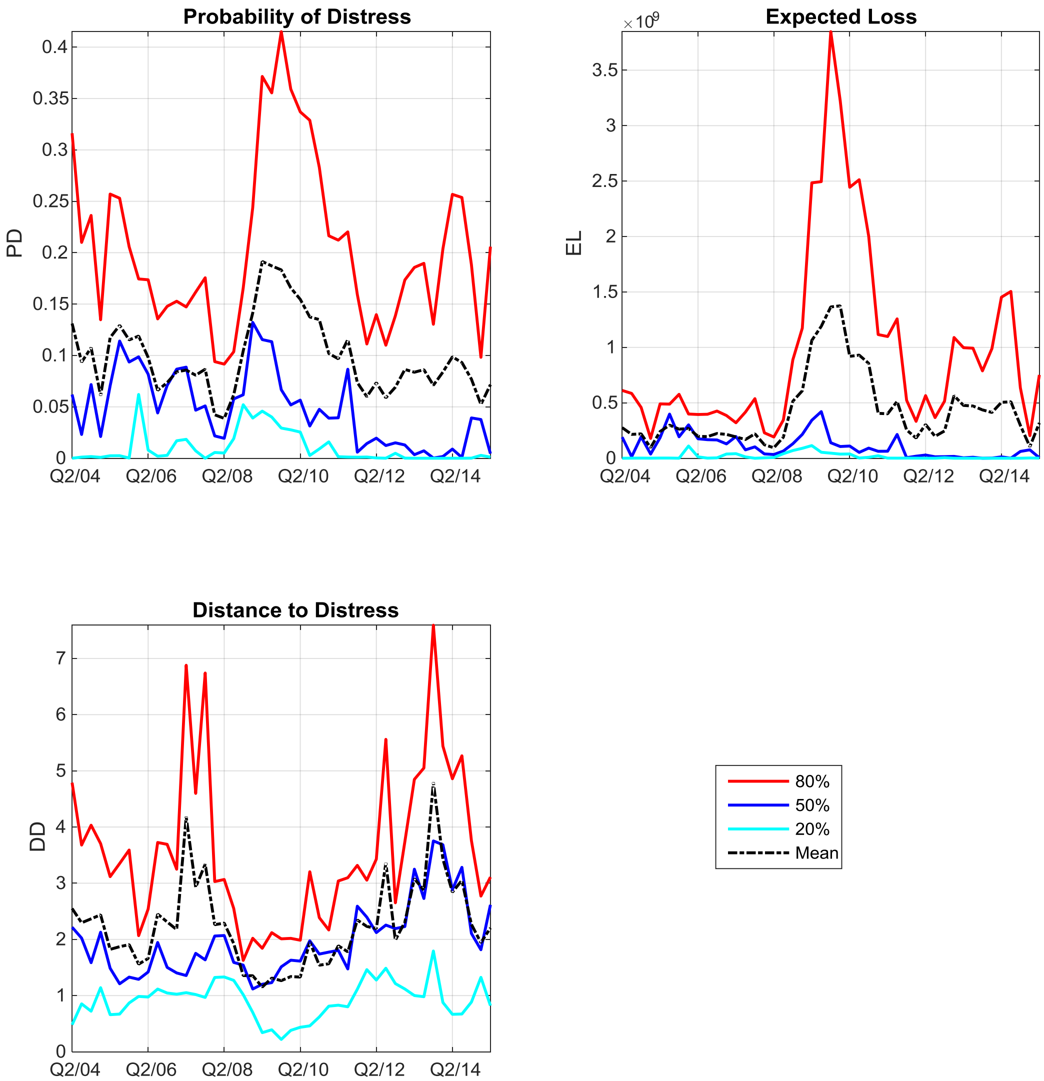

Figure 1b: Systemically Important Banking Groups

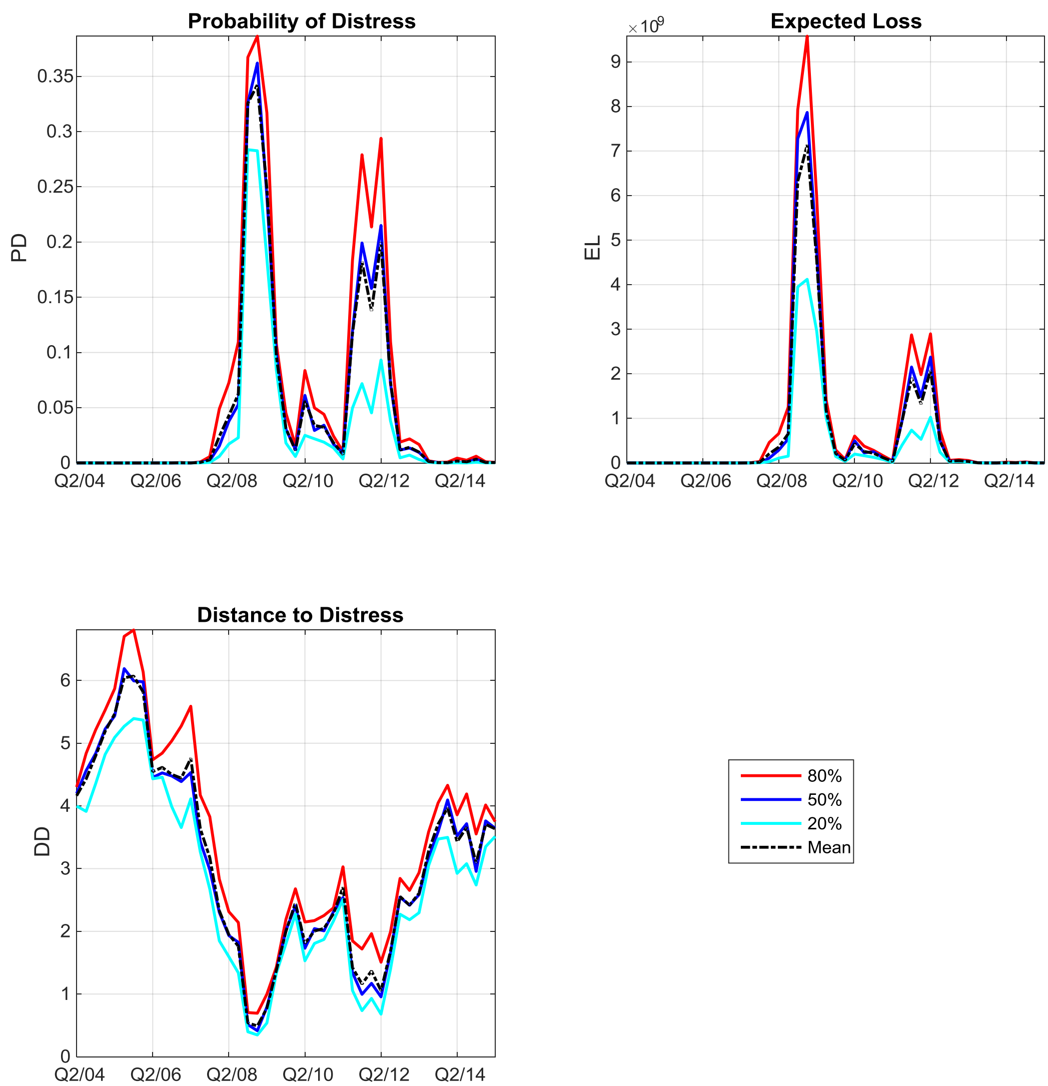

Figure 1c: Luxembourg Investment Funds

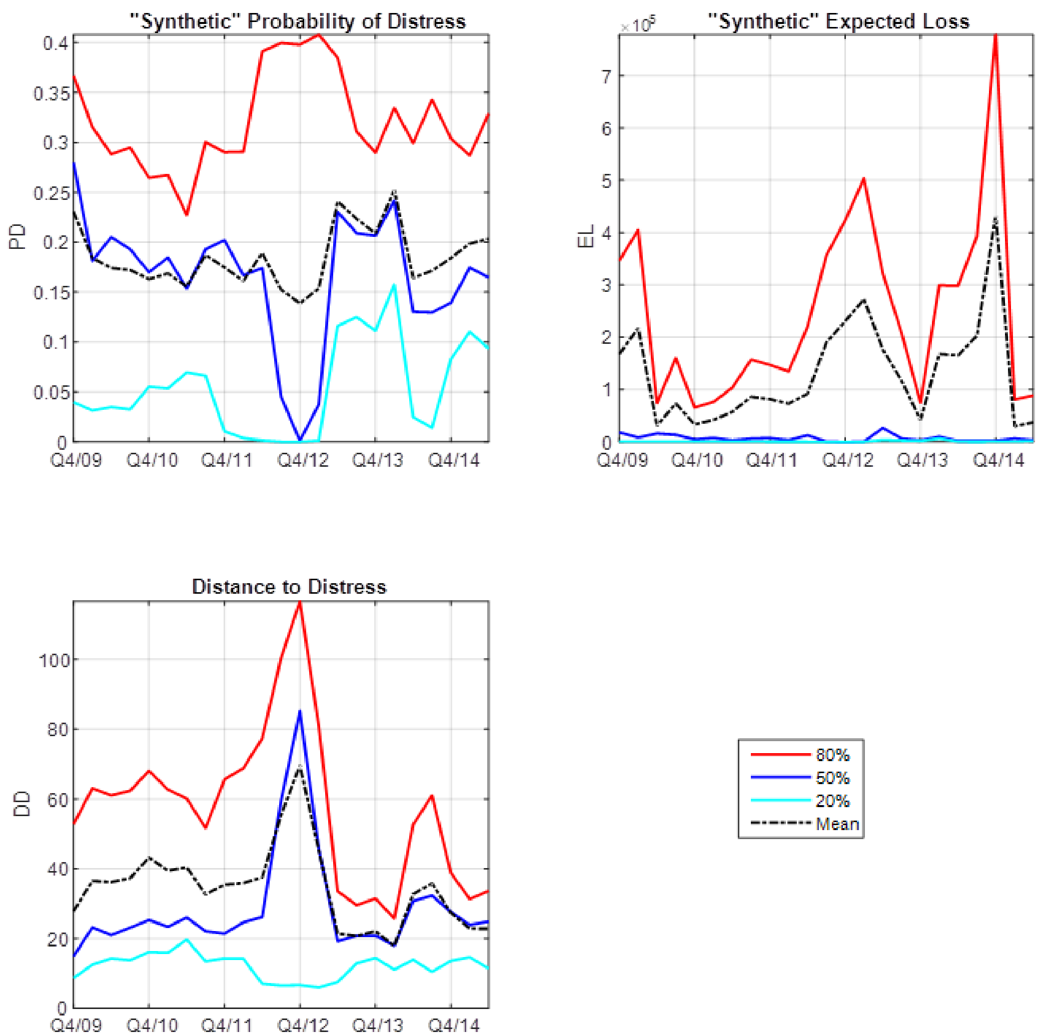

Figure 2: Asset Return Correlations among Luxembourg OSIIs, Banking Groups and IFs

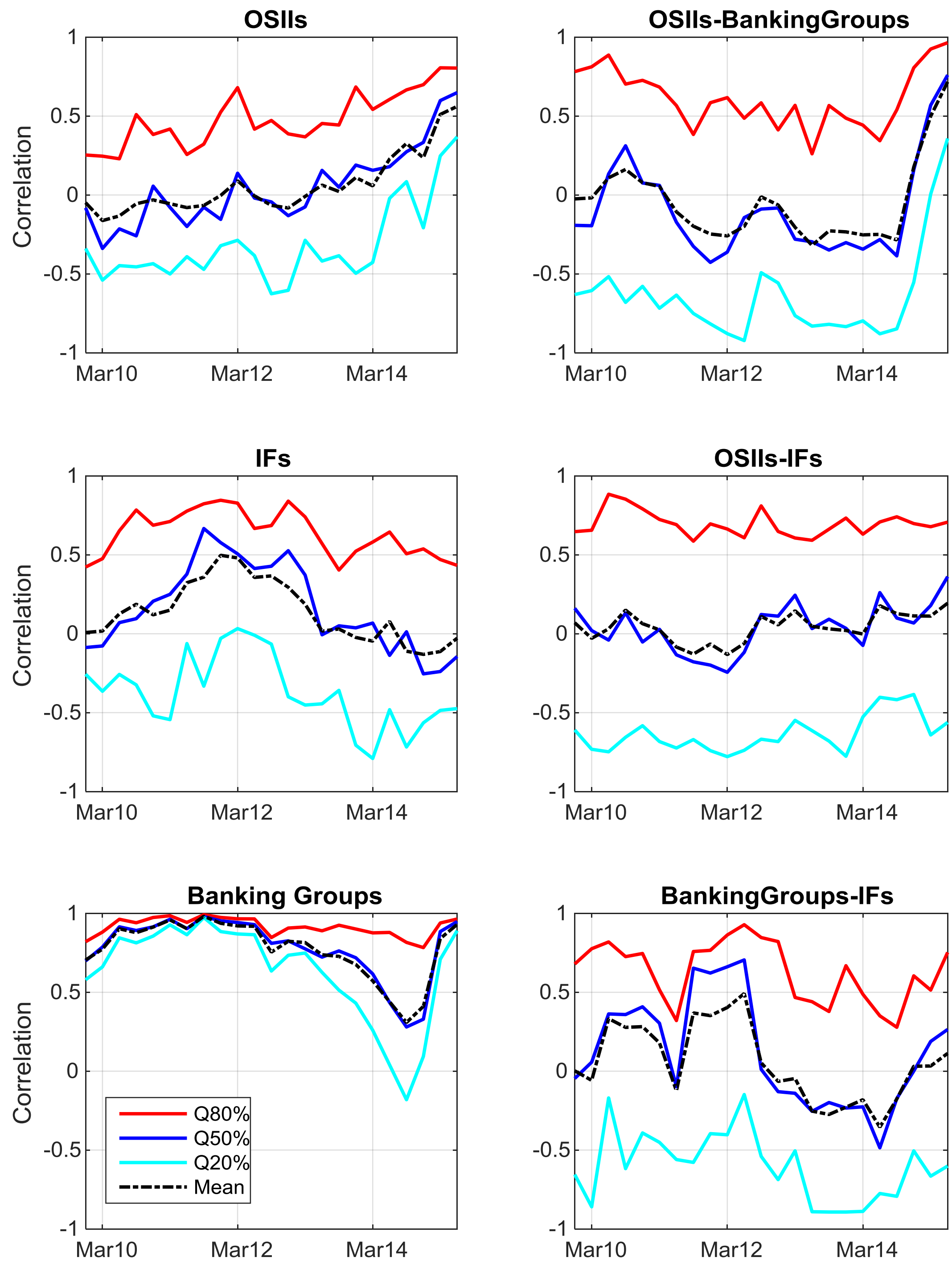

Figure 3: Systemic Risk Measures for Luxembourg OSIIs

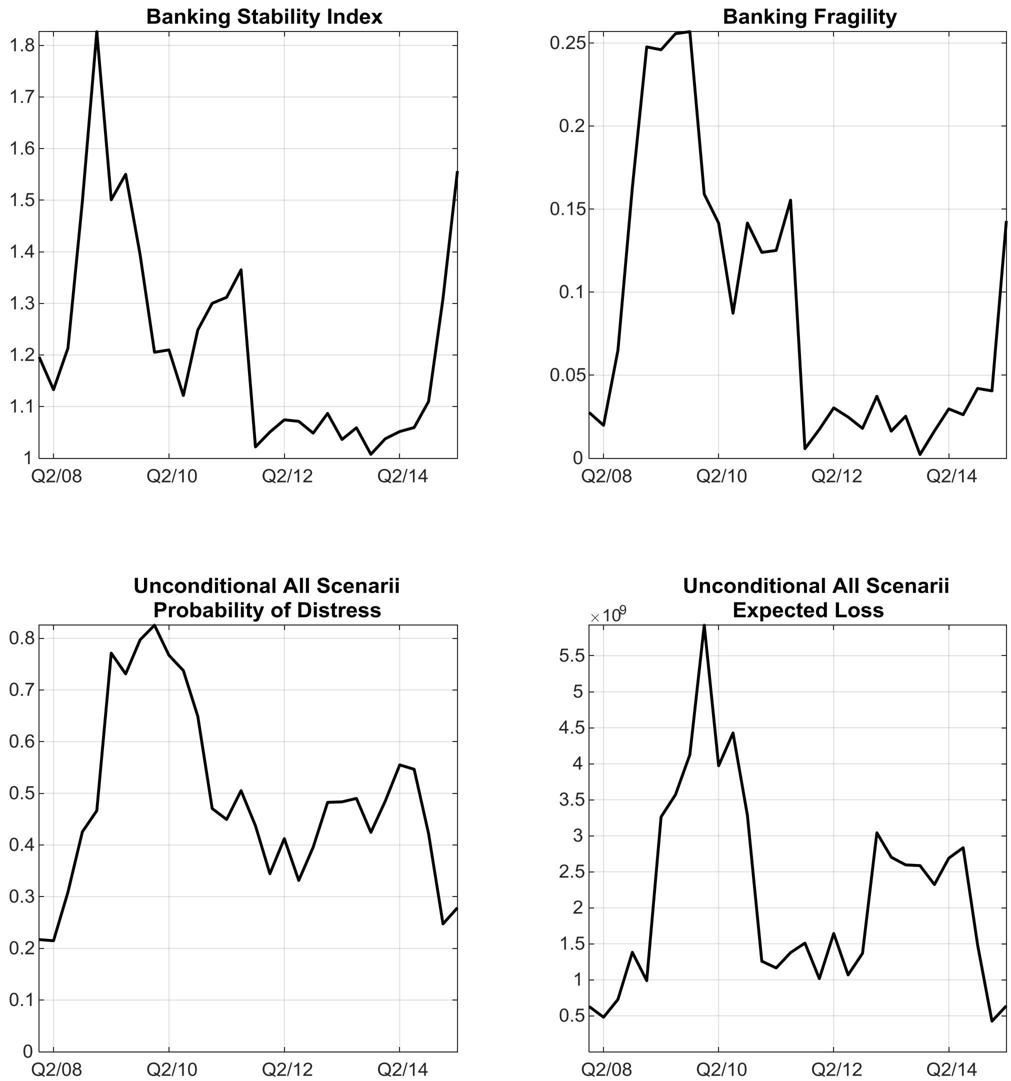

Figure 4: PAO, PAO Expected Loss, and Conditional Implicit Government Guarantees for Luxembourg OSIIs

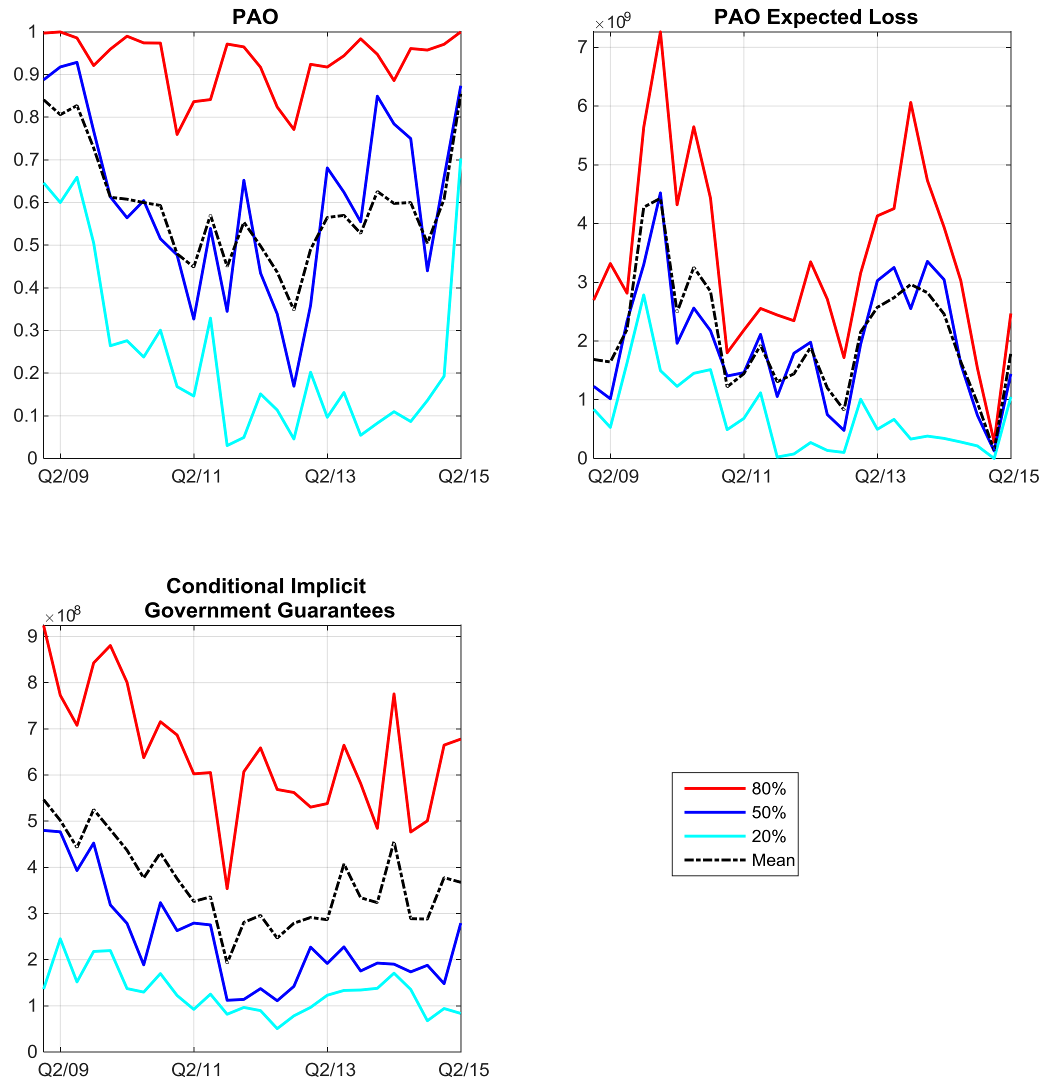

Figure 5: PAO, PAO Expected Loss, and Conditional Implicit Government Guarantees for Luxembourg OSIIs stemming from Banking Groups

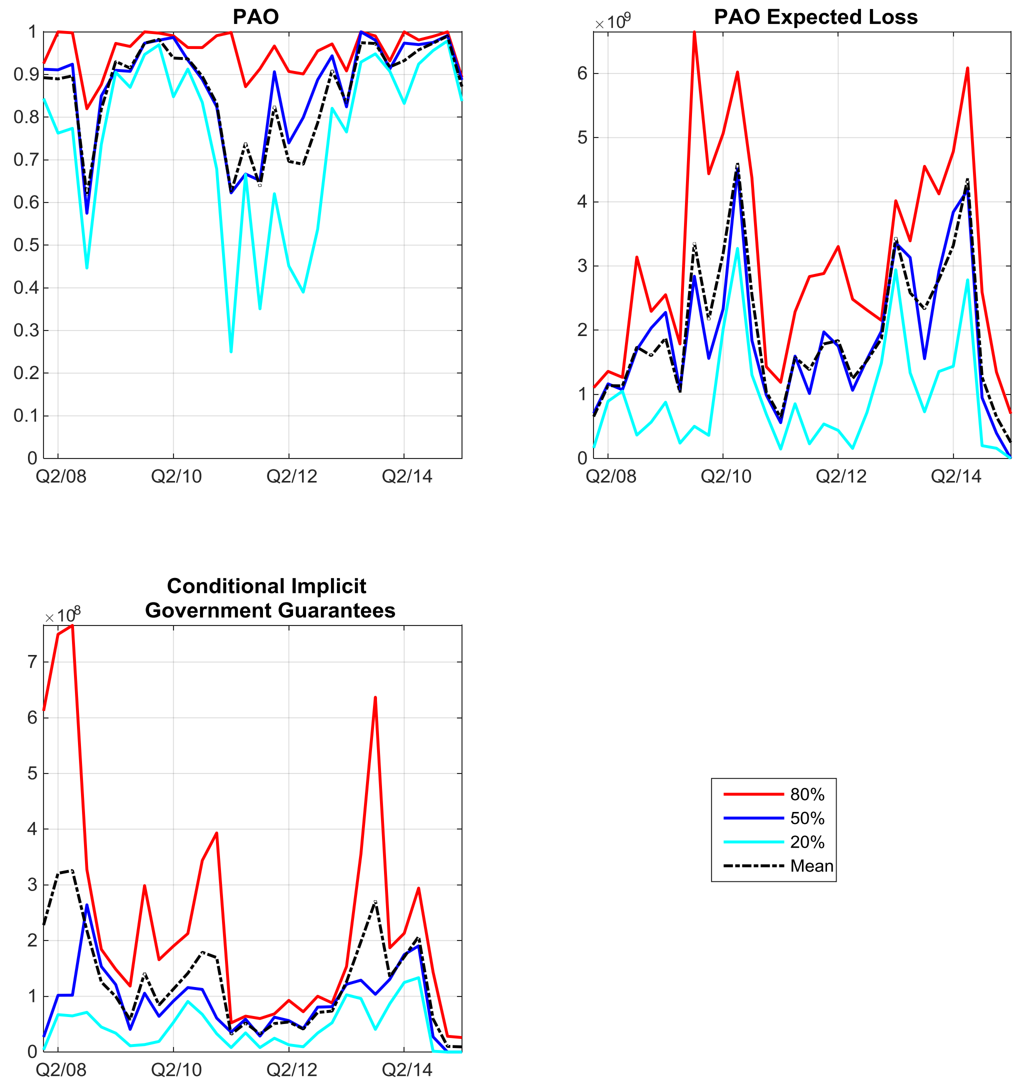

Figure 6: PAO, PAO Expected Loss, and Conditional Implicit Government Guarantees for Luxembourg OSIIs stemming from Investment Funds

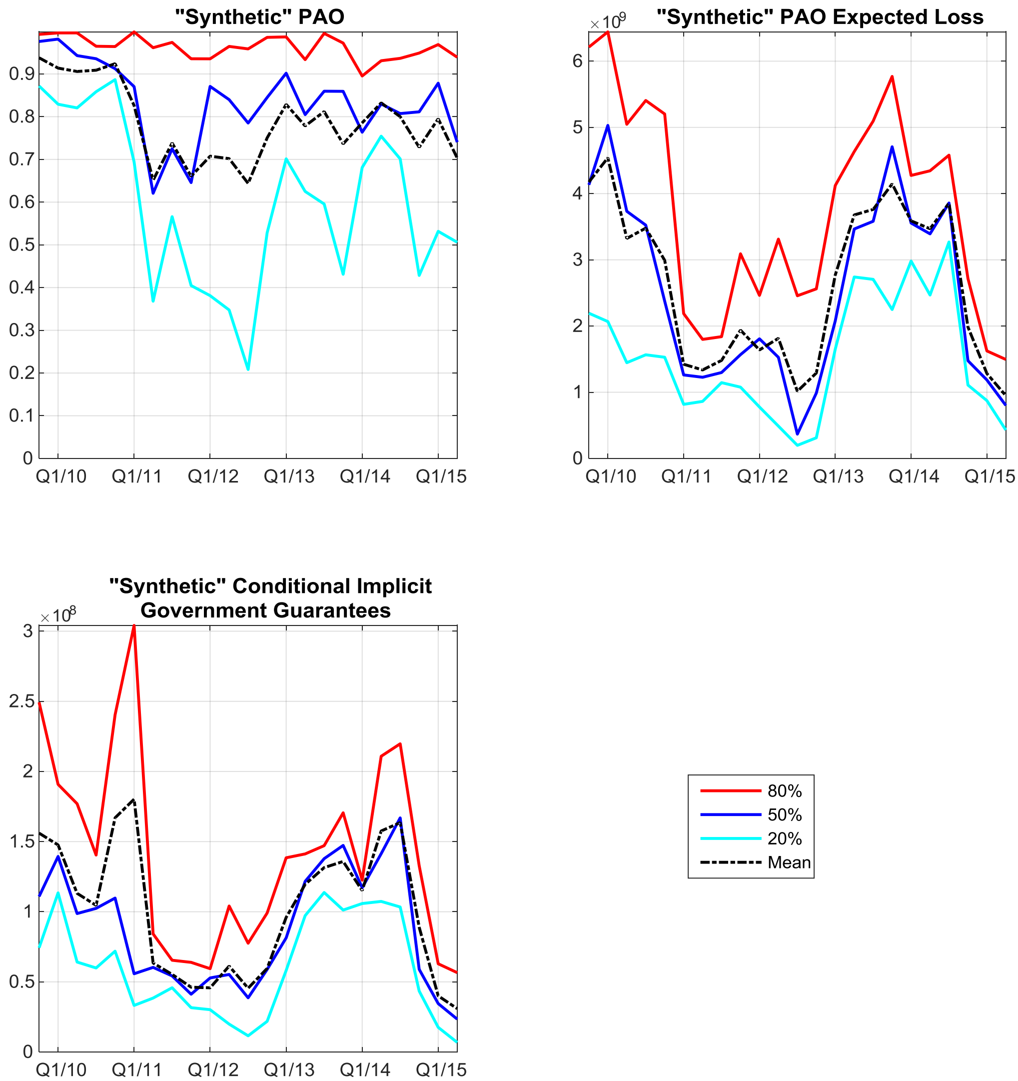

Figure 7: Risk Measures for Luxembourg Non-financial Corporate Sector and Household Sector

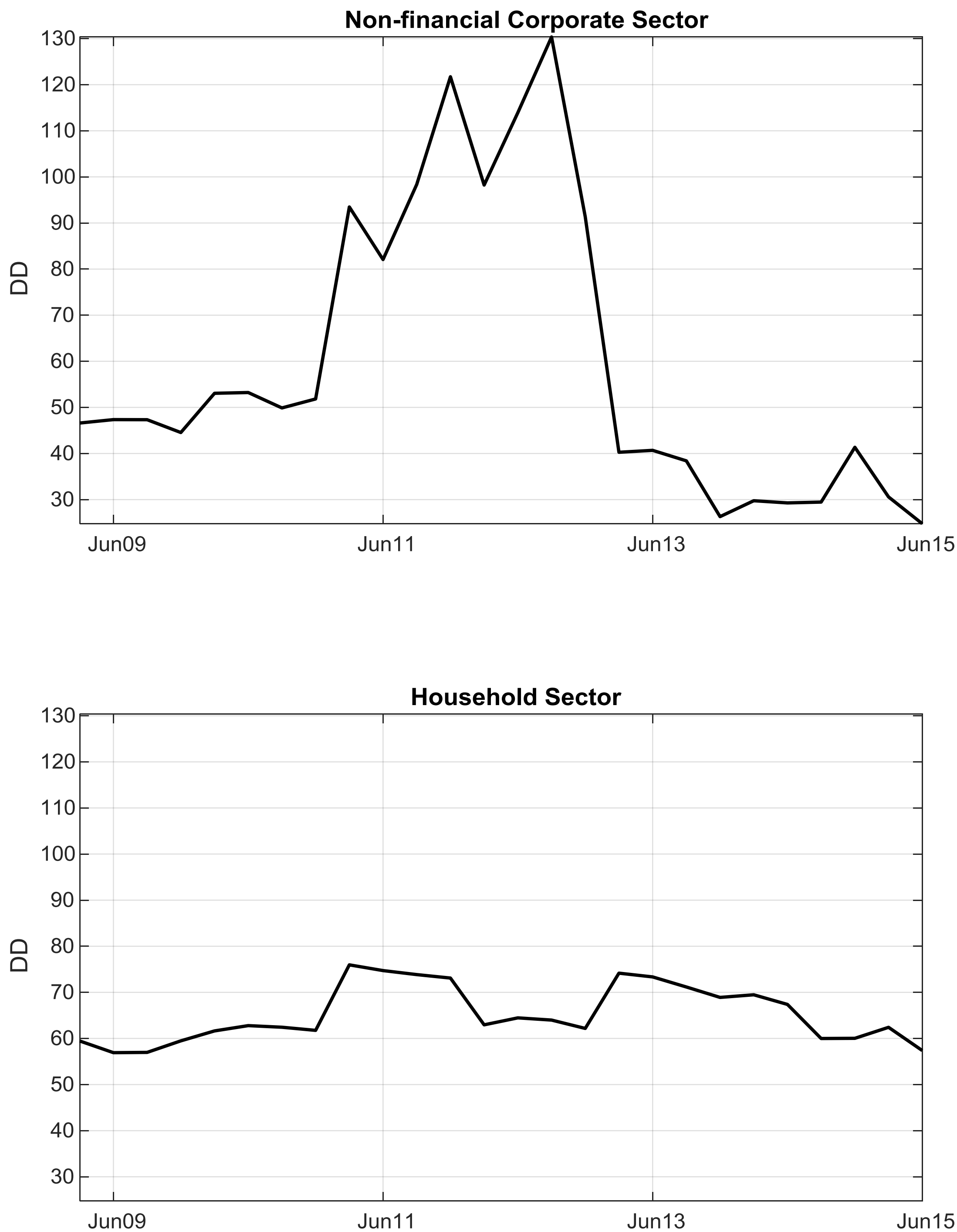

Figure 8: Sovereign Risk Measures for Luxembourg

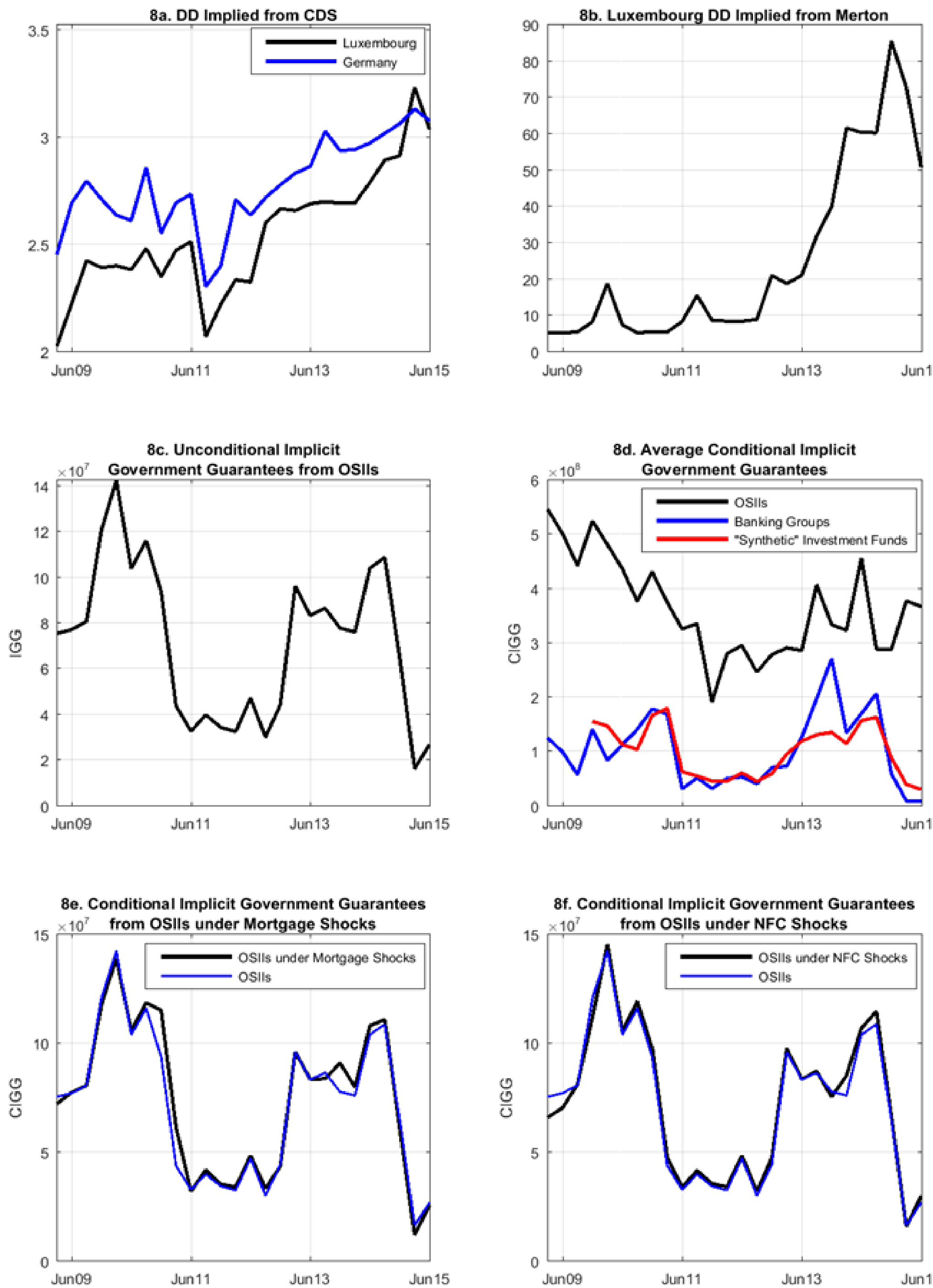

Figure 9: Luxembourg Sovereign Risk Conditional DD under Conditional Implicit Government Guarantees shocks (assuming 40% higher Sovereign Asset Value Volatility)

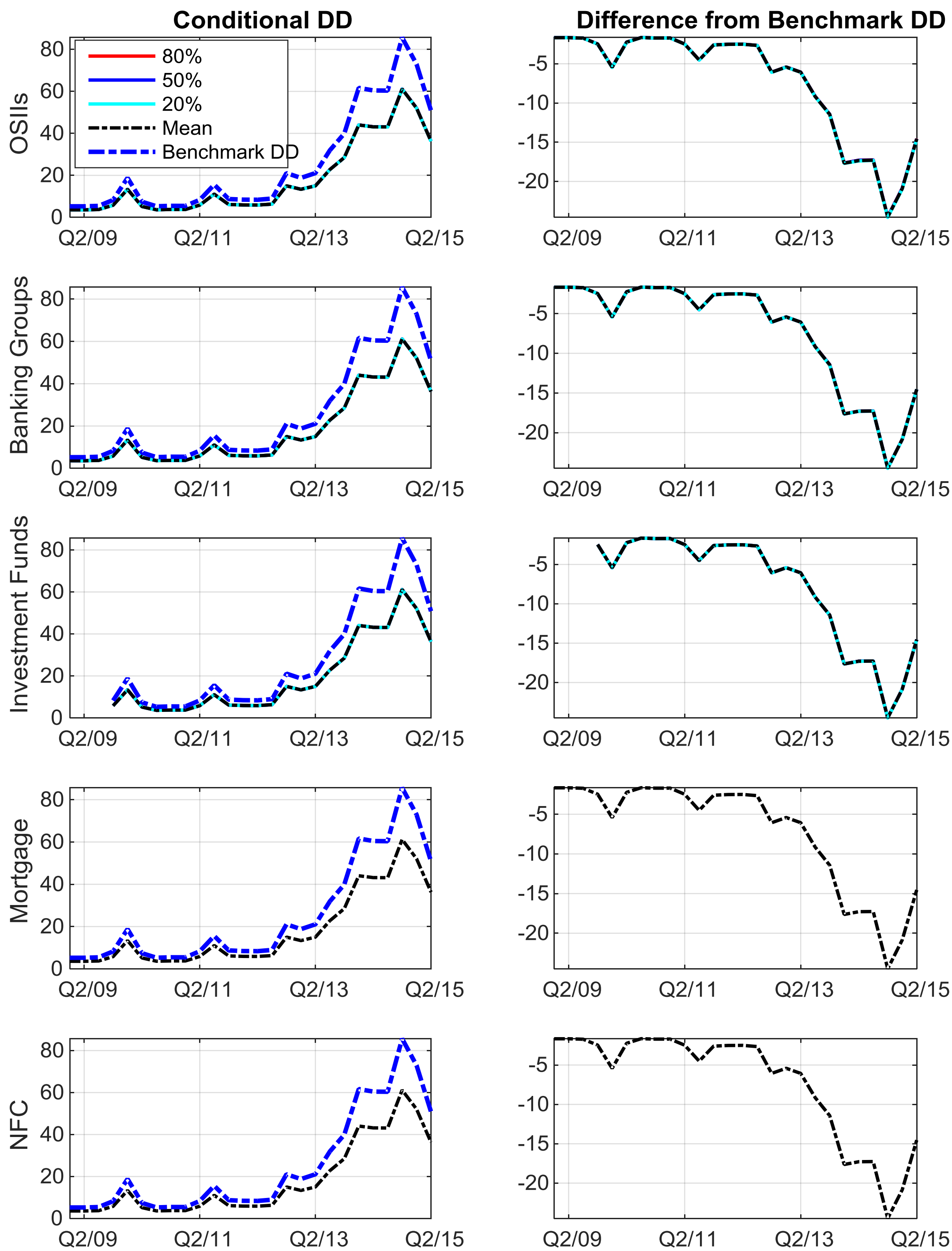

Table 1: The Expected Losses (in Billion) of DDM between OSIIs and Banking Groups and Investment Funds

OSIIs	OSIIs							Banking Groups					Investment Funds						
	OSII_A	OSII_B	OSII_C	OSII_D	OSII_E	OSII_F	Average	BG_A	BG_B	BG_C	BG_D	Average	IF_A	IF_B	IFB	IF_C	IF_D	IF_E	Average
30-Jun-2010																			
OSII_A	1.02	0.04	0.00	0.00	0.00	0.01	0.18	0.60	0.09	0.00	0.01	0.18	0.23	0.04	0.00	0.01	0.00	0.01	0.05
OSII_B	7.57	8.29	0.01	2.05	0.22	1.12	3.21	7.29	8.26	0.26	2.02	4.46	7.05	7.16	0.12	1.98	0.37	0.74	2.90
OSII_C	0.00	0.00	1.73	0.00	0.32	0.04	0.35	0.00	0.00	0.65	0.00	0.16	0.00	0.00	1.39	0.00	0.19	0.01	0.27
OSII_D	0.01	0.05	0.00	1.41	0.03	0.10	0.27	0.02	0.04	0.00	0.60	0.17	0.02	0.05	0.00	0.23	0.04	0.10	0.07
OSII_E	0.00	0.02	0.96	0.10	2.14	0.09	0.55	0.00	0.01	0.72	0.11	0.21	0.00	0.01	1.10	0.10	0.88	0.02	0.35
OSII_F	3.08	1.56	2.00	5.94	1.71	6.00	3.38	2.99	1.18	2.32	5.83	3.08	2.95	1.88	1.78	5.67	1.87	5.99	3.36
Average	1.95	1.66	0.78	1.58	0.74	1.23	1.32	1.82	1.60	0.66	1.43	1.38	1.71	1.52	0.73	1.33	0.56	1.15	1.17
30-Jun-2011																			
OSII_A	0.58	0.00	0.00	0.00	0.00	0.00	0.10	0.05	0.00	0.00	0.00	0.01	0.12	0.00	0.00	0.00	0.00	0.00	0.02
OSII_B	0.00	6.65	6.48	0.82	1.59	2.14	2.95	0.00	6.62	6.50	0.84	3.49	0.01	6.31	4.82	0.81	1.51	1.99	2.57
OSII_C	0.00	0.18	1.53	0.00	0.07	0.05	0.31	0.00	0.88	1.52	0.00	0.60	0.00	0.19	0.24	0.01	0.08	0.06	0.10
OSII_D	0.00	0.07	0.01	1.64	0.05	0.01	0.30	0.01	0.04	0.01	1.63	0.42	0.00	0.08	0.02	0.53	0.06	0.01	0.12
OSII_E	0.00	0.01	0.01	0.00	0.75	0.00	0.13	0.00	0.02	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.02	0.00	0.01
OSII_F	0.55	2.51	2.32	0.08	0.54	3.61	1.60	0.65	2.75	2.33	0.08	1.45	0.68	2.46	1.96	0.22	0.72	3.41	1.57
Average	0.19	1.57	1.73	0.42	0.50	0.97	0.90	0.12	1.72	1.73	0.43	1.00	0.14	1.51	1.17	0.26	0.40	0.91	0.73
30-Jun-2012																			
OSII_A	0.57	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.02
OSII_B	0.00	1.11	0.00	0.00	0.00	0.00	0.19	0.00	1.11	0.00	0.00	0.28	0.00	0.96	0.00	0.02	0.00	0.03	0.17
OSII_C	0.28	0.00	1.70	0.00	0.02	0.09	0.35	0.16	0.00	0.19	0.00	0.09	0.25	0.00	0.75	0.01	0.05	0.10	0.19
OSII_D	0.03	0.46	0.01	1.78	0.29	0.05	0.44	0.04	0.28	0.01	0.29	0.16	0.02	0.46	0.01	0.32	0.14	0.06	0.17
OSII_E	0.00	0.01	0.00	0.02	0.74	0.00	0.13	0.00	0.03	0.00	0.01	0.01	0.00	0.01	0.00	0.01	0.02	0.00	0.01
OSII_F	4.62	3.91	2.98	0.97	0.02	4.76	2.88	4.32	4.17	2.49	1.26	3.06	4.53	3.73	2.90	1.23	0.33	4.27	2.83
Average	0.92	0.91	0.78	0.46	0.18	0.82	0.68	0.75	0.93	0.45	0.26	0.60	0.82	0.86	0.61	0.27	0.09	0.74	0.57
30-Jun-2013																			
OSII_A	0.46	0.00	0.00	0.00	0.00	0.00	0.08	0.01	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.00	0.00	0.00	0.01
OSII_B	2.21	3.82	0.69	1.69	0.00	0.10	1.42	1.64	3.82	0.61	1.19	1.81	1.14	3.82	0.53	0.98	0.00	0.17	1.11
OSII_C	0.07	0.01	1.12	0.02	0.02	0.02	0.21	0.03	0.02	0.42	0.02	0.12	0.04	0.03	0.03	0.01	0.02	0.01	0.02
OSII_D	0.00	0.00	0.00	0.23	0.00	0.00	0.04	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
OSII_E	0.00	0.00	0.00	0.00	0.26	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OSII_F	2.75	0.72	5.08	5.03	3.10	6.21	3.82	2.72	0.36	4.71	4.50	3.07	2.93	1.39	3.99	4.33	2.82	5.57	3.50
Average	0.91	0.76	1.15	1.16	0.56	1.05	0.93	0.73	0.70	0.96	0.95	0.84	0.69	0.88	0.76	0.89	0.47	0.96	0.77
30-Jun-2014																			
OSII_A	1.38	0.09	0.00	0.02	0.39	0.02	0.32	1.31	0.23	0.00	0.02	0.39	0.54	0.06	0.00	0.02	0.25	0.02	0.15
OSII_B	4.71	6.54	0.10	5.43	1.98	0.28	3.18	4.77	6.55	0.39	4.56	4.07	3.96	5.97	0.83	4.52	1.81	0.51	2.94
OSII_C	0.00	0.00	0.25	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00
OSII_D	0.00	0.00	0.00	0.36	0.00	0.00	0.06	0.00	0.00	0.00	0.04	0.01	0.00	0.00	0.00	0.04	0.00	0.00	0.01
OSII_E	0.00	0.00	0.00	0.00	0.33	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OSII_F	1.11	0.34	3.80	2.26	2.02	4.46	2.33	1.10	0.19	3.23	1.84	1.59	1.32	0.50	3.01	1.87	1.87	3.46	2.00
Average	1.20	1.16	0.69	1.34	0.79	0.79	1.00	1.20	1.16	0.60	1.08	1.01	0.97	1.09	0.64	1.08	0.66	0.66	0.85
30-Jun-2015																			
OSII_A	0.86	0.01	0.70	0.34	0.54	0.02	0.41	0.87	0.01	0.20	0.37	0.36	0.04	0.00	0.01	0.01	0.01	0.00	0.01
OSII_B	4.14	6.63	4.40	1.10	4.88	4.65	4.30	3.67	6.64	5.28	1.19	4.20	3.71	4.99	4.44	0.83	3.50	2.87	3.39
OSII_C	0.92	0.02	0.94	0.37	0.52	0.03	0.47	0.94	0.04	0.91	0.41	0.57	0.08	0.01	0.03	0.03	0.04	0.01	0.03
OSII_D	0.52	0.01	0.44	1.06	0.17	0.02	0.37	0.81	0.00	0.16	1.08	0.51	0.06	0.00	0.02	0.03	0.02	0.01	0.02
OSII_E	0.02	0.00	0.02	0.00	0.40	0.00	0.07	0.06	0.00	0.04	0.02	0.03	0.02	0.00	0.00	0.00	0.01	0.00	0.01
OSII_F	2.21	1.46	2.18	0.96	1.92	2.26	1.83	2.14	1.90	2.28	1.04	1.84	2.02	1.25	2.08	0.49	1.19	1.12	1.36
Average	1.45	1.35	1.45	0.64	1.41	1.16	1.24	1.42	1.43	1.48	0.68	1.25	0.99	1.04	1.10	0.23	0.79	0.67	0.80

Note: These matrices present the expected loss of each of the OSIIs in the row, conditonal on each of the financial institutions in the columes become distressed.

Table 2: The Systemic Risk Transmitting Channels from Financial Sector, Non-financial Corporate Sector and & Household Sector

		OSIIs							Banking Groups					Investment Funds							NFC & Household	
Systemic Risk Transmitting through OSIIs	Date	OSII_A	OSII_B	OSII_C	OSII_D	OSII_E	OSII_F	Average	BG_A	BG_B	BG_C	BG_D	Average	IF_A	IF_B	IFB	IF_C	IF_D	IF_E	Average	Non-financial Corporate Sector	Household Sector
Expected Loss in Billion (include the assumed distressed OSIIs)	30-Jun-2010	5.354	9.580	3.923	5.725	3.861	7.076	5.920	2.114	6.145	1.972	2.549	3.195	3.580	5.139	0.452	3.886	1.873	5.007	3.323	3.938	4.004
	30-Jun-2011	1.127	8.986	3.654	2.376	1.775	5.504	3.904	0.650	0.465	0.010	1.416	0.636	0.687	1.512	1.538	0.941	0.937	2.406	1.337	1.181	1.159
	30-Jun-2012	4.330	4.282	4.709	2.736	1.071	4.903	3.672	3.765	0.078	2.226	1.276	1.836	3.115	0.515	1.794	1.261	0.427	3.775	1.815	1.665	1.644
	30-Jun-2013	3.512	4.483	5.870	4.091	3.257	6.313	4.588	3.158	3.562	2.847	4.211	3.445	3.068	2.743	3.863	4.344	2.737	5.312	3.678	2.707	2.699
	30-Jun-2014	5.590	6.924	3.977	4.177	2.693	4.706	4.678	0.514	5.080	3.592	4.090	3.319	2.381	5.144	3.401	4.002	2.505	3.383	3.469	2.768	2.755
	30-Jun-2015	2.307	8.063	2.514	1.481	1.720	6.809	3.816	0.000	0.997	0.000	0.000	0.249	0.733	2.124	0.524	0.209	0.868	1.226	0.947	0.839	0.669
Conditional Implicit Government Guarantees in Billion	30-Jun-2010	1.140	0.332	0.643	0.111	0.231	0.142	0.433	0.068	0.222	0.115	0.047	0.113	0.118	0.180	0.176	0.066	0.060	0.080	0.113	0.105	0.106
	30-Jun-2011	0.592	0.391	0.621	0.101	0.083	0.167	0.326	0.052	0.019	0.003	0.053	0.032	0.112	0.072	0.071	0.039	0.036	0.050	0.063	0.034	0.032
	30-Jun-2012	0.723	0.125	0.653	0.085	0.096	0.150	0.305	0.098	0.004	0.079	0.033	0.054	0.077	0.014	0.125	0.033	0.022	0.095	0.061	0.049	0.049
	30-Jun-2013	0.583	0.196	0.521	0.128	0.115	0.187	0.288	0.111	0.162	0.099	0.132	0.126	0.105	0.126	0.118	0.136	0.080	0.153	0.120	0.084	0.084
	30-Jun-2014	1.522	0.467	0.189	0.176	0.169	0.137	0.443	0.164	0.225	0.108	0.185	0.171	0.190	0.259	0.108	0.174	0.109	0.106	0.158	0.107	0.108
	30-Jun-2015	1.212	0.277	0.542	0.472	0.040	0.236	0.463	0.000	0.037	0.000	0.000	0.009	0.000	0.084	0.016	0.010	0.031	0.045	0.031	0.030	0.026
Change of Sovereign Risk DD (assuming 40% higher sovereign asset value volatility)	30-Jun-2010	-2.259	-2.243	-2.249	-2.239	-2.241	-2.240	-2.245	-2.238	-2.241	-2.239	-2.238	-2.239	-2.239	-2.240	-2.240	-2.238	-2.238	-2.238	-2.239	-2.239	-2.239
	30-Jun-2011	-2.496	-2.490	-2.497	-2.481	-2.481	-2.484	-2.488	-2.480	-2.479	-2.479	-2.480	-2.480	-2.482	-2.481	-2.481	-2.480	-2.480	-2.480	-2.480	-2.480	-2.480
	30-Jun-2012	-2.513	-2.505	-2.513	-2.504	-2.504	-2.505	-2.507	-2.504	-2.503	-2.504	-2.503	-2.503	-2.504	-2.503	-2.505	-2.503	-2.503	-2.504	-2.504	-2.503	-2.503
	30-Jun-2013	-6.089	-6.069	-6.087	-6.066	-6.065	-6.069	-6.074	-6.065	-6.068	-6.064	-6.066	-6.066	-6.065	-6.066	-6.065	-6.066	-6.063	-6.067	-6.065	-6.063	-6.063
	30-Jun-2014	-17.518	-17.334	-17.299	-17.298	-17.299	-17.292	-17.340	-17.295	-17.304	-17.286	-17.298	-17.296	-17.299	-17.309	-17.286	-17.296	-17.287	-17.286	-17.294	-17.286	-17.286
	30-Jun-2015	-14.645	-14.571	-14.601	-14.547	-14.539	-14.564	-14.578	-14.535	-14.539	-14.535	-14.535	-14.536	-14.535	-14.545	-14.537	-14.536	-14.538	-14.540	-14.538	-14.538	-14.538

Note: These matrices present the expected loss, the conditional implicit government guarantees, and the change of sovereign risk DD through OSIIs in the row conditonal on shocks from the financial sector, the non-financial corporate sector, and household Sector.

Appendix I

Let us assume a Cobb-Douglas production function with constant returns to scale and a constant elasticity of substitution between physical capital and labor equal to one:

$$Y(K,L) = A(t)K^{1-\alpha}L^{\alpha},$$

where Y is output, A is total factor productivity, K is physical capital, and L is labor. The share of physical capital in production is $(1-\alpha)$ and the share of labor in production is α. Profit maximization implies that the total remuneration of physical capital equals $\pi = (1-\alpha)PY$ and the total remuneration of labor is $wL = \alpha PY$, where w is the real wage and P is the price of output Y.

The part of the non-financial corporate sector balance sheet not accounted for by other asset holdings is equal to the present value of the after-tax physical capital income over a given time horizon T:

$$A_C = E_t \sum_{i=t}^{T} (1+r)^{-(i-t)} (1-\tau_C)\pi_i,$$

where A_C is the after-tax physical capital income, r the interest rate and τ_C is the marginal tax rate on income from physical capital. Similarly, the part of the household balance sheet not represented by physical and financial asset holdings is equal to the present value of after-tax labor income:

$$A_L = E_t \sum_{i=t}^{T} (1+r)^{-(i-t)} (1-\tau_L) w_i L_i,$$

where A_L is the after-tax labor income and τ_L is the marginal tax rate on wage income. After simple algebra, it results:

$$A_L = \frac{\alpha(1-\tau_L)}{(1-\alpha)(1-\tau_C)} A_C,$$

which allows to produce an internally consistent calibration of the household and non-financial corporate sectors' other asset holdings. As stated in the text, the financial components of balance sheets of the two sectors are obtained from public flow of funds statistics and the household's stock of residential property is taken from national accounts.

Appendix II

The short-term debt (BS047) and the long-term debt (BS051) from Bloomberg can have annual, semi-annual, and quarterly frequencies, and are not consistent. Therefore, to make the data consistent, four filtering rules are applied as follows:

I. Take any zero as missing data.

II. If the annual data exist and are not equal to the semi-annual/quarterly data, then let semi-annual/quarterly data be equal to the annual data. (Take annual data as trusted).

III. If the annual data do not exist, and both the semi-annual/quarterly data and the annual data exist at the previous and the next fiscal years, but semi-annual/quarterly data are very different from the corresponding annual data at the same previous and next fiscal years, then treat the semi-annual/quarterly as missing data. (To avoid unreliable semi-annual /quarterly data)

IV. If the annual data do not exist, and annual data exist at both the previous and the next fiscal years, but they are very different from the semi-annual/quarterly data, then treat the semi-annual/quarterly data as missing data. (To avoid unreliable and too choppy semi-annual /quarterly data between the previous and the next fiscal years)

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