EUROPEAN CENTRAL BANK

EUROSYSTEM

WORKING PAPER SERIES

NO 1599 / OCTOBER 2013

DISENTANGLING THE BOND-CDS NEXUS

A STRESS TEST MODEL OF THE CDS MARKET

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The refereeing process of this paper has been coordinated by a team composed of Gerhard Rünstler, Kalin Nikolov and Bernd Schwaab (all ECB).

The paper is released in order to make the research of MaRs generally available, in preliminary form, to encourage comments and suggestions prior to final publication. The views expressed in the paper are the ones of the author(s) and do not necessarily reflect those of the ECB or of the ESCB.

Acknowledgements
The opinions expressed in this paper are those of the authors and should not be regarded as those of the European Central Bank, the Eurosystem or the European Systemic Risk Board. We are grateful for useful comments to Philipp Hartmann, Martin Hellwig, Philippe Martin, Marco Pagano and Oreste Tristani, as well as to all members of the ESRB Advisory Scientific Committee and to all members of the ESRB CDS Expert Group, in particular Markus Brunnermeier, Laurent Clerc and Martin Scheicher.We thank seminar and conference participants at Deutsche Bundesbank, the European Commission Joint Research Center, the European Financial Management Association (EFMA), the Financial Engineering and Banking Society (FEBS), the French Economic Association, the INFINITI 2013 Conference, the International French Finance Association, CEQURA 2013 Conference and Sciences-Po.

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ISSN 1725-2806 (online)
EU Catalogue No QB-AR-13-096-EN-N (online)

Abstract

This paper presents a stress test model for the CDS market, with a focus on the interplay between banks' bond and CDS holdings. The model enables the analysis of credit risk transfer mechanisms, includes features of market and liquidity risk, and allows for contagious propagation of counterparty failures. As an illustration, we calibrate the model using sovereign bond and CDS data for 65 major European banks. The model simulation shows that, in case of a sovereign credit event, banks' losses due to direct and correlated bond exposures are significantly higher than losses due to CDS exposures. The main risk for CDS sellers is found to be sudden increases in collateral requirements on multiple correlated CDS exposures. Close-out netting considerably reduces the extent to which contagion may occur.

J.E.L. Codes: G21, H63, G15.

Keywords: Credit event, Credit default swap, Contagion, Collateral, Market risk, Liquidity risk, Stress test.

Non-technical summary

This paper presents a stress test model for the CDS market, with a focus on the interplay between banks' bond and CDS holdings. The model enables the analysis of credit risk transfer mechanisms, includes features of market and liquidity risk, and allows for contagious propagation of counterparty failures. One contribution of the model is that it explicitly incorporates several features proper to OTC derivatives markets, including collateralization, collateral netting agreements and close-out netting procedures in case of counterparty default. It also provides a modelling framework to assess the potentially risk-mitigating or risk-amplifying role of the CDS market in case of a credit event.

The model includes several channels through which an exogenous credit event may affect banks, focusing on the interplay between their bond and CDS holdings. Five transmission channels to banks are featured: *(i)* direct losses on bond holdings, *(ii)* write-downs on other (available for sale and held for trading) bond exposures, *(iii)* direct CDS repayments triggered by the simulated credit event, *(iv)* increased collateral requirements to cope with higher CDS spreads on other non-defaulted reference entities, and *(v)* contagious propagation of counterparty failures either through insolvency or illiquidity.

To provide an example with publicly available data, the model is calibrated using balance sheet data released by the European Banking Authority (EBA) on 65 major European banks related to the EU 2011 Capital Exercise. The dataset includes both sovereign bond and CDS holdings at the bank level for 28 European sovereign entities, while banks' bilateral CDS exposures are estimated and their market values simulated. To analyse the relative magnitude of each transmission channel to banks, we simulate exogenous credit event scenarios for a wide range of recovery rates.

We find several interesting results. First, following a simulated credit event, banks' losses due to direct and correlated bond exposures are significantly higher than losses purely due to CDS exposures and to counterparty risk on the CDS market, even though the relative share of each failure channel depends on the recovery rate. Given the home bias of banks' portfolios, potential losses on direct bond exposures are found to be more substantial for domestic banks, whereas potential losses through correlated bond exposures are more important for foreign banks. Second, after a simulated credit event, CDS repayments are overall found to remain small compared to banks' capital or liquid assets. Even though the observed distribution of net protection bought through CDS does not match the distribution of underlying sovereign bond holdings, we do not find significant failures due to the inability of some banks to honour their contractual repayments in case of a credit event. Instead, the main risk for CDS sellers is found to be sudden increases in collateral to be posted on multiple correlated exposures. This channel dominates when the recovery rate is high enough, and is more important if the pool of available collateral is correlated with the bond exposure experiencing a credit event. Third, contagion purely due to banks' CDS exposures is found to be limited in our simulations. Potential explanations include the effectiveness of collateral management schemes, the fact that none of the major dealers is found to fail, and that several types of interconnections between banks (interbank loans and deposits, other derivatives) are not accounted for. Fourth, the effectiveness of risk-mitigation mechanisms, including collateralization, collateral netting agreements and close-out netting is analysed. Overall, we find that collateral netting agreements increase banks' liquidity. Moreover, close-out netting in case of counterparty default is found to effectively reduce the extent of contagion in our model. Finally, we are not able to document redistributive effects of net CDS repayments in case of a simulated credit event, neither from banks with low exposure to highly-exposed banks nor from highly-liquid banks to banks with lower liquidity.

1 Introduction

Following recent credit events such as those of Lehman Brothers or Greece, and due to large notional CDS amounts outstanding (25.1 trillion USD in December 2012, according to the BIS), there have been growing concerns about the ability of the market to settle a major credit event and about its potential consequences to financial stability. Even though credit events have been studied empirically (see e.g. Coudert and Gex (2010)), so far no encompassing model has been developed and estimated to assess various consequences of a credit event on a financial system where banks are connected through their CDS exposures.

The contribution of this paper is twofold. First, from a theoretical perspective, it presents a stress test model for the CDS market. Whereas the stress testing literature on interbank networks is well-developed, it is close to non-existent as regards to derivatives markets. Our framework, while building on assumptions in the stress test literature (e.g. the exogeneity of shock scenarios), captures several features of the derivatives market which have not been modeled in earlier studies. Conditional on a credit event, the model features five loss and contagion channels: *(i)* direct losses on bond holdings, *(ii)* write-downs on other correlated bond exposures, *(iii)* CDS repayments triggered by the credit event, *(iv)* increased collateral requirements to meet higher CDS spreads on non-defaulted reference entities, and *(v)* contagious propagation of counterparty failures either through insolvency or illiquidity.

Second, from an empirical perspective, we provide an illustration of the working of the model by calibrating it using a unique, publicly available dataset released by the European Banking Authority (EBA) on 65 major European banks, comprising their sovereign bond and CDS holdings. We simulate a set of sovereign credit event scenarios and focus on the relative magnitude of each of the transmission channels for a wide range of recovery rates. Our main focus, however, is not on the sovereign dimension of the credit event. This choice is guided by data limitations for other types of bond and CDS holdings.

The modelling framework enables us to address two main concerns expressed about the potential fragility of the CDS market. First, concerns related to the ability of the market to settle a major credit event, which mainly stem from the large notional CDS amounts at stake. Despite the importance of gross notional amounts, we find net CDS repayments between banks to be relatively low compared to banks' capital and liquid assets. Such finding gives ground to the observation by Coudert and Gex (2010) about the historical resiliency of the CDS market at times defaults with large open interests had to be settled. By contrast, we show that the main vulnerability inherent to the CDS market, beyond a failure of a large market maker, is the potential inability of one or several CDS sellers to post collateral on multiple correlated CDS exposures whose spreads increase simultaneously. Besides, we are not able to document redistributive effects of net CDS repayments in case of a simulated credit event, neither from banks with low exposure to highly-exposed banks nor from highly-liquid banks to banks with lower liquidity.

Second, we address concerns regarding counterparty risk and the potential for contagion. A comprehensive survey on this issue has been provided by ECB (2009), whereas counterparty risk on OTC markets has been studied by Acharya and Bisin (2013). A stylized fact about the CDS market is that most institutions are both gross buyers and sellers, thus relying on receivables from third parties to honor their own repayments in case of a credit event. Our simulation results show little contagion due to the imputation of counterparty failures, partly due to the fact that the failing banks are not the major dealers on the CDS market. Whereas the effect of collateralization is relatively limited in the present empirical estimation, close-out netting mechanisms are found to reduce considerably the extent of potential contagion.

The paper has some limitations, which we would like to make clear upfront. First, similarly to the widespread practice in the stress testing literature, we make strong assumptions on the exogenous trigger scenario. While in the interbank literature it is common to assume a jump-to-default of one bank (see e.g. (Degryse and Nguyen, 2007; Gai et al., 2011; Memmel et al., 2012)), the paper assumes a jump-to-default of one sovereign entity. Therefore, our model is not fit for assessing rising stress on CDS reference entities in the absence of a credit event. Second, we focus on counterfactual simulations on a particular market segment only. Whereas existing papers restrict themselves on interbank loans and deposits, absent any other type of exposure (e.g. derivatives), we focus our attention on banks' bond and CDS exposures to produce counterfactual statements. Third, another limitation of our paper arises from data restrictions. Even though our dataset is unique—the most comprehensive publicly available dataset on banks' sovereign CDS and bond exposures to this date—the bilateral structure of CDS exposures has to be estimated. Thus, whereas our model is general and accomodates potentially any type of bond and CDS data, we need more assumptions to provide a full-fledged illustration of its working in this paper. However, assumptions on exposures are similar to those made in numerous papers (e.g. Upper and Worms (2004); Degryse and Nguyen (2007)).

Potentially due to data restrictions, very few comparable papers exist in the literature. Whereas the literature on contagion in the interbank market, recently surveyed by Upper (2011), is large, we are aware of only two papers modelling and investigating defaults on the CDS market. Heise and Kuhn (2012) propose a stochastic model in which financial institutions are interconnected through the CDS market. In their model, the CDS market can amplify contagion rather than mitigate it, due to the fact that CDS are primarily used to expand banks' loan books as they are thought to offload additional credit risk from their balance sheets. Furthermore, Markose et al. (2012) study the centrality of the main market participants and their potential "super-spreader" role in a network structure. Their results, based on data simulated from aggregate FDIC fill-ins, suggest that a set of institutions concentrating a large share of the activity, or "too interconnected to fail" should be taxed based on their centrality.

Our modelling framework differs from the above studies in several aspects. First, we do not focus on CDS exposures in isolation, but rather on the interplay between banks' CDS and bond holdings. Considering derivatives exposures without considering the portfolio of underlying credit exposures might lead to biased results, as one cannot then observe whether CDS are used for hedging the underlying positions, for macro hedging or for other purposes. Second, our framework captures several features inherent to derivatives markets that have not been accounted for in the existent academic literature. This includes collateralization through variation margins, as well as close-out netting in case of a counterparty failure. Moreover, our model is flexible and can accommodate different assumptions on collateral management (computation of margin requirements and pledgeable assets, rehypothetication and collateral netting). Third, rather than focusing on only one channel through which contagion may occur, our framework captures five channels with factors related to idiosyncratic and system-wide risks as well as to solvency and liquidity risks.

The rest of the paper is structured as follows. Section 2 presents the modelling framework. Section 3 describes the dataset, while Section 4 exposes the calibration. Section 5 shows several scenarios of sovereign credit events and simulation results. Section 6 explores the dynamics of the model with alternative collateral management schemes. Most tables and figures are presented in the appendices.

2 The modelling framework

2.1 Timeline

There is a set $\Omega = \{1, ..., n\}$ of financial institutions (or banks) indexed by i and a set $\Theta = \{1, ..., J\}$ of bonds indexed by j. The holdings by bank i of bonds emitted by entity j are denoted B_{ij}. In addition, each institution holds a CDS portfolio where the gross CDS notional sold by bank i to bank k on the reference entity j is denoted g^j_{ik}. The assets are financed both with equity K_i (also called "capital") and other liabilities.

The timeline of the model features an initial exogenous credit event. The sequence of events, which includes both direct and indirect effects of a credit event on financial institutions' balance sheets and interconnections, goes as follows:

- **(1)** An entity experiences a credit event. A recovery rate is observed on its debt and corresponding direct losses are imputed on banks' capital.
- **(2)** Banks' non-defaulted bond holdings are marked to market and written down, impacting the level of banks' capital.
- **(3)** CDS protection sellers are required to post more collateral to face overall higher CDS spreads, while the pledgeable value of their bond holdings is lower. If they cannot meet the collateral requirement, they fail from collateral shortage.
- **(4)** CDS payments are triggered on the entity that first experienced a credit event.
- **(5)** Banks failing at stages **(1)**, **(2)** and **(3)** are not able to honor their CDS payments. Their derivatives contracts with other banks on *all* reference entities are terminated using close-out netting and potentially leading to additional losses for their counterparties.
- **(6)** Losses from counterparty to counterparty are imputed until no more bank fails.

Next, the different phases of the model are discussed in more detail.

2.2 Imputation of losses

Two types of losses are induced by the initial credit event. First, any bond holding that cannot be recovered is imputed negatively on banks' capital. Denote $\bar{j} \in \Theta$ any initially defaulting reference entity and $RR_{\bar{j}}$ its recovery rate. A *scenario* is fully defined by $\{\bar{j}, RR_{\bar{j}}\}$. Any bank i is insolvent if:

$$K_i - B_{i\bar{j}}(1 - RR_{\bar{j}}) \leq 0 \tag{1}$$

In addition to direct losses, banks face indirect losses on their other bond holdings. There is ample evidence for the co-movement of similar asset classes in response to a shock affecting only one of them. Such spillovers for sovereign entities have been documented (Gande and Parsley, 2005).

Denote p_j the market price of a one-unit bond j. To estimate the change of other bonds' prices induced by a credit event of $\bar{j}$, we assume a jump of $p_{\bar{j}}$ at the time of the simulation to $p^{RR}_{\bar{j}}$, the no-arbitrage price implied by the assumed recovery rate. Assuming the recovery value is paid immediately, the market price of a defaulted bond with a one euro face value must exactly equal the recovery rate. Thus, $p^{RR}_{\bar{j}} = RR_{\bar{j}}$.

For a bank i holding B_{ij}, its write-down equals $\epsilon_j \alpha_{i,j} B_{ij}$, where ϵ_j is the change in price of bond j conditional of $\bar{j}$ jumping to default and where $\alpha_{i,j}$ is the share of its bond exposure to j that is either available for sale or held for trading (therefore marked to market). The remaining share $(1-\alpha_{i,j})\,B_{ij}$, held-to-maturity, is not marked to market according to the prevailing accounting standards, and is therefore not assumed to suffer from any immediate write-down. The empirical estimation of ϵ_j is described in the section on calibration. After the imputation of all losses on bond exposures, a bank is *insolvent* if:

$$K_i - B_{i\bar{j}}(1 - RR_{\bar{j}}) - \sum_{j \in \Theta_{-\bar{j}}} \epsilon_j \alpha_{i,j} B_{ij} \leq 0 \tag{2}$$

2.3 CDS holdings and collateral requirements

CDS are now introduced. Depending on their observed distribution among banks, they may either play a mitigating or an amplifying role in the case of credit event.

For each reference entity $j \in \Theta$, there exists a $n \times n$ matrix of bilateral gross notional CDS sold on the reference entity j. Each of its components g^j_{ik} is the gross notional sold by bank i to bank k on the reference entity j. $g^j_{ii} = 0$ must hold for all i. The matrix of net protection sold, whose components are denoted n^j_{ik} is given by:

$$n^j_{ik} = \begin{cases} 0 & \text{if} \qquad g^j_{ki} > g^j_{ki} \\ g^j_{ik} - g^j_{ki} & \text{otherwise.} \end{cases} \tag{3}$$

Each CDS exposure in our framework is assumed to be collateralized and only collateral posting by protection sellers is considered. According to the ISDA, well-above 90% of the transactions on CDS are collateralized (ISDA, 2012a). The fact that a transaction is collateralized, however, does not imply that it is *fully* collateralized. In conformity with a widespread market practice, a CDS position is assumed to be fully collateralized if the amount of collateral required to be posted by the selling institution i to the buying institution k is *(i)* the market value of the contract in case it is negative for i or *(ii)* zero if it is positive for i.

Partial collateralization is nevertheless a current market practice. Only a fraction τ^j_{ik} of any deal between i and k on a CDS on reference entity j is assumed to be collateralised. τ is positive and here constrained to be below one, i.e. we do not account for the possibility of over-collateralisation. Furthermore τ is not market-specific but exposure-specific so as to account for the diversity of market practices and of differences in perceived counterparty risk. It is assumed to be fixed by contract, so that it does not increase with the CDS spread q^j. Finally, we assume reciprocity in bilateral transactions, i.e. $\tau^j_{ik} = \tau^j_{ki}$.

Denote $V^j_{ik,t+h}\left(\lambda^j_{t+h}, q^j_t\right)$ the market value at date $t+h$ of a CDS contract signed at date t between counterparties i and k on reference entity j. From the buyer's perspective, it is the difference between the present value of the default-contingent payment and that of the future stream of premia. It depends on the agreed-upon premia q^j_t to be paid annually by the protection buyer per unit of notional amount and of the prevailing default intensity λ^j_{t+h}. In the following, $V^j_{ik,t+h}$ consistently denotes the market value for the buyer i (from seller k) of a CDS on the reference entity j. The value for the seller is given by $V^j_{ki,t+h} = -V^j_{ik,t+h}$.

Any bilateral exposure n^j_{ik} between any i and k may result from several offsetting or reinforcing transactions as it is common in the CDS market, each of them contracted at a different point in time and having a different present market value. The net market value for i of a bilateral exposure with k on reference entity j is given by the sum of all positive and negative market values of the non-matured transactions performed in the past and is denoted $\tilde{V}^j_{ik,t+h}$, where $\tilde{V}^j_{ik,t+h} = \sum_{v<h} V^j_{ik,t+h-v}$.

The amount of collateral to be posted at some date t by any institution i to any institution $k \neq i$ on any reference entity j, denoted c^j_{ik} is then:

$$c^j_{ik} = \begin{cases} 0 & \text{if} \quad \tilde{V}^j_{ik,t+h}\left(\lambda^j_{t+h}, q^j_t\right) < 0 \\ \tau^j_{ik}\tilde{V}^j_{ik,t+h} & \text{if} \quad \tilde{V}^j_{ik,t+h}\left(\lambda^j_{t+h}, q^j_t\right) > 0 \end{cases} \tag{4}$$

The amount c^j_{ik} corresponds only to variation margins. Initial margins do not change with fluctuations in the market values of portfolio and are therefore not modeled.

If there were no collateral netting agreements across reference entities - i.e. if both parties were to post collateral to one another - the total amount of collateral posted by any bank i to $k \neq i$ would be equal to $\hat{c}_{ik} = \sum_j \mathbf{1}_{\{\tilde{V}^j_{ki,t+h}>0\}} \tau^j_{ik}\tilde{V}^j_{ki,t+h}$, where $\mathbf{1}_{\{\}}$ denotes the indicator function. Nevertheless collateral netting agreements became very popular among financial institutions after 2000 as documented by ISDA (2012a). In the current framework, we assume collateral netting between all CDS on reference entities in Θ. With collateral netting, the total amount of collateral to be posted by i to k on all CDS trades is:

$$\begin{aligned} c_{ik} &= \max\left\{0, \sum_{j=1}^{J} \tau^j_{ik}\left[\mathbf{1}_{\left\{\tilde{V}^j_{ki,t+h}>0\right\}}\tilde{V}^j_{ki,t+h} - \mathbf{1}_{\left\{\tilde{V}^j_{ik,t+h}>0\right\}}\tilde{V}^j_{ik,t+h}\right]\right\} && (5) \\ &= \max\left\{0, \hat{c}_{ik} - \hat{c}_{ki}\right\} && (6) \end{aligned}$$

This implies that in any combination of two banks, only one is pledging collateral *vis-a-vis* the other. Finally, the total amount of collateral to be posted by bank i at any time to all counterparties and for all reference entities is equal to:

$$c_i = \sum_{k\in\Omega\setminus\{i\}} c_{ik} \tag{7}$$

Denote $\bar{C}_i$ the pledgeable value of the assets A_i of institution i. According to ISDA (2012a), more that 90% of collaterals on OTC markets are cash and sovereign bonds. The pledgeable value of a sovereign bond is typically smaller than its face value, as an haircut is applied. No haircut applies on cash collateral. The pledgeable value of the assets of institution i is:

$$\bar{C}_i = \sum_m a_{mi}\left(1 - h_m\right) \tag{8}$$

, where $h_m \in [0;1]$ is the haircut demanded on the m-th asset a_m, and where we ensure that $\sum_m a_{mi} = A_i$ for all i. Thereafter the pledgeable value of bond holdings is affected by credit events which affect the creditworthiness of sovereign bonds. Importantly, we do not include collateral received in $\bar{C}_i$, i.e. we do not allow for rehypothecation.

In this framework, a bank is said to be liquid at some point in time if it is able to meet its margin calls. In contrast, a bank is *illiquid* and fails from *collateral shortage* if:

$$c_i > \bar{C}_i \tag{9}$$

Such definition of illiquidity ignores other funding issues that lie outside the scope of this model. Nonetheless, the difference between failures from *insolvency* - the value of an institution's assets falling below the value of its liabilities - and failures from *illiquidity* -

the inability to meet collateral calls - is important to highlight, as the policy implications arising from one or another are of different nature.

2.4 Margin calls

At this stage, we add two joint mechanisms that possibly contribute to the spread of the contagion once the credit event for a reference entity $\bar{j}$ occurs. First, the spreads of all CDS on reference entities $j \in \Theta_{-\bar{j}}$ might increase, thereby increasing collateral requirements on net CDS sold on all - or on a subset of - non-defaulted reference entities. Second, the value of the pledgeable collateral decreases.

We assume haircuts to be fixed on all asset classes, and model instead the decreasing value of the assets on which these haircuts are applied. The total increase in collateral to be posted by any bank i is given by:

$$\Delta c_i = \sum_{k \in \Omega \setminus \{i\}} \max \left\{ 0, \sum_{j=1}^{J} \Delta \tilde{V}^j_{ik,t+h} \left(\bullet, \Delta q_j \right) \tau^j_{ik} \left[\mathbf{1}_{\{\tilde{V}^j_{ki,t+h} > 0\}} - \mathbf{1}_{\{\tilde{V}^j_{ik,t+h} > 0\}} \right] \right\} \tag{10}$$

, where $\Delta q^{\bar{j}}$ is the change of the price of a CDS of the reference entity j conditional on $\bar{j}$ jumping to default. Its estimation is discussed in the section on calibration.

Parallel to this increased collateral requirement, the value of the pledgeable assets falls as a result of direct losses and write-downs on pledgeable bonds. The value of the pledgeable collateral drops from $\bar{C}_i$ to:

$$\bar{C}'_i = \bar{C}_i - B_{i\bar{j}} \left(1 - RR_{\bar{j}} \right) - \sum_{j \in \Theta_{-\bar{j}}} B_{ij} \left[1 - \epsilon_j \alpha_{i,j} \right] \left(1 - h_j \right) \tag{11}$$

In equation 11, the decrease in the value of the collateral pool depends on its composition. If the collateral pool of a bank is composed to a large extent of bond $\bar{j}$ or of other bonds positively correlated with $\bar{j}$, then it might shrink as a result of particular scenarios.

For a bank i to be liquid once the increased collateral requirements and the shrinkage of the pool of pledgeable assets are accounted for, condition 12 needs to hold:

$$\bar{C}'_i \geq c_i + \Delta c_i \tag{12}$$

In case it does not hold, bank i fails.

2.5 CDS repayments and counterparty risk

CDS repayments are paid out of the pool of cash and liquid assets that is also used to post collateral, i.e. $\bar{C}'_i$. If no bank failed, then any bank i is able to honour its scheduled CDS repayments if:

$$\bar{C}'_i - \left(c_i + \Delta c_i \right) + \sum_k n^{\bar{j}}_{ki} \geq \sum_k n^{\bar{j}}_{ik} - \sum_k c^{\bar{j}}_{ik} \tag{13}$$

The left-hand side of equation 13 corresponds to the amount of cash and liquid assets that has not yet been pledged as collateral plus the net repayments to be expected from all counterparties k. Its right-hand side corresponds to the sum of what has to be paid less the collateral that has already been posted on those positions to cover for the increased credit risk. If condition 13 does not hold for bank i, it fails from *contagious illiquidity*.

Until now, no counterparty risk has been accounted for in this framework. We here propose a model of counterparty failures replicating several real-world features of derivatives market. When studying the CDS market, taking counterparty risk into account is of particular importance given the substantial difference between gross and net notional outstandings. If each institution is relying on repayments from other institutions to make its own payments, then one bank's failure to pay within the whole chain of obligations may entail a cascade of contagious bank failures.

To model counterparty risk and the potential for contagious failures, we use a sequential procedure that accounts for the specificities of the derivatives market, in particular the *close-out netting* of all derivatives' deals in case of a counterparty failure. Close-out netting refers to the termination procedure of all derivatives transactions concluded under a given contract, usually the ISDA Master Agreement. Three steps are involved : *(i)* the termination of all obligations contracted between a failing and a non-failing party, *(ii)* the calculation of the replacement value of each of the deals, and *(iii)* the summation of all positive and negative replacement values in order to derive a single net payable or receivable. A clear description of the functionning of close-out netting can be found in Mengle (2010). The *ex post* advantages of close-out netting for risk mitigation are clear. If each transaction were to be considered as a separate contract, the non-failing party would have to repay immediately all the replacement values of its out-of-the-money derivatives deals with the failing party, and then to wait for months before receiving some part of its ongoing transactions that were in-the-money.

Another feature of our framework is that, during the resolution procedure, banks might fail from contagious failures through either a solvency channel or a liquidity channel. The *contagious insolvency* channel comes from losses due to counterparty failures that drive the capital of a bank below zero. The *contagious illiquidity* channel is due to a bank being unable to deliver its own CDS repayments in case some of its counterparties do not repay them. The combination of these two channels implies that, when the default imputation procedure stops, all non-failed banks *(i)* have positive equity and *(ii)* have been able to honour all repayments imposed by the resolution scheme. We must mention here that our modelling framework does not feature contagion through other types of interbank exposures.

Before contagion, the set of failed banks is given (by equations 2 and 12) as the union of the two sets of insolvent and illiquid institutions. When a bank k fails as a consequence of a credit event affecting $\bar{j}$, the losses for each of its counterparties $i \in \Omega \backslash \{k\}$ are twofold. First, contingent payments due to the failure of $\bar{j}$ cannot be honoured. Second, all other derivatives contracts, including CDS on all reference entities other than $\bar{j}$, are terminated. Given the close-out netting mechanism, those two losses can be considered at once.

As regards CDS, the termination of all CDS contracts is considered, not the termination of the particular contract between i and k on reference entity $\bar{j}$. Similarly, we consider collateral pooled across all positions between any two institutions. For all i, k and j, denote $\tilde{V}^j_{ik,def} = \tilde{V}^j_{ik,t+h} + \Delta\tilde{V}^j_{ik,t+h}$ the market value of a transaction once the credit event affecting $\bar{j}$ occured. A particular case is that of $\tilde{V}^{\bar{j}}_{ik,def}$, which equals the CDS repayments that have to take place between i and k, and which depends on the recovery rate $RR_{\bar{j}}$ on the defaulted bond.

Whether the failure of k creates a liability of k vis-a-vis i or the contrary is determined by the sign of $\tilde{V}_{ik,def} = \sum_j \tilde{V}^j_{ik,def}$. Two cases may arise. If $\sum_j \tilde{V}^j_{ik,def} < 0$, i.e. if the market value of all derivatives positions between i and k is negative for the non-failed party i, then it has to repay $\sum_j \tilde{V}^j_{ki,def}$ to k in the due execution of the contract. It is paid with available cash or with highly liquid securities similar to those used as collateral. A fraction τ_{ik} of this position being already collateralized, bank i must repay only a share $1-\tau_{ik}$ of this net payable. If it is not able to do so, it fails from *contagious illiquidity.*

In the second case, where $\sum_j \tilde{V}^j_{ik,def} > 0$, then the failed party k has a liability *vis-a-vis* i that it cannot honour in full. The party i can recover the collateral that k posted before the jump-to-default. In addition, the recovery rate on the uncollateralized part of the exposure is here assumed to be exogeneously given and equal to RR_k. The overall recovery value for i is then given by:

$$\min\left\{1, \frac{\bar{C}'_k}{c_k+\Delta c_k}\right\} c_{ik} + (1-\tau_{ik})\, RR_k \sum_j \tilde{V}^j_{ik,def} \tag{14}$$

The first term in equation 14 corresponds to the collateral received by i from k. In case k was liquid but failed from insolvency, it delivered all collateral due, i.e. c_{ik}. On the contrary, if it failed for insolvency, it was only able to deliver a fraction $\bar{C}'_k / (c_k+\Delta c_k)$ of the collateral c_{ik} it was supposed to post. The second term corresponds to the uncollateralized part of the counterparty risk on which a counterparty-specific recovery rate is applied.

The total loss for counterparty i due to the termination of all its CDS contracts with k is equal to

$$(1-\tau_{ik})\,(1-RR_k)\sum_j \tilde{V}^j_{ik,def} \tag{15}$$

This loss is imputed on K_i, the capital of institution i, and for all failing counterparties k. If it is large enough and drives K_i below zero, then i fails from *contagious insolvency.*

The sequential procedure for the imputation of counterparty failures then works as follows:

- **(1)** The set of institutions failing conditional on a scenario is known *ex ante*. Losses due to partial CDS repayments and termination of other contracts are imputed to all non-failing institutions. Their net value (i.e. the net value of their equity) is computed.
- **(2)** If all net values are positive, the procedure stops. On the contrary, all institutions for which $K_i < 0$ fail from contagious insolvency. For failed institutions, an endogenously determined recovery rate is computed (the amount of their scheduled repayments that they will be able to honour).
- **(3)** All institutions need to honour their CDS repayments, either in full (if non-failed) or partially (if failed). If a not-yet-failed institution does not hold enough cash and liquid assets to repay for the protection it sold (equation 13), it fails from contagious illiquidity.

Failures at stages **(2)** and **(3)** might entail losses for other institutions. All CDS repayments due to the failure of $\bar{j}$ have been settled, partially or in full, during stage **(3)** of this first iteration. The only losses that can be imputed at this stage are those linked to the termination of other derivatives contracts with positive value. We iterate on the previously described steps.

- **(4)** All institutions failling at stage **(2)** and **(3)** terminate all their CDS contracts. These losses are imputed on the capital of the smaller set of non-failed institutions.
- **(5)** Iterate stage **(4)**. The procedure stops either when all banks are bankrupted or when all non-failed institutions have a positive equity value after imputation of all losses due to the failure of their counterparties.

3 The dataset

Our main dataset has been released by the European Banking Authority (EBA) in December 2011 as part of its EU Capital Exercise. It is unique as it includes both the bond holdings and the corresponding gross CDS exposures for the 65 major European banks listed in table 13. This paper is the first academic paper to exploit this feature of this data. Bond and CDS data are available for 28 European sovereigns[4], where sovereign bond holdings are broken down by maturity and by type of holding ("held to maturity", "available for sale" or "held for trading"). Due to data availability, we are therefore constrained to illustrate the working of our model with on one type of credit event, namely sovereign credit events. Our focus, however, is not on scenarios as such, but on the relative magnitude of each transmission channel. Finally, the dataset also includes extensive information on the capital composition of each institution and is complemented with additional public price and balance sheet information extracted from Bloomberg.

Regarding the quality of the data, one of its features is the high degree of harmonisation across all European countries (see EBA (2011)). Regarding CDS exposures, a reassuring feature of the data is that the notional amount of CDS bought and sold by the 65 sample banks represent around one half of the notional bought and sold worldwide for each reference entity. For the four countries for which we simulate a sovereign credit event, the ratios of CDS sold by EBA banks to total worldwide notional amounts (retrieved from DTCC' Trade Information Warehouse public data) are 51% for Irish CDS, 49% for Italian CDS, 56% for Portuguese CDS and 44% for Spanish CDS. Descriptive statistics on reference entities are presented in table 8. Overall, the sample represents a gross notional of 346 billion euros for CDS sold.

4 Calibration

4.1 Bond exposures and capital

We use total net bond exposures to calibrate B_{ij} for all i and j. Net exposures differ from gross exposures in that they account for provisions. In addition to bonds, they may include loans and advances, which are also assumed to experience the credit event. The capital K_i of each institution is calibrated as its common equity. Such a definition of capital excludes hybrid instruments, ordinary shares subscribed by governments or existing government support measures, whose value would be uncertain in case of credit event.

4.2 Bilateral CDS exposures

Our dataset contains notional CDS exposures at a bank level, but not the full matrix of bilateral exposures. For each reference entity, we estimate such a matrix through an augmented entropy maximization method. Simple entropy maximisation has been widely

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[4] These sovereigns are : Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the United Kingdom.

used in the literature to estimate interbank loans and borrowings and to assess contagion in the absence of observed interbank lending patterns (see Upper and Worms (2004)). The ability of this method to fit actual interbank loans exposures is discussed in Mistrulli (2011).

A first step consists of approximating the share of the CDS exposure of the sample banks that is held by other sample banks. For each reference entity, we retrieve the global CDS gross notional amount from the DTCC and compute the share of which our sample banks account for. The share of the exposure of our sample banks *vis-a-vis* other sample banks is assumed to be equal to this ratio.

The entropy maximization method is not described here in full details, as a full derivation of the optimization problem can be found in Wells (2004). It is solved numerically by using the RAS-algorithm (Blien and Graef, 1991). One drawback of the entropy maximisation method is that the estimated network is not sparse as links of even small magnitude are estimated between any two institutions with a strictly positive aggregate exposure. We overcome this shortcoming by imposing a lower bound on the notional value of each bilateral exposure. Once the non-sparse matrix estimated by simple entropy maximization is obtained, all exposures whose notional value g_{ik}^{j} is below $\bar{g} = 5$ million euros are dropped and $g_{ik}^{j} = 0$ is imposed instead [5]. The bilateral exposure matrix is then re-estimated so that the cross-entropy between this sparse matrix and the outcome matrix is minimized, under the constraint that the bilateral buy and sell exposures sum up to their true value for each bank. This augmented method has two advantages. First, it generates sparse matrices. Second, we can run the whole simulation exercise for various values of $\bar{g}$, i.e. different densities of the CDS network for an given aggregate notional exposure. The results presented later on the number of failures and on the relative share of each failure channel are found to be robust to changes in $\bar{g}$.

4.3 CDS portfolios

Bilateral exposures on the CDS market typically result from several offsetting or reinforcing transactions. In order to compute the market value of each particular exposure of a bank i vis-a-vis its counterparty k, one needs to know the dates at which each of the transactions that make up the exposure have been opened, as well as their maturity. Such data is not available in the dataset and must be simulated. Consequently, all CDS are assumed to have a 5-years maturity, i.e. the most common maturity on the market (see Chen et al. (2011)). Any net bilateral exposure between two banks i and k is assumed to result from multiple (potentially offsetting) trades, each of them having an average notional amount equal to 8 million euros [6]. For each reference entity, a numerical algorithm ensures that the number of transactions from which each position results and its notional value are drawn from the distributions detailed in table 1, but also that the resulting gross and net positions equal those available in the data.

Each simulated transaction is randomly assigned a date (the time at which the CDS is bought) drawn from a truncated Gaussian density function with support $[-5; 0]$. Its mean, equal to -1.5, is such that the average remaining maturity of a contract is 3.5

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[5] Chen et al. (2011) showed that the median CDS of a trade on the CDS market is about 8 million euros. Even though the network becomes denser when a lower cut-off threshold is imposed, our results regarding the risk propagation channels are robust and remain unchanged to a large extent when a different threshold is imposed. This is due to the fact that contagion purely due to CDS exposures is relatively limited in our simulations (see below).

[6] The average notional amount of a trade is calibrated using public data provided by DTCC. On a weekly basis, DTCC releases data on the weekly transcation activity, including the gross notional amount traded and the number of trades, for 1000 reference entities.

Variable	**Distribution**	**Calibration**
Average transactions number	Power law	Scale = 2
Average transaction notional	Log-normal	$\mu = 8$ Mn, $\sigma = 2$ Mn
Date of transaction	Truncated Gaussian	Support $[-5; 0]$ $\mu = -1.5$ Mn, $\sigma = 1$

Table 1 – CALIBRATIONS FOR CDS PORTFOLIO SIMULATIONS

years. The randomly drawn dates are then matched with particular trading days and with the corresponding price data, therefore enabling the computation of market values.

4.4 Market values of CDS portfolios

The computation of the market values of CDS portfolios is based on the valuation method exposed in O'Kane and Turnbull (2003). At any time t_v, the market value of a CDS position is equal of the current market value of the remaining protection minus the expected present value of all premia to be paid until default or maturity, whichever is sooner. For the CDS buyer, it can be written as :

$$V(t_v, t_m) = [q\,(t_v, t_m) - q\,(t_0, t_m)] \times RPV01\,(t_v, t_m) \tag{16}$$

, where $q\,(t_0, t_m)$ is the contractual spread, $q\,(t_v, t_m)$ the spread at the time of valuation and $RPV01\,(t_v, t_m)$ the risky present value of one basis point paid on the premium leg of the CDS contract until either default or maturity. The calculation of $RPV01\,(t_v, t_m)$ requires a model accounting for the probability of the reference entity surviving at each premium payment date. The term structure of arbitrage-free hazard rates is obtained from CDS of different maturities through a bootstrapping procedure.

4.5 Pledgeable assets

We consider only cash and government securities to be usable as pledgeable collateral $\bar{C}_i$. According to ISDA (2012b), these two asset classes represent far above 90% of the collateral used in the OTC derivatives markets. We obtain data on banks' cash from Bloomberg. To obtain $\bar{C}_i$, haircuts have to be applied on sovereign bonds included in the pool of free collateral. Haircuts on sovereign bonds typically depend on the rating of the issuer as well as on the maturity of the pledged bond. For each sovereign entity, ratings are retrieved from Fitch Ratings as of 30 September 2011. Countries are classified by ratings into three buckets : from AA- to AAA (prime and high grade), from BB- to A+ (medium grade) and from D to BB+ (speculative grade or defaulted). Haircuts for the higher bucket (broken down by maturity) are obtained from CME (CME, 2012). Haircuts for the medium bucket are assumed to be twice higher than haircuts for the higher bucket. Bonds in the lower bucket are assumed not to be pledgeable, in conformity with the usual market practice. Haircuts by rating and maturity are presented in table 2.

$\bar{C}_i$ is then the sum of cash holdings plus the pledgeable value of sovereign bonds. Whereas cash is valuable as collateral in full amount, part of the sovereign bond holdings are assumed to be encumbered, i.e. pledged as collateral in other transactions (e.g.

Rating range	Countries	0-5 years	5-10 years	$>$ 10 years
AA- to AAA	AT, BE, CZ, DK, FI, FR, DE, NE, NO, SL, SP, SW, UK	6%	7,50%	9%
BBB- to A+	BU, CY, EE, HU, IR, IT, LT, LN, MT, PL, PT, RO, SK	12%	15%	18%
D to BB+	GR, IC	Not pledgeable	Not pledgeable	Not pledgeable

Table 2 – HAIRCUTS ON PLEDGEABLE ASSETS BY RATING AND MATURITY. Ratings are as of 30 September 2011, by Fitch Ratings.

repurchase agreements, covered bonds, etc.). The ratio of asset encumbrance is assumed to be 50%.

4.6 Collateralisation level

The ISDA (see ISDA (2012a)) provides data on the average collateralization level of OTC derivatives transactions by type of counterparty. For banks and broker-dealers, the average collateralization level was 78.6% in 2011. Given that the sample consists of major European banks, we assume each τ_{ik}^{j} to be drawn out of a uniform distribution with support $[0.6; 1]$.

4.7 Tail dependences for bonds and CDS

Tail correlations of bond prices are estimated from weekly price data retrieved from Bloomberg. We retrieve prices (excluding accrued interest between coupon dates) of 5-years government bonds maturing in 2012. Therefore, we hold between 3 and 4 years-long time series ranging from the emission of a bond to the date of the stress scenarios (30 September 2011).

The estimation of tail dependences gives rise to a large econometric literature. Widely used methods include quantile regressions or copula models. In this paper, the price change of bonds $j \neq \bar{j}$ in response to a jump of $\bar{j}$ to its recovery value is estimated using a copula framework. Given our later focus on jumps to default, the t-copula (described in Demarta and McNeil (2005)) is chosen for its ability to account for statistically extreme events. Several papers have shown that the empirical fit of the t-copula is generally superior to that of the Gaussian copula for modeling financial returns (see Mashal and Zeevi (2002) or Breymann et al. (2003)). The bivariate copula density between the prices of bonds j and k is given by $C\left(u_j, u_k\right) = F\left(F_j^{-1}\left(u_j\right), F_k^{-1}\left(u_k\right)\right)$, where F_j^{-1} and F_k^{-1} are the quantile functions of the margins. The parameters for the copula that best fit the data are obtained by maximum likelihood. Given a drop $\epsilon_{\bar{j}} = p_{\bar{j}} - p_{\bar{j}}^{RR}$ in the price of bond $\bar{j}$, the correlated drop (or eventually rise) of the price of any bond j at the quantile κ, denoted ϵ_j, is obtained according to:

$$\epsilon_j = \rho_{\bar{j}j}\epsilon_{\bar{j}} + \sqrt{1 - \left(\rho_{\bar{j}j}\right)^2} F^{-1}\left(\kappa\right) \tag{17}$$

, where $\rho_{\bar{j}j}$ is the correlation between the spreads of price of bonds j and $\bar{j}$. The estimated correlation parameters for the t copula are presented in table 10, together with the unconditional correlations (table 9). As can be seen from the table, high correlations are estimated between the bond prices of stressed countries.

The tail dependences between CDS prices on reference entities $\bar{j}$ and j are estimated using the same copula framework from weekly observations of senior 5-year CDS spreads. We assume a Student t distribution for the margins of the CDS spreads in first-differences. Given a price rise $\Delta q_{\bar{j}}$, the response of the CDS spread on reference entity j is given by:

$$\Delta q^{j} = \Delta q^{\bar{j}} \rho_{\bar{j}j}^{CDS} + \sqrt{1 - \left(\rho_{\bar{j}j}^{CDS}\right)^{2}} F^{-1}(\kappa) \tag{18}$$

, where $\rho_{\bar{j}j}^{CDS}$ is the correlation between the spreads of CDS on reference entities j and $\bar{j}$. The first difference (i.e. the CDS returns) of each series is then filtered by an ARMA-GARCH model, using an ARMA(2,2) and a GARCH(2,2) model. The residuals are then fed to the t copula. The unconditional correlation coefficients together with the estimated correlation parameters for the t copula are presented in tables 11 and 12. High CDS return correlations are observed between stressed countries.

For the estimation of both tail correlations, we test two alternatives to the t copula, a Gaussian copula and Archimedean copulas. The pattern of estimated correlations remains unchanged to a large extent. As a robustness check, the whole set of simulations has been re-run for the three copula specifications. The main results, regarding the number of failures and the relative magnitude of each default channel, do change only marginally. The difference between the results presented below and the results for alternative specification is of at most one failure[7].

4.8 Recovery rate

The recovery rate $RR_{\bar{j}}$ on the bond $\bar{j}$ experiencing the credit event is a key parameter of the model, as it impacts directly the loss incurred on bond holdings but also the magnitude of jumps of both other bonds' value and of CDS spreads. Data on recovery rates are scarce due to the relatively rare occurrence of sovereign credit events. Sturzenegger and Zettelmeyer (2005) or Moody's (2012) more recently document case-specific factors leading to a high variability of recovery rates. 30-days post-default prices of bonds as a percentage of the par value during the last 15 years range from 18 in Russia (in 1998) to 95 in Dominican Republic (in 2005). Over the sovereign defaults studied by Moody's (2012), the average recovery rate lies around 53%. In the analysis, we study the relative importance of each contagion channel under a wide range of recovery rates.

5 Simulation of credit events and results

We simulate credit events of four European countries, i.e. Ireland, Italy, Portugal and Spain and we restrict ourselves to simulated jumps-to-default of one particular country

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[7] The results obtained with alternative specifications are not presented here. They are available upon request.

at the time. The date of the stress scenarios is 30 September 2011 (due to available data[8]).

5.1 Bank failure channels

Table 3 summarizes the main results concerning the relative magnitude of each bank failure channel identified in the modelling framework, whereas tables 14 to 17 present the number of bank failures and the relative magnitude of each of the failure channels for a wide range of recovery rates.

	Recovery rate	**Direct bond loss**	**Correlated bond losses**	**Collateral shortage**	**Contagious insolvency**	**Contagious illiquidity**	**Total**
Ireland	0,1	0	10 (83%)	2 (17%)	0	0	12
	0,5	0	0	3 (100%)	0	0	3
	0,9	0	0	0	0	0	0
Italy	0,1	6 (24%)	17 (68%)	2 (8%)	0	0	25
	0,5	1 (8%)	10 (77%)	2 (15%)	0	0	13
	0,9	0	0	2 (100%)	0	0	2
Portugal	0,1	3 (43%)	2 (29%)	2 (29%)	0	0	7
	0,5	0	1 (33%)	1 (33%)	0	1 (33%)	3
	0,9	0	0	0	0	0	0
Spain	0,1	5 (21%)	17 (71%)	2 (8%)	0	0	24
	0,5	2 (15%)	9 (69%)	2 (15%)	0	0	13
	0,9	0	0	3 (100%)	0	0	3

TABLE 3 – RELATIVE MAGNITUDE OF THE BANK FAILURE CHANNELS. The table shows the number of failed banks (common equity<0), while the percentages in parentheses indicate the relative share of each failure channel. Please note that percentages may not sum up to 1 due to rounding.

For all simulated countries, the number of bank failures and the relative importance of each bank failure channel is found to depend importantly on the bond recovery rate. When the recovery rate is low, bank failures due to insolvency play a predominant role, and are mainly driven by failures due to write-downs on correlated bond exposures. Failures due to direct losses on bonds increase in number when the recovery rate decreases, but are limited in most cases to domestic banks (as indicated by the red figures in parentheses in tables 14 to 17). When the recovery rate increases, the relative importance of bank failures due to insolvency decreases, whereas failures due to collateral shortage become more prominent. For higher recovery rates, only a few (if any) failures of banks due to their inability to meet collateral calls are observed. It is important to note that we assume that banks have not hedged the interest rate risk in their bond portfolios that are subject to mark-to-market, and thus the estimated losses on correlated bond exposures are to be seen as the upper bound.

Regarding CDS-related bank failures, interestingly, we find the collateral shortage on the CDS market to be a more important vulnerability than direct CDS repayments for the settlement of contracts on the reference entity affected by the credit event. The importance of the collateral shortage channel is magnifided for banks, which have a relatively high net CDS exposure compared to their pool of liquid assets, and subsists

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[8] In October 2012, the EBA released the final results of the EU Capital Exercise, showing that the European Banks involved in the exercise had increased their capital by more than 200 billion euros between December 2011 and June 2012. At the same time, banks had increased their bond exposures, particularly in the countries under market stress. Unfortunately, the latter data disclosure by the EBA does not include banks' sovereign CDS positions.

in most scenarios even for high recovery rates. In contrast, we find that even though not all CDS repayments are paid in full, they are found not to trigger contagion. This result is discussed in further details below.

5.2 The distribution of capital ratios

Tables 18 and 19 show the percentage of banks that have respectively a ratio of common equity over risk-weighted assets below 0% and below 4.5% (i.e. undercapitalisation according to Basel III threshold). In case of a Spanish or Italian credit event with low recovery rates, up to one third of the European banking system may end up with negative equity and about two third may be under-capitalised, whereas the consequences of an Irish or Portuguese credit event are more limited. Moreover, failing or undercapitalised banks are mainly smaller banks (in terms of risk-weighted assets) as the share of defaulted banks is steadily higher than the share of defaulted assets.

How are capital shortfalls brought about ? The model allows losses to be incurred through three different types of channels, namely *(i)* direct losses on the defaulted bonds, *(ii)* correlated losses on the non-defaulted bond exposures and *(iii)* termination losses due to counterparty failures. The decomposition of capital losses is presented in tables 20 to 23 over a wide range of recovery rates. Whereas direct losses are predominant for local banks, correlated losses are, on average, an important source of losses for foreign banks, highlighting the importance of price effects. The main explanation for the importance of direct losses on bond exposures for local banks is that they typically hold a disproportionately high share of their own sovereign bonds relative to their other sovereign exposures (i.e. home bias).

5.3 The redistributive effects of CDS

Even though CDS repayments are not the main source of bank failures stemming from the CDS market as a consequence of the simulated credit events, analysing CDS repayments is nevertheless interesting in two respects, namely regarding *(i)* their magnitude and *(ii)* the extent of their redistributive effects.

Concerning the magnitude of CDS repayments, table 24 presents the net payables and the actual repayments at a system level for the four credit event scenarios and three recovery rates. Aggregate actual repayments are of low magnitude (compared to the total pool of liquid assets, which is 2.9 trillion euros), as their maximum is 2.6 billion euros (in the case of Italian credit event with 0.1 recovery rate) and rarely exceed 1 billion euros. The ratio of actual repayments over net payables increases with the recovery rate, but remains high overall (0.72 on average when the recovery rate is 0.5) so that it cannot explain the low level of actual repayments. The ratio is the smallest in case of Spanish credit event and the highest in case of Portuguese credit event.

Regarding the redistributive effects of CDS payments, two effects are analysed. First, we compute a liquidity ratio for each institution (defined as the ratio of liquid assets $\bar{C}_i$ over risk-weighted assets) and observe whether, in all pairs of banks proceeding to a strictly positive net bilateral CDS repayment, the beneficiary of the repayment has a lower liquidity ratio *ex ante* than the payer, i.e. whether CDS repayments tend to go from "high liquidity" banks to "low liquidity" banks. Second, we compute a loss ratio for each bank (defined as the ratio of direct bond losses incurred over risk-weighted assets) and look whether, in the same pairs of banks, repayments tend to flow from "low loss" banks to "high loss" banks.

Redistributive effect	**Ireland**	**Italy**	**Portugal**	**Spain**
From "high liquidity" to "low liquidity"	0,60	0,46	0,52	0,47
From "low loss" to "high loss"	0,52	0,63	0,51	0,49

Table 4 – REDISTRIBUTIVE EFFECTS OF CDS REPAYMENTS. The ratios correspond to the percentage of pairs of banks for which a redistributive effect is observed over the total number of pairs of banks for which a net CDS repayment exists.

The results for the four credit event scenarios are presented in table 4. Overall, we observe little redistributive effects, as the percentage of pairs of banks for which a redistribution is observed is close to 50%. Such result must nevertheless be interpreted cautiously, as we do not observe the full portfolio of the counterparties in the CDS market. Moreover, it may be that direct sovereign bond holdings are imperfect proxies for actual country-specific exposures, therefore that the loss ratio defined earlier might not be an ideal way to assess the true redistributive effects of CDS repayments.

5.4 Contagion

In the simulations, we find only one contagious bank failure (see table 16). Five main explanations account for the limited extent of contagion. First, our framework only captures one type of interconnections between banks, i.e. bilateral CDS exposures, and misses other important exposures, chiefly interbank exposures and other derivatives exposures. This caveat nevertheless enables us to focus on contagion purely due to banks' CDS exposures, and therefore to isolate and quantify the importance of this particular channel of contagion. Second, losses due to counterparty failures are of low magnitude. This can be seen from table 5, which compares banks' losses due to counterparty failures with their remaining capital after the imputation of losses on direct and correlated bond exposures. Third, collateralization and close-out netting play a risk-mitigating role (the details are explained below).

	Ireland	**Italy**	**Portugal**	**Spain**
Losses due to counterparty risk	0.2	1.5	0.1	1.1
Remaining capital	797.5	503.9	895.7	509.2

Table 5 – LOSSES DUE TO COUNTERPARTY RISK AND REMAINING CAPITAL (in billion euros). Remaining capital corresponds to the aggregate capital that remains in the banking sector once losses on direct and correlated bond exposures have been imputed.

The fourth reason for the low extent of the contagion is due to the network structure. A large share of the links in each estimated gross CDS network (between 52% and 86% depending on the reference entity - and a mean of 76%) are reciprocal[9], implying that potentially contagious chains of financial institutions are relatively limited.

Finally, we do not observe the default of one of the main dealers on the CDS market.

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[9] A link between two banks i and k exists on the reference entity j whenever $g^j_{ik} > 0$ or $g^j_{ki} > 0$ and is said to be reciprocal if $g^j_{ik} > 0$ and $g^j_{ki} > 0$.

6 Robustness checks and extensions of the model

In this section, we present simulation results when some of the main calibration parameters or assumptions are altered to analyse the robustness of the results. Moreover, this enables us to explore the risk-mitigating role of certain collateral management schemes and of close-out netting.

6.1 Collateral agreements and the level of collateralization

Collateral netting agreements used in the model reduce to a large extent the amount of collateral to be posted at a system level. Whereas the aggregate collateral requirement is 2.7 billion euros when netting agreements are in place, it would rise to 36.6 billion euros if they were to be suppressed. In that regard, collateral netting agreements in this setting increase the overall liquidity of the banking sector, as less cash and liquid assets have to be pledged as collateral. Such a positive role of collateral netting agreements should nonetheless be considered cautiously, as the modelling framework does not capture strategic bank balance sheet decisions when the institutional framework changes. For example, the existence of collateral netting agreements is likely to induce a higher leverage *ex ante*, as larger derivative portfolios can be sustained with a given level of pledgeable assets.

Regarding the level of collateralization of each trade (i.e. τ_{ik}^{j}), it plays an ambiguous role in the present setup. On the one hand, collateralization reduces the extent of potential contagion by decreasing the loss incurred in case of counterparty failure. On the other hand, failures from illiquidity (i.e. inability to meet collateral calls) are more likely to occur when the required level of trade collateralization is higher, as the pool of cash and liquid assets remains constant.

Up to now, we have assumed that all transactions were collateralized, but that the level of collateralization was transaction-specific. We now assume that only a fraction $\upsilon \in [0; 1]$ of the deals are collateralized (with a collateralization level drawn from the same distribution as before), whereas a fraction $(1 - \upsilon)$ is left uncollateralized. We focus of the dynamics of the model when υ ranges from 0 to 1. Losses due to counterparty failures for selected values of υ when the recovery rate is 0.5 are presented in table 6.

Level of collateralization (υ)	**Ireland**	**Italy**	**Portugal**	**Spain**
0	318.8	1914.9	33.5	1442.0
0.3	293.6	1790.3	20.3	1290.3
0.7	261.7	1560.5	16.5	1123.2
1	221.4	1476.4	10.4	1071.5

Table 6 – LOSSES DUE TO COUNTERPARTY FAILURES WITH DIFFERENT LEVELS OF COLLATERALIZATION (in million euros). The recovery rate is set to 0.5.

Overall, we do find limited effects of changes in the level of collateralization. Losses due to counterparty failures are higher when collateralization is lower, but there is no one-to-one relationship (meaning that doubling the number of collateralized trades does not half the losses due to counterparty failures, but by a much smaller amount - except in the case of Portugal's credit event). In general, the losses remain of low magnitude, partly due to the fact that our dataset captures only part of banks' actual derivatives portfolios. Regarding the consequences of a lower value of υ on banks' liquidity, we find only one case - when Portugal experiences a credit event - where a lower level of trade collateralization reduces the number of bank failures due to banks' inability to deliver eligible collateral. It is important to stress, once again, that such a result does not account for strategic balance decisions of banks in a dynamic setting, where a lower level of collateralization *ex ante* may induce banks to take on more leverage and make the whole system more vulnerable.

6.2 Close-out netting

In order to assess the extent to which close-out netting mechanisms mitigate bank-to-bank contagion in case of counterparty failure, we test the baseline specification of the modelling framework (section 4) in an environment where close-out netting would not apply. This implies that, when a bank k fails, each of the bilateral derivative exposures between k and its non-failed counterparties i is considered as a separate asset or liability. More precisely, all CDS positions that were in-the-money for k are considered as *immediately payable* liabilities (equal to the market value of the position) for the non-failed party i. Similarly, positions which were out-of-the money for k (therefore in-the-money for i) are assets for i. But because k failed, the payments of these assets may be delayed for months or years and only a part of it can be recovered. Testing for the consequences of such a framework compared to an environment where close-out netting is implemented enables assessing the risk-mitigating role of the close-out netting.

Solving for the contagion process in such a framework is a problem similar to the one studied by Eisenberg and Noe (2001). We make use of their clearing payment vector approach to solve for the equilibrium number of failures. Using a fixed-point argument, they show the existence of a unique clearing payment vector in a system of institutions mutually interconnected through assets and liabilities, where banks can become insolvent if the value of their liabilities rises above those of their assets. Moreover, an attractive feature of this algorithm is that it satisfies both limited liability of banks and proportional sharing of the recovery value in the case of failure of a bank.

	Ireland	**Italy**	**Portugal**	**Spain**
Fundamental failures	5	15	2	12
Contagious failures with close-out netting	0	0	1	0
Contagious failures without close-out netting	1	30	0	30
Total failures with close-out netting	5	15	3	12
Total failures without close-out netting	6	45	2	42
Share of failed assets with close-out netting	0,03	0,17	0.02	0,17
Share of failed assets without close-out netting	0,04	0,88	0.01	0,89

Table 7 – THE NUMBER OF BANK FAILURES WITHOUT CLOSE-OUT NETTING. Columns denote countries for which a credit event is simulated. The recovery rate is set to 0.5.

We use the Eisenberg and Noe (2001) algorithm to clear the network of CDS exposures as a consequence of fundamental failures. The results of the simulations are presented in table 7 for a recovery rate equal to 0.5. We observe that, in contrast to the situation where close-out netting is enforced, contagious failures may be substantial when it does not exist. This is even more true for the credit event scenarios of Italy and Spain, where a large share of banks exposed to the CDS market is driven to failure (45 and 42 bank fail respectively). Interestingly, and contrary to what is observed when close-out netting is introduced, we do observe the failure of some or all the main dealers when close-out netting does not exist. This is reflected in the very large share of failed assets at a system level (defined as the ratio of assets of the *ex post* failing banks over the *ex ante* total assets in the system), which reaches 88% following a failure of Italy and 89% following a failure of Spain. One exception is Portugal, where we find one contagious failure with close-out netting but zero failure without. This result highlights the major role played by close-out netting to limit contagion and the importance of the well-functioning of this very process.

7 Conclusion

This paper presents a stress test model for the CDS market, with a focus on the interplay between banks' bond and CDS holdings. The model enables the analysis of credit risk transfer mechanisms, includes features of market and liquidity risk, and allows for contagious propagation of counterparty failures. One contribution of the model is that it explicitly incorporates several features proper to OTC derivatives markets, including collateralization, collateral netting agreements and close-out netting procedures in case of counterparty default. It also provides a modelling framework to assess the potentially risk-mitigating or risk-amplifying role of the CDS market in case of a credit event. Thus, the paper aims at filling a gap in the existing literature, which mainly focuses on interbank loans and deposits.

According to the simulation results, banks' losses due to bond exposures appear to be significantly more important in magnitude than losses due to pure CDS exposures and to counterparty risk on the CDS market. We do not find significant failures due to the inability of some banks to honour their CDS repayments. Overall, CDS repayments remain at low levels compared to banks' liquid asset pools and to capital ratios. In this regard, the usual focus - at least in the financial press - on the large (gross) amounts at stake on the CDS market might be misleading, as it occults another more important source of fragility. According to our results, the largest source of vulnerability for the CDS protection sellers is found to be the sudden increases in collateral to be posted, i.e. the inability of financial institutions to meet collateral calls. Paradoxically, whereas collateral posting and variation margins are counterparty risk mitigation mechanisms, they can turn out to be major drivers of counterparty failures at times of elevated financial stress, i.e. when collateral has to be delivered on multiple positions at the same time.

As regards to contagion, we do not find evidence for significant contagion purely due to failures of counterparties on the CDS market. Potential explanations include the effectiveness of collateral management schemes, the fact that none of the major dealers is found to fail, and that several types of interconnections between banks (interbank loans and deposits, other derivatives) are not accounted for in the model. Moreover, close-out netting of the whole CDS portfolio in case of counterparty failure is shown to play a major risk-mitigating role, as contagion would affect most of the banks active on the CDS market if it were not to be implemented.

Finally, we are not able to document redistributive effects of net CDS repayments in case of a simulated credit event, neither from banks with low exposure to highly-exposed banks nor from highly-liquid banks to banks with lower liquidity.

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Appendices

Statistics	**Sample**
Number of banks	65
Number of reference entities	28
Gross notional bought - all refs.	327.6 Bns
Gross notional sold - all refs.	346.5 Bns
Net notional sold	28.2 Bns
Ireland	
Gross notional sold	11.9 Bns
Gross notional bought	11.3 Bns
Italy	
Gross notional sold	83.6 Bns
Gross notional bought	78.4 Bns
Portugal	
Gross notional sold	20.6 Bns
Gross notional bought	20.1 Bns
Spain	
Gross notional sold	40.3 Bns
Gross notional bought	38.8 Bns

Table 8 – DESCRIPTIVE STATISTICS This table present descriptive statistics for our CDS data. Ireland, Italy, Portugal and Spain are the four countries for which we simulate a jump-to-default credit event. Source : EBA 2011 EU-wide Capital Exercise.

	AT	**BE**	**CZ**	**DK**	**FI**	**FR**	**DE**	**IR**	**IT**	**NE**	**NO**	**PL**	**PT**	**SP**	**SW**	**UK**
IR	0,13	0,35	0,04	-0,09	0,01	0,10	0,05	0	0,54	0,01	-0,05	-0,03	0,65	0,53	-0,09	-0,06
IT	0,53	0,71	0,34	0,10	0,32	0,52	0,40	0,54	0,00	0,33	0,07	-0,01	0,44	0,77	0,04	-0,02
PT	0,14	0,28	0,00	-0,05	0,07	0,11	0,07	0,65	0,44	0,08	-0,06	0,00	.	0,47	-0,04	0,03
SP	0,49	0,67	0,29	0,09	0,31	0,49	0,38	0,53	0,77	0,29	0,08	-0,08	0,47	.	0,05	0,13

Table 9 – UNCONDITIONAL CORRELATIONS OF SOVEREIGN BOND RETURNS. This table presents the unconditional correlation of sovereign bond returns estimated with the Student t copula from weekly 5-year government bond returns. Data source : Bloomberg.

	AT	**BE**	**CZ**	**DK**	**FI**	**FR**	**DE**	**IR**	**IT**	**NE**	**NO**	**PL**	**PT**	**SP**	**SW**	**UK**
IR	0,21	0,44	0,01	-0,09	0,09	0,16	0,07	.	0,59	0,09	-0,06	0,09	0,63	0,58	-0,07	-0,13
IT	0,45	0,69	0,23	0,05	0,25	0,43	0,27	0,59	0,00	0,26	.	-0,02	0,46	0,78	0,04	-0,07
PT	0,20	0,36	-0,08	-0,04	0,15	0,16	0,10	0,63	0,46	0,15	-0,04	0,01	.	0,48	0,00	0,02
SP	0,53	0,71	0,25	0,12	0,32	0,51	0,37	0,58	0,78	0,33	0,05	-0,06	0,48	.	0,07	0,11

Table 10 – ESTIMATED CORRELATIONS OF SOVEREIGN BOND RETURNS WITH THE T COPULA. This table presents the correlation of sovereign bond returns estimated with the Student t copula from weekly 5-year government bond returns. Data source : Bloomberg.

	AT	**BE**	**CZ**	**DK**	**FI**	**FR**	**DE**	**IR**	**IT**	**NE**	**NO**	**PL**	**PT**	**SP**	**SW**	**UK**
IR	-0,27	-0,11	-0,39	-0,18	-0,17	-0,04	-0,31	.	0,04	-0,24	-0,18	-0,39	0,17	0,16	-0,11	0,21
IT	0,00	0,65	0,00	0,12	-0,04	0,27	0,03	0,04	.	0,11	-0,01	0,09	0,55	0,57	0,10	0,21
PT	-0,02	0,54	0,01	0,00	0,08	0,39	0,05	0,17	0,55	-0,05	-0,06	0,30	.	0,74	0,06	0,28
SP	0,06	0,66	0,02	0,03	0,18	0,48	0,05	0,16	0,57	0,04	-0,02	0,44	0,74	.	0,12	0,37

Table 11 – UNCONDITIONAL CORRELATIONS OF SOVEREIGN CDS RETURNS. This table presents the unconditional correlation of sovereign CDS returns estimated from weekly 5-year CDS returns. Data source : Bloomberg.

	AT	**BE**	**CZ**	**DK**	**FI**	**FR**	**DE**	**IR**	**IT**	**NE**	**NO**	**PL**	**PT**	**SP**	**SW**	**UK**
IR	-0,09	-0,16	-0,24	-0,32	-0,13	-0,03	-0,20	.	0,04	-0,36	-0,33	-0,34	0,22	0,10	-0,12	0,23
IT	-0,04	0,54	0,01	0,15	-0,03	0,24	-0,01	0,04	.	0,14	-0,02	0,10	0,51	0,40	0,18	0,22
PT	-0,14	0,50	0,00	0,02	0,06	0,48	0,04	0,22	0,51	-0,03	-0,09	0,51	.	0,82	0,26	0,38
SP	0,00	0,56	0,04	0,03	0,17	0,52	0,08	0,10	0,40	0,01	-0,02	0,57	0,82	.	0,36	0,41

Table 12 – ESTIMATED CORRELATIONS OF SOVEREIGN CDS RETURNS WITH THE T COPULA. This table presents the correlation of sovereign CDS returns estimated with the Student t copula from weekly 5-year CDS returns. Data source : Bloomberg.

Country	Bank	Country	Bank
AT	ERSTE GROUP	FR	SOCIETE GENERALE
AT	RAIFFEISEN ZENTRALBANK	UK	ROYAL BANK OF SCOTLAND
AT	OESTERREICHISCHE VOLKSBANK	UK	HSBC HOLDINGS
BE	DEXIA	UK	BARCLAYS
BE	KBC BANK	UK	LLOYDS BANKING GROUP
CY	MARFIN POPULAR BANK	HU	OTP BANK NYRT.
CY	BANK OF CYPRUS	IE	ALLIED IRISH BANKS
DE	DEUTSCHE BANK	IE	BANK OF IRELAND
DE	COMMERZBANK	IE	IRISH LIFE AND PERMANENT
DE	LANDESBANK BADEN-WURTTEMBERG	IT	INTESA SANPAOLO
DE	DZ BANK	IT	UNICREDIT
DE	BAYERISCHE LANDESBANK	IT	BANCA MONTE DEI PASCHI DI SIENA
DE	NORDDEUTSCHE LANDESBANK	IT	BANCO POPOLARE
DE	HYPO REAL ESTATE HOLDING	IT	UNIONE DI BANCHE ITALIANE
DE	WESTLB AG	LU	BANQUE ET CAISSE DEPARGNE DE LETAT
DE	HSH NORDBANK	MT	BANK OF VALLETTA
DE	LANDESBANK HESSEN-THURINGEN	NL	ING BANK
DE	LANDESBANK BERLIN	NL	RABOBANK NEDERLAND
DE	DEKABANK	NL	ABN AMRO BANK
DE	WGZ BANK	NL	SNS BANK
DK	DANSKE BANK	NO	DNB NOR BANK
DK	JYSKE BANK	PL	POWSZECHNA BANK
DK	SYDBANK	PT	CAIXA GERAL DE DEPOSITOS
DK	NYKREDIT	PT	BANCO COMERCIAL PORTUGUES
SP	BANCO SANTANDER	PT	ESPIRITO SANTO FINANCIAL GROUP
SP	BANCO BILBAO VIZCAYA ARGENTARIA	PT	BANCO BPI
SP	BFA-BANKIA	SE	NORDEA BANK
SP	CAJA DE AHORROS Y PENSIONES DE BARCELONA	SE	SKANDINAVISKA ENSKILDA BANKEN
SP	BANCO POPULAR ESPANOL	SE	SVENSKA HANDELSBANKEN
FI	OP-POHJOLA GROUP	SE	SWEDBANK
FR	BNP PARIBAS	SI	NOVA LJUBLJANSKA BANKA
FR	CREDIT AGRICOLE	SI	NOVA KREDITNA BANKA MARIBOR
FR	BPCE		

Table 13 – SAMPLE OF BANKS SORTED BY THEIR HOME COUNTRY. This table presens the sample of banks used in the empirical simulation of the model. For each bank, its domestic country is indicated. Source: EBA 2011 EU-wide Capital Exercise.

Recovery rate	**Direct bond loss**	**Correlated bond losses**	**Collateral shortage**	**Contagious insolvency**	**Contagious illiquidity**	**Total**
0	0	10 (2)	2	0	0	12 (2)
0,1	0	7 (2)	2	0	0	9 (2)
0,2	0	5 (2)	2	0	0	7 (2)
0,3	0	2	2	0	0	4
0,4	0	1	3	0	0	4
0,5	0	0	3	0	0	3
0,6	0	0	2	0	0	2
0,7	0	0	2	0	0	2
0,8	0	0	1	0	0	1
0,9	0	0	0	0	0	0

TABLE 14 – FAILURE CHANNELS - IRELAND This table shows the number of failed banks by failure channel and recovery rate in case of a simulated Irish credit event. Red figures in parentheses indicate the number of domestic banks among the total number of failing banks. The absence of parentheses indicates that all failing banks through one channel are foreign banks.

Recovery rate	**Direct bond loss**	**Correlated bond losses**	**Collateral shortage**	**Contagious insolvency**	**Contagious illiquidity**	**Total**
0	7 (5)	17	2	0	0	26 (5)
0,1	6 (4)	17 (1)	2	0	0	25 (5)
0,2	6 (4)	14 (1)	2	0	0	22 (5)
0,3	4 (3)	12 (2)	2	0	0	18 (5)
0,4	3 (3)	11 (2)	2	0	0	16 (5)
0,5	1 (1)	10 (3)	2	0	0	13 (4)
0,6	1 (1)	7 (3)	2	0	0	10 (4)
0,7	1 (1)	2	3 (1)	0	0	6 (2)
0,8	0	1 (1)	3	0	0	4 (1)
0,9	0	0	2	0	0	2

TABLE 15 – FAILURE CHANNELS - ITALY This table shows the number of failed banks by failure channel and recovery rate in case of a simulated Italian credit event. Red figures in parentheses indicate the number of domestic banks among the total number of failing banks. The absence of parentheses indicates that all failing banks through one channel are foreign banks.

Recovery rate	Direct bond loss	Correlated bond losses	Collateral shortage	Contagious insolvency	Contagious illiquidity	Total
0	3 (3)	3 (1)	2	0	0	8 (4)
0,1	3 (3)	2 (1)	2	0	0	7 (4)
0,2	2 (2)	2 (2)	3	0	0	7 (4)
0,3	1 (1)	3 (3)	3	0	0	7 (4)
0,4	1 (1)	2 (2)	2	0	0	5 (3)
0,5	0	1 (1)	1	0	1	3 (1)
0,6	0	0	1	0	0	1
0,7	0	0	0	0	0	0
0,8	0	0	0	0	0	0
0,9	0	0	0	0	0	0

Table 16 – FAILURE CHANNELS - PORTUGAL This table shows the number of failed banks by failure channel and recovery rate in case of a simulated Portuguese credit event. Red figures in parentheses indicate the number of domestic banks among the total number of failing banks. The absence of parentheses indicates that all failing banks through one channel are foreign banks.

Recovery rate	Direct bond loss	Correlated bond losses	Collateral shortage	Contagious insolvency	Contagious illiquidity	Total
0	5 (5)	20	2	0	0	27 (5)
0,1	5 (5)	17	2	0	0	24 (5)
0,2	4 (4)	14 (1)	2	0	0	20 (5)
0,3	4 (4)	11 (1)	3	0	0	18 (5)
0,4	3 (3)	11 (2)	3	0	0	17 (5)
0,5	2 (2)	9 (3)	2	0	0	13 (5)
0,6	0	8 (4)	3	0	0	11 (4)
0,7	0	4 (2)	2	0	0	6 (2)
0,8	0	0	3	0	0	3
0,9	0	0	3	0	0	3

Table 17 – FAILURE CHANNELS - SPAIN This table shows the number of failed banks by failure channel and recovery rate in case of a simulated Spanish credit event. Red figures in parentheses indicate the number of domestic banks among the total number of failing banks. The absence of parentheses indicates that all failing banks through one channel are foreign banks.

	Recovery rate	**0**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
Ireland	% Banks	0.15	0.11	0.08	0.03	0.02	0.00	0.00	0.00	0.00	0.00
		(0.03)	(0.03)	(0.03)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
	% Assets	0.07	0.04	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00
		(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Italy	% Banks	0.37	0.35	0.31	0.25	0.22	0.17	0.12	0.05	0.02	0.00
		(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.06)	(0.06)	(0.02)	(0.02)	(0.00)
	% Assets	0.32	0.31	0.27	0.18	0.16	0.13	0.11	0.02	0.01	0.00
		(0.10)	(0.10)	(0.10)	(0.10)	(0.10)	(0.09)	(0.09)	(0.01)	(0.01)	(0.00)
Portugal	% Banks	0.09	0.08	0.06	0.06	0.05	0.02	0.00	0.00	0.00	0.00
		(0.06)	(0.06)	(0.06)	(0.06)	(0.05)	(0.02)	(0.00)	(0.00)	(0.00)	(0.00)
	% Assets	0.03	0.02	0.02	0.02	0.02	0.01	0.00	0.00	0.00	0.00
		(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)
Spain	% Banks	0.38	0.34	0.28	0.23	0.22	0.17	0.12	0.06	0.00	0.00
		(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.06)	(0.03)	(0.00)	(0.00)
	% Assets	0.35	0.29	0.21	0.19	0.19	0.16	0.09	0.06	0.00	0.00
		(0.13)	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)	(0.07)	(0.05)	(0.00)	(0.00)

Table 18 – FAILED BANKS AND ASSETS This table presents the share of failed banks and the share of their assets as a percentage of the system's total assets. A bank is said to be failed if its common equity K is negative, in accordance with the Basel III requirement. "% Banks" refers to the percentage of defaulted banks. % Assets refers to the share of the assets held by these failed banks.

	Recovery rate	**0**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
Ireland	% Banks	0.46	0.38	0.35	0.31	0.23	0.20	0.11	0.05	0.03	0.03
		(0.05)	(0.05)	(0.05)	(0.03)	(0.02)	(0.02)	(0.00)	(0.00)	(0.00)	(0.00)
	% Assets	0.39	0.28	0.26	0.25	0.11	0.09	0.06	0.02	0.01	0.01
		(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)
Italy	% Banks	0.65	0.63	0.55	0.54	0.45	0.43	0.38	0.20	0.14	0.06
		(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.05)	(0.03)
	% Assets	0.69	0.68	0.53	0.52	0.43	0.42	0.33	0.16	0.11	0.03
		(0.10)	(0.10)	(0.10)	(0.10)	(0.10)	(0.10)	(0.10)	(0.10)	(0.06)	(0.02)
Portugal	% Banks	0.22	0.20	0.18	0.17	0.09	0.09	0.09	0.05	0.03	0.03
		(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.02)	(0.00)	(0.00)
	% Assets	0.15	0.10	0.09	0.08	0.03	0.03	0.03	0.01	0.01	0.01
		(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.00)	(0.00)
Spain	% Banks	0.65	0.63	0.62	0.52	0.45	0.40	0.31	0.23	0.15	0.05
		(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.02)
	% Assets	0.69	0.64	0.63	0.49	0.40	0.37	0.27	0.20	0.16	0.03
		(0.13)	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)	(0.02)

Table 19 – UNDERCAPITALISED BANKS AND ASSETS. This table presents the share of undercapitalized banks and the share of their assets as a percentage of the system's total assets. A bank is said to be undercapitalized if its common equity K is below 4.5% of its total assets, in accordance with the Basel III requirement. "% Banks" refers to the percentage of undercapitalised banks. % Assets refers to the share of the assets held by these undercapitalised banks.

Recovery rate	Banks	Direct losses	Correlated losses	Termination losses
0.1	Domestic	0.51	0.49	0
	Foreign	0.05	0.95	<0.01
0.5	Domestic	0.52	0.48	0
	Foreign	0.06	0.94	<0.01
0.9	Domestic	0.66	0.33	0
	Foreign	0.02	0.98	0

Table 20 – DECOMPOSITION OF LOSSES - IRELAND, (Percent). The table shows the share of bank losses due to direct losses on the bonds experiencing the credit event, losses on correlated bond exposures, and termination losses due to counterparty failures in case of simulated credit of Ireland. The table is arranged by recovery rate and by the domicile of the bank.

Recovery rate	Banks	Direct losses	Correlated losses	Termination losses
0.1	Domestic	0.55	0.45	0
	Foreign	0.12	0.87	<0.01
0.5	Domestic	0.55	0.45	0
	Foreign	0.12	0.88	<0.01
0.9	Domestic	0.54	0.46	0
	Foreign	0.13	0.86	<0.01

Table 21 – DECOMPOSITION OF LOSSES - ITALY, (Percent). The table shows the share of bank losses due to direct losses on the bonds experiencing the credit event, losses on correlated bond exposures, and termination losses due to counterparty failures in case of simulated credit of Italy. The table is arranged by recovery rate and by the domicile of the bank.

Recovery rate	Banks	Direct losses	Correlated losses	Termination losses
0.1	Domestic	0.58	0.42	0
	Foreign	0.05	0.95	<0.01
0.5	Domestic	0.75	0.25	0
	Foreign	0.11	0.89	<0.01
0.9	Domestic	0.56	0.44	0
	Foreign	0.08	0.92	<0.01

Table 22 – DECOMPOSITION OF LOSSES - PORTUGAL, (Percent). The table shows the share of bank losses due to direct losses on the bonds experiencing the credit event, losses on correlated bond exposures, and termination losses due to counterparty failures in case of simulated credit of Portugal. The table is arranged by recovery rate and by the domicile of the bank.

Recovery rate	Banks	Direct losses	Correlated losses	Termination losses
0.1	Domestic	0.58	0.42	0
	Foreign	0.06	0.94	<0.01
0.5	Domestic	0.57	0.43	0
	Foreign	0.06	0.94	<0.01
0.9	Domestic	0.57	0.43	0
	Foreign	0.06	0.94	<0.01

Table 23 – DECOMPOSITION OF LOSSES - SPAIN, (Percent). The table shows the share of bank losses due to direct losses on the bonds experiencing the credit event, losses on correlated bond exposures, and termination losses due to counterparty failures in case of simulated credit of Spain. The table is arranged by recovery rate and by the domicile of the bank.

	Recovery rate	**Total net exposure**	**Net payable**	**Actual repayments**	**Repayments / Payable**
Ireland	0.1	848	763	569	0.75
	0.5	848	424	321	0.76
	0.9	848	84	84	1.00
Italy	0.1	4772	4295	2601	0.61
	0.5	4772	2386	1626	0.68
	0.9	4772	477	458	0.96
Portugal	0.1	1462	1316	1149	0.87
	0.5	1462	731	639	0.87
	0.9	1462	146	146	1.00
Spain	0.1	2375	2138	910	0.43
	0.5	2375	1188	658	0.55
	0.9	2375	237	229	0.97

Table 24 – AGGREGATE CDS REPAYMENTS (Mn euros). This table presents statistics on actual CDS repayments for the four scenarios and three recovery rates. Net payable corresponds to the total net exposure multiplied by the loss given default.