

Anand, Kartik; Chapman, James; Gai, Prasanna

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## Covered bonds, core markets, and financial stability

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# Covered bonds, core markets, and financial stability

Kartik Anand \*

James Chapman \*\*

Prasanna Gai \*\*\*



\* Technische Universität Berlin, Germany

\*\* Bank of Canada

\*\*\* University of Auckland

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# Covered bonds, core markets, and financial stability

Kartik Anand<sup>a</sup>, James Chapman<sup>b</sup>, Prasanna Gai<sup>\*,c</sup>

<sup>a</sup>*Technische Universität Berlin*

<sup>b</sup>*Bank of Canada*

<sup>c</sup>*University of Auckland*

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## Abstract

We examine the financial stability implications of covered bonds. Banks issue covered bonds by encumbering assets on their balance sheet and placing them within a dynamic ring fence. As more assets are encumbered, jittery unsecured creditors may run, leading to a banking crisis. We provide conditions for such a crisis to occur. We examine how different over-the-counter market network structures influence the liquidity of secured funding markets and crisis dynamics. We draw on the framework to consider several policy measures aimed at mitigating systemic risk, including caps on asset encumbrance, global legal entity identifiers, and swaps of good for bad collateral by central banks.

*Key words:* covered bonds, over-the-counter markets, systemic risk, asset encumbrance, legal entity identifiers, velocity of collateral

*JEL classification codes:* G01, G18, G21

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\*Corresponding author; p.gai@auckland.ac.nz.

## 1. Introduction

The global financial crisis and sovereign debt concerns in Europe have focused attention on the issuance of covered bonds by banks to fund their activities. Unsecured debt markets – the bedrock of bank funding – froze following the collapse of Lehman Brothers in September 2008, and continue to remain strained, making the covered bond market a key funding source for many banks. Regulatory reforms have also spurred interest in this asset class: new ‘bail-in’ regulations for the resolution of troubled banks offer favorable treatment to covered bondholders; the move towards central counterparties for over-the-counter (OTC) derivatives transactions has increased the demand for ‘safe’ collateral; and covered bonds help banks meet Basel III liquidity requirements.

Covered bonds are bonds secured by a ‘*ring-fenced*’ pool of high quality assets – typically mortgages or public sector loans – on the issuing bank’s balance sheet.<sup>1</sup> If the issuer experiences financial distress, covered bondholders have a preferential claim over these ring-fenced assets. Should the ring-fenced assets in the cover pool turn out to be insufficient to meet obligations, covered bondholders also have an unsecured claim on the issuer to recover the shortfall and stand on equal footing with the issuer’s other unsecured creditors. Such ‘*dual recourse*’ shifts risk asymmetrically towards unsecured creditors. Moreover, the cover pool is ‘*dynamic*’, in the sense that a bank must replenish weak assets with good quality assets over the life of the bond to maintain the requisite collateralization. Covered bonds are, thus, a form of secured issuance, but with an element of unsecured funding in terms of the recourse to the balance sheet as a whole.

All else equal, these characteristics make covered bonds less risky for the providers of funds and, in turn, a cheaper source of longer-term borrowing for the issuing bank. The funding advantages of covered bonds – which should increase with the amount and quality of collateral being ring-fenced – have led several countries to introduce legislation to clarify the risks and protection afforded to creditors, particularly unsecured depositors. In Australia and New Zealand, prudential regulations limit covered bond issuance to 8 per cent and 10 per cent of bank total assets respectively. Similar caps on covered bond issuance in North America have been proposed at 4 per cent of an institution’s total assets (Canada) and liabilities (United States). But in Europe, where covered bond markets are well established and depositor subordination less pertinent, there are few limits on encumbrance levels and no common European regulation. Some countries do not apply encumbrance limits, while others set thresholds on a case-by-case basis.

The covered bond market is large, with € 2.5 trillion outstanding at the end of 2010. Denmark, Germany, Spain, France and the United Kingdom account for most of the total, with very large issues (‘jumbos’) trading in liquid secondary markets that are dominated by OTC trading. Covered bonds are also a source of high quality collateral in private bilateral and tri-party repo transactions which, in turn, are intimately intertwined with OTC derivatives markets.<sup>2</sup> Although the bulk of collateral posted for repo transactions is in the form of cash and government securities, limits to the rehypothecation (or reuse) of collateral mean that financial institutions

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<sup>1</sup>Unlike other forms of asset-back issuance, such as residential mortgage backed-securities, covered bonds remain on the balance sheet of the issuing bank.

<sup>2</sup>See, for example, the FSB (2012) report on securities lending and repo. For example, a repo can be used to obtain a security for the purpose of completing a derivatives transaction. Whiteley (2012) notes that covered bonds usually require some form of hedging arrangement since cash flows on cover pool assets do not exactly match payments due on the covered bonds. In balance-guaranteed swaps, the issuer of the covered bond agrees to pay a hedging provider the average receipts from a fixed proportion of the cover pool on each payment date. The hedging provider, in exchange, agrees to pay amounts equal to the payments due under the covered bond.

are increasingly using assets such as high-grade covered bonds to help meet desired funding volumes (see IMF (2012)).

Over-the-counter secured lending markets are highly concentrated. In the secondary market for covered bonds, the dealer bank underwriting the issue assumes the market making for that bond and for all outstanding jumbo issues of the issuer. As a result, top market makers trade around 200-300 covered bonds while others trade only a few ((see ECB (2008)).<sup>3</sup> In the repo market, the top 20 reporting institutions account for over 80% of transactions. Dealer banks, thus, occupy a privileged position when investors seek out terms when attempting to privately negotiate OTC trades. The network structure for OTC secured financing transactions thus appears to resemble the core-periphery (or dealer-intermediated) structure depicted in Figure reffig-coreperi.<sup>4</sup>

Recent events have highlighted the systemic importance of covered bond markets.<sup>5</sup> Notwithstanding their almost quasi-government status, spreads in secondary covered bond markets rose significantly in 2007-2008 (Figure 2). The continued strains in funding conditions, coupled with concerns about the liquidity (and solvency) of a number of financial institutions in the euro area, have prompted the European Central Bank to support the market through the outright purchase of covered bonds. Under its Covered Bond Purchase Program (CBPP), which commenced in July 2009, the ECB purchased € 60 billion in covered bonds. It has recently announced its intention to purchase a further € 40 billion.

In this paper, we explore some financial stability implications of covered bonds. In our model, commercial banks finance their operations with a mix of unsecured and secured funding. Unsecured creditors are akin to depositors, while secured creditors are holders of covered bonds. A financial crisis occurs when there is a run on the commercial banking system by unsecured creditors. We show how the critical threshold for the run is an outcome of a coordination game that depends, critically, on the extent of encumbered assets on banks' balance sheets and the liquidity of secured lending markets.

A feature of our model is that the factors driving the price of assets in OTC markets for secured finance are modeled explicitly. Liquidity depends on the willingness of investors to accept financial products based on covered bond collateral without conducting due diligence. The speed with which investors absorb the assets put up by bondholders thus drives the extent of the price discount. We show how this speed depends on the relative payoffs from taking on the asset, the structure of the OTC network, and the responsiveness of the investors, i.e., the probability that they choose a (myopic) best response given their information.

The disposition of investors to trade covered bond products without undertaking due diligence on the underlying collateral can be likened to Stein's (2012) notion of "moneyness". We contrast how investors' willingness to trade in OTC markets differs for complete and core-periphery structures. Dealer-dominated networks promote moneyness, limiting the extent of the firesale discount. The tendency of dealer banks to trade with each other makes it much more likely that other investors take on the asset. And the larger are the returns from such trade, the greater is the readiness to transact.

Our model is relevant to recent policy debates on asset encumbrance, counterparty trace-

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<sup>3</sup>In euro-area covered bond markets, an industry group comprising the 8 market makers with the largest jumbo commitments and the 8 largest bond issuers (the "8 to 8" committee) sets recommendations in deteriorating market conditions.

<sup>4</sup>Core-periphery structures are common to other OTC networks. Li and Schurhoff (2012) document that the US municipal bond OTC network also exhibits such a structure, with thirty highly connected dealer banks in the core and several hundred firms in the periphery.

<sup>5</sup>See Carney (2008) for discussion of the need to ensure the continuous operation of core funding markets for financial stability and the role of the central bank as market maker of last resort in these markets.

ability, and the design of liquidity insurance facilities at central banks. Haldane (2012a) notes that, at high levels of encumbrance, the financial system is susceptible to procyclical swings in the underlying value of banks' assets and prone to system-wide instability. Our results justify such concerns. The dynamic adjustment of a bank's balance sheet to ensure the quality of the cover pool increases systemic risk. Moreover, the larger the pool of ring-fenced assets, and the greater the associated uncertainty, the more jittery are unsecured creditors. Limits to encumbrance may therefore help forestall financial crises. There may also be a case for such limits to be time-varying, increasing when macroeconomic conditions (and hence returns) are buoyant and decreasing when business cycle conditions moderate.

Recent efforts by the Financial Stability Board to establish a framework for a global legal entity identifier (LEI) system to bar-code counterparty linkages and, ultimately, unscramble the elements of each OTC transaction, including collateral, can also be considered within our framework. In our model, the implementation of such a regime lowers the costs of monitoring collateral and ensures that strategic coordination risk is minimized – OTC market liquidity is enhanced and driven solely by credit quality.

The extent to which collateral, such as covered bond securities, is re-used is central to the private money creation process ushered in by the emergence of the shadow banking system. In the wake of the crisis, a decline in the rate of collateral re-use has slowed credit creation, leading some commentators to advocate swaps of central bank money for illiquid or undesirable assets as part of the monetary policy toolkit (e.g. Singh and Stella (2012)). Our model provides a vehicle with which to assess such policy. By acting as a central hub in the OTC network and willingly taking on greater risk on its balance sheet, the central bank influences both the investors' opportunity cost of collateral and their disposition to participate in secured lending markets. Systemic risk is lowered as a result. When the central bank pursues a contingent liquidity policy, lending cash against illiquid collateral when macroeconomic conditions are fragile, their actions may preempt the total collapse of OTC markets.

## 2. Related literature

The systemic implications of covered bonds have received little attention in the academic literature, despite their increasingly important role in the financial system.<sup>6</sup> Our analysis brings together ideas from the literature on global games pioneered by Morris and Shin (2003) and the literature on social dynamics (see Durlauf and Young (2001)). Bank runs and liquidity crises in the context of global games have previously been studied by Goldstein and Pauzner (2005), Rochet and Vives (2004), Chui et al. (2002) among others, and we adapt the latter for our purposes. In modeling the OTC market in secured lending, we build on Anand et al. (2011) and Young (2011). These papers, which stem from earlier work by Blume (1993) and Brock and Durlauf (2001), study how rules and norms governing bilateral exchange spread through a network population. Behavior is modeled as a random variable reflecting unobserved heterogeneity in the ways that agents respond to their environment. The framework is mathematically equivalent to logistic models of discrete choice, with the (logarithm of) the probability that an agent chooses a particular action being a positive linear function of the expected utility of the action.

Our paper complements the existing literature on securitization and search frictions in OTC markets. Dang et al. (2010) and Gorton and Metrick (2011) highlight how, during the crisis, asset-backed securities thought to be information-insensitive became highly sensitive to infor-

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<sup>6</sup>See Packer et al. (2007) for an overview of the covered bond market in the lead-up to the global financial crisis.

mation, leading to a loss of confidence in such securities and a run in the repo market. In our model, the willingness (or otherwise) of investors to trade in OTC markets without due diligence is comparable to such a notion. Stein (2012) also presents a model in which information-insensitive short-term debt backed by collateral is akin to private money. Geanakoplos (2009) is another contribution that also focuses on how collateral and haircuts arise when agents' optimism about asset-backed securities leads them to believe that the asset is safe.<sup>7</sup>

Our modeling of the OTC market in covered bond transactions is related to search-theoretic analyses of the pricing of securities lending (e.g. Duffie et al. (2005, 2007) and Lagos et al. (2011)). This strand of literature emphasizes how search frictions are responsible for slow-recovery price dynamics following supply or demand shocks in asset markets. The initial price response to the shock, which reflects the residual demand curve of the limited pool of investors able to absorb the shock, is typically larger than would occur under perfect capital mobility.<sup>8</sup> And the sluggish speed of adjustment following the response reflects the time taken to contact and negotiate with other investors.

In our model, by contrast, the degree of liquidity in the OTC market (and hence the residual demand for covered bond assets) is determined by the willingness of investors to treat these assets as money-like. And slow-recovery price dynamics reflect hysteresis due to local interactions on the network. While investors' decisions are made on the basis of fundamentals, they are also influenced by the majority opinion of their near-neighbors. Investor optimism (or pessimism) for covered bond assets is self-consistently maintained in the face of gradual changes to fundamentals. And once a firesale takes hold, prices can take a long time to recover.

The OTC trading network in our model is exogenously specified to be a undirected graph. Atkeson et al. (2012) develop a search model of a derivatives trading network in which credit exposures are formed endogenously. Their results also suggest that a concentrated dealer network can alleviate liquidity problems, including those arising from search frictions. In their model, the larger size of dealer banks allows them to achieve internal risk diversification, allowing for greater risk bearing capacity. But the network is also fragile since bargaining frictions, by preventing dealers from realizing all the system benefits that they provide, induces inefficient exit. Recent work that also considers OTC networks includes Babus (2011), Gofman (2011), and Zawadowski (2011).

Finally, our findings are relevant to recent analyses of the quest for safety by investors and financial 'arms races'.<sup>9</sup> Debelle (2011) and Haldane (2012a) have voiced concerns that the recent trend towards secured issuance and the (implicit) attempt by investors to position themselves at the front of the creditor queue is unsustainable and socially inefficient. Recent academic literature has begun to formalize such concerns. Glode et al. (2012) develop a model of financial arms races in which market participants invest in financial expertise. Brunnermeier and Oehmke (2012) and Gai and Shin (2004) also study creditor races to the exit, where investors progressively seek to shorten the maturity of their investments to reduce risk.

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<sup>7</sup>Gorton and Metrick (2011) provide a comprehensive survey of the literature on securitization, including the implications for monetary and financial stability. Our model is also related to recent empirical work that examines whether covered bonds can substitute for mortgage-backed securities (see Carbo-Valverde et al. (2011)).

<sup>8</sup>Acharya et al. (2010) also offer an explanation for why outside capital does not move in quickly to take advantage of fire sales based on an equilibrium model of capital allocation. See Shleifer and Vishny (2010) for a survey of the role of asset fire sales in finance and macroeconomics.

<sup>9</sup>In addition, policy proposals advocating limited purpose banking (see Chamley et al. (2012)) point to institutions where covered bonds dominate balance sheets (e.g. in Denmark, Germany and Sweden) as exemplars of mutual fund banking.

Assets	Liabilities
$A_i^F$	$L_i^D$
$A_i^L$	$K_i$

Table 1: Initial balance sheet of bank  $i$ .

### 3. Model

#### 3.1. Structure

There are three dates,  $t = 0, 1, 2$ . The financial system is assumed to comprise  $N^B$  commercial banks who have access to investment opportunities in the real economy,  $N^O$  financial firms who deal in over-the-counter (OTC) securities and derivatives, and a large pool of depositors.

Table 1 illustrates the  $t = 0$  balance sheet for bank  $i$ . On the asset side of the balance sheet, the bank holds liquid assets,  $A_i^L$ , which can be regarded as government bonds.  $A_i^F$  denotes investments in a risky project. On the liability side,  $L_i^D$  denotes retail deposits and  $K_i$  represents the bank's equity. The balance sheet satisfies  $A_i^L + A_i^F = K_i + L_i^D$ . The risky investment yields a return  $X_i A_i^F$ , where  $X_i$  is a normally distributed random variable with mean  $\mu$  and variance  $\sigma^2$ . While the value of  $X_i$  is realized at  $t = 1$ , the realized returns are received by the bank only in the final period. Once the returns are received, the bank is contracted to pay an interest rate  $r_i^D$  to each depositor.

We suppose that commercial banks are risk averse and, thus, seek to diversify their balance sheets by investing in a second (risky) project. The bank invests  $\tilde{A}_i^F$  into this second project, which also yields returns  $Y_i \tilde{A}_i^F$  at  $t = 2$ , where  $Y_i$  is normally distributed with mean  $\mu$  and variance  $\sigma^2$ . As with the returns  $X_i$ , the random variable  $Y_i$  is realized in the interim period, while payments are made to the bank only in the final period. To keep matters simple,  $X_i$  and  $Y_i$  are independent of each other.

Banks cannot raise equity towards their second investment, nor can they borrow further from depositors. Instead they can issue covered bonds backed by on-balance sheet collateral. As described in the introduction, covered bonds are senior to all other classes of debt. And, if the assets within the covered bond asset pool are deemed to be non-performing, the bank is obliged to replenish those assets with its other existing assets so that payments to bondholders are unaffected. In the event of the bank defaulting, the covered bondholders have recourse to the asset pool.

The commercial bank therefore creates a ring fence  $A_i^{RF}$ , where it deposits a fraction,  $\alpha$ , of assets  $A_i^F$ . In this analysis we regard  $\alpha$  as a measure of asset encumbrance. The bank then issues a covered bond with expected value

$$\begin{aligned} & (1 - q_i) \alpha \mu A_i^F + q_i \alpha \mu A_i^F p(\alpha A_i^F) \\ &= \alpha \mu A_i^F (1 + q_i [p(\alpha A_i^F) - 1]), \end{aligned} \quad (1)$$

where  $q_i$  is the probability that the bank fails and  $p(\alpha A_i^F)$  is the residual demand curve for assets in the secondary market. Equation (1) states that if the bank is solvent, with probability  $1 - q_i$ , it will transfer  $\alpha \mu A_i^F$  as cash to the bondholder in the final period. But if the bank defaults, the ring-fenced assets are handed over to the bondholder who must sell them on the secondary market. Sales on the secondary market are potentially subject to a discount, the extent of which is governed by the slope of the residual demand curve.

The maximum amount the bank can borrow is

$$L_i^{CB} = \mu \alpha A_i^F (1 - h_i), \quad (2)$$



Assets	Liabilities
$A_i^{RF} = \alpha A_i^F$	$L_i^{CB}$
$(1 - \alpha)A_i^F + \tilde{A}_i^F$	$L_i^D$
$A_i^L + \underbrace{(1 - h_i)\mu \alpha A_i^F - \tilde{A}_i^F}_{\tilde{A}_i^L}$	$K_i$

Table 2: Bank  $i$ 's balance sheet following issuance of covered bonds.

where the haircut satisfies

$$h_i = q_i \left( 1 - p(\alpha A_i^F) \right). \quad (3)$$

We assume that the residual demand curve takes the form

$$p(x) = e^{-\lambda x}, \quad (4)$$

where  $\lambda$  reflects the degree of illiquidity and  $x$  is the amount sold on the secondary market. We initially treat  $\lambda$  as exogenous, before returning to endogenize it. Table 2 depicts the commercial bank's balance sheet as a consequence of the covered bond issue. Note that  $\tilde{A}_i^L = (1 - h_i)\mu \alpha A_i^F - \tilde{A}_i^F$  is the cash that remains after investment in the second risky project. The constraints that the bank only invests  $\tilde{A}_i^F$  in the new project may be thought of as a consequence of the partial pledgeability of future returns in writing of the contract between the bank and its creditors.<sup>10</sup> Moreover, the total return  $X_i(1 - \alpha)A_i^F + Y_i\tilde{A}_i^F$  on assets outside the ring fence is also normally distributed with mean  $\mu \left[ (1 - \alpha)A_i^F + \tilde{A}_i^F \right]$ , and variance  $\sigma^2 \left[ (1 - \alpha)^2 (A_i^F)^2 + (\tilde{A}_i^F)^2 \right]$ .

In the setting considered here, the creditor must be indifferent between purchasing a covered bond and buying an outside option (such as a government bond). So the sum of payments in the interim and final period must be equal to  $L_i^{CB} (1 + R^G)$ , where  $R^G$  is the interest earned on government bonds. Under the assumption  $R^G = 0$ , government bonds amount to a safe storage technology that preserves bondholder wealth across time without earning interest. Strictly speaking, covered bonds stipulate that the debtor must make regular payments to the creditor until maturity. However, we do not model these interim periods and assume that the bank is able to credibly demonstrate that the expected value of the ring fenced assets is able to pay back the bond holder.<sup>11</sup>

At the interim date, the bank privately learns that the ring-fenced assets are not performing and must be written off. Specifically, suppose that the mean and variance of  $X_i$  collapse to zero. By contrast, the expected return to  $Y_i$  remains unchanged. In order to demonstrate that there are sufficient assets within the ring fence – maintain over-collateralization – the bank must therefore swap assets from outside to inside the ring. Table 3 illustrates the updated balance sheet of the commercial bank. The returns on assets outside the ring fence is now  $Y_i(1 - \alpha)\tilde{A}_i^F$ , with mean  $\mu(1 - \alpha)\tilde{A}_i^F$ , and variance  $\sigma^2(1 - \alpha)^2 (\tilde{A}_i^F)^2$ . To economize on notation we normalize  $\tilde{A}_i^F = 1$  in what follows.

<sup>10</sup>While a full account of partial pledgeability is beyond the scope of our paper, we can nevertheless think of it as a consequence of agency costs that arise from misaligned incentives between the bank and its creditors. Since creditors cannot observe the bank's actual effort in managing the assets, they benchmark their lending to the lower bound of efforts, which is common knowledge. See Holmström and Tirole (2011) for a fuller account. Additionally, as creditors demand a minimum recoverable amount from the bank in case of default, the bank is forced to maintain a high level of liquid assets on its balance sheet, which further constraints how much it can invest into the risky project.

<sup>11</sup>In other words, the bank maintains  $\mathbb{E}[A_i^{RF}] \geq L_i^{CB}$  across the lifetime of the bond.

Assets	Liabilities
$A_i^{RF} = \alpha \tilde{A}_i^F$	$L_i^{CB}$
$A_i^F + (1 - \alpha)\tilde{A}_i^F$	$L_i^D$
$A_i^L + \tilde{A}_i^L$	$K_i$

Table 3: Bank  $i$ 's balance sheet after dynamic readjustment to a shock.

			Commercial bank	
Time of payoff			Solvent	Default
Depositor	Rollover	$t = 2$	$1 + r_i^D$	0
	Withdraw	$t = 1$	$1 - \tau$	$1 - \tau$

Table 4: Payoff matrix for a representative depositor.

At  $t = 0$ , risk-neutral depositors are endowed with a unit of wealth and have access to the same safe storage technology as covered bond holders. But they are also able to lend to the commercial bank, with a promise of repayment and interest  $r_i^D > 0$  at  $t = 2$  if the bank is solvent. At the interim date, however, following the realization of returns  $Y_i$ , depositors have a choice of withdrawing their deposits and must base this decision on a noisy signal on the returns of the assets outside the ring fence. Specifically, a depositor  $k$  of the bank receives a signal  $s_k = Y_i + \epsilon_k$ , where  $\epsilon_k$  is normally distributed with mean zero and variance  $\sigma_\epsilon^2$ . A depositor who withdraws incurs a transaction cost  $\tau$ , for a net payoff of  $1 - \tau$ . A depositor who rolls over receives  $1 + r_i^D$  in the final period if the bank survives, but receives zero otherwise.

In deriving the survival condition for the bank we must account for the dual recourse of the covered bond holders, where we distinguish between two cases. First, suppose that the realized returns on the ring fenced assets are more than sufficient to pay back the covered bond holders in the final period, i.e.,  $\alpha Y_i > L_i^{CB}$ . However, the surplus  $\alpha Y_i - L_i^{CB}$  cannot be made available at the interim period to the unsecured depositors wanting to withdraw their funds. This follows from the timing of our model, where the bank will pay the covered bond holders only in the final period, and it is at this time that the surplus becomes available. Thus, in deciding to withdraw or rollover, the unsecured depositors are only interested in the returns to the unencumbered assets.

Second, if  $\alpha Y_i < L_i^{CB}$ , then the returns on encumbered assets are insufficient to pay back the covered bond holders. In this case, the covered bond holders will reclaim the deficit  $L_i^{CB} - \alpha Y_i$  from the unencumbered assets at  $t = 2$  on an equal footing with other unsecured depositors who rollover their loans. Once again, in deciding to withdraw their funds at  $t = 1$ , the unsecured depositors care only on the returns to the unencumbered assets.

If  $\ell_i$  is the fraction of depositors who withdraw their deposits from the bank, the solvency condition for the bank at  $t = 2$  is given by

$$(1 - \alpha) Y_i + A_i^L + \tilde{A}_i^L - \psi \ell_i L_i^D - \ell_i L_i^D \geq (1 - \ell_i)(1 + r_i^D) L_i^D, \quad (5)$$

where  $\psi \geq 0$  reflects the cost of premature foreclosures by depositors.<sup>12</sup> The payoff matrix for the representative depositor is summarized in Table 4.

<sup>12</sup>The cost  $\psi$  captures in a parsimonious way both the firesale losses to the bank from liquidating assets to satisfy the demands of depositor withdrawals, and productivity losses incurred by the bank – for example, the bank may layoff managers responsible for the assets, resulting in looser monitoring and lower returns. A more detailed approach to capture such dead-weight losses would follow along the lines of Rochet and Vives (2004) and Koenig (2010).

### 3.2. The consequences of dynamic cover pools

We now solve for the unique equilibrium of the global game in which depositors follow switching strategies around a critical signal  $s^*$ . Depositor  $k$  will run whenever his signal  $s_k < s^*$  and roll over otherwise. Accordingly, the fraction of depositors who run is

$$\begin{aligned}\ell_i &= \mathbf{Pr}[s_k < s^* | Y_i] = \frac{1}{\sqrt{2\pi}\sigma_\epsilon} \int_{-\infty}^{s^* - Y_i} e^{-\frac{1}{2}(\epsilon/\sigma_\epsilon)^2} d\epsilon \\ &= \Phi\left[\frac{s^* - Y_i}{\sigma_\epsilon}\right].\end{aligned}\quad (6)$$

A critical value of returns,  $Y_i^*$ , determines the condition where the proportion of fleeing depositors is sufficient to trigger distress, i.e.,

$$Y_i^* = \frac{L_i^D}{1 - \alpha} \left(1 + r_i^D + \Phi\left[\frac{s^* - Y_i^*}{\sigma_\epsilon}\right] (\psi - r_i^D)\right) - \frac{(A_i^L + \tilde{A}_i^L)}{1 - \alpha}. \quad (7)$$

At this critical value, depositors must also be indifferent between foreclosing and rolling over their deposits in the bank, i.e.,

$$1 - \tau = (1 + r_i^D) \mathbf{Pr}[Y > Y_i^* | s_k], \quad (8)$$

which yields

$$\frac{1 - \tau}{1 + r_i^D} = 1 - \Phi\left[\sqrt{\frac{\sigma_\epsilon^2 + \sigma^2}{\sigma_\epsilon^2 \sigma^2}} \left(Y_i^* - \frac{\sigma_\epsilon^2 \mu + \sigma^2 s^*}{\sigma_\epsilon^2 + \sigma^2}\right)\right]. \quad (9)$$

Equations (7) and (9) together allow us to obtain the critical value of returns,  $Y_i^*$ , in the limit that  $\sigma_\epsilon \rightarrow 0$

$$Y_i^* = \frac{L_i^D}{1 - \alpha} \left[1 + r_i^D + \frac{(\psi - r_i^D)(1 - \tau)}{1 + r_i^D}\right] - \left(\frac{A_i^L + (1 - h_i)\mu\alpha - 1}{1 - \alpha}\right). \quad (10)$$

And recalling that the haircut depends on  $q_i$ , it follows that the probability of a run on the commercial bank is given by the solution to the fixed point equation

$$q_i = \Phi\left[\frac{Y_i^*(q_i) - \mu}{\sigma}\right]. \quad (11)$$

Our focus, in what follows, is on liquidity and network structure in the OTC secured lending markets, including the secondary covered bond and repo markets. We therefore do not consider the influence of network structure on commercial banks and assume they have identical balance sheets.<sup>13</sup> It follows that haircuts  $h_i$  and probabilities  $q_i$  are the same for all banks, i.e.,  $h_i = h$  and  $q_i = q$ . So  $q$  serves as a measure for systemic risk in the commercial banking system.

Figure 3 shows how  $q$  decreases with increasing expected returns,  $\mu$ . The probability of a (systemic) bank run is illustrated in the case of a regime with, and without, covered bonds.<sup>14</sup> If the secondary market is perfectly liquid,  $\lambda = 0$ , for sufficiently small values of  $\mu$ , the probability of a bank run is greater under the covered bond regime. As  $\mu$  increases, this situation is reversed

<sup>13</sup>Formally, the joint distribution of liquid assets, deposits and interest rates, i.e.,  $A_i^L$ ,  $L_i^D$  and  $r_i^D$ , respectively, factorizes into a product of Kronecker delta functions;  $\prod_{i=1}^N \delta_{A_i^L, A^L} \delta_{L_i^D, L^D} \delta_{r_i^D, r^D}$ , where  $\delta_{i,j} = 1$  if and only if  $i = j$ , and zero otherwise.

<sup>14</sup>In the case without covered bonds,  $\alpha$  is set to zero.

– the probability of a systemic bank run is higher under the regime without covered bonds. When asset valuations are high, unsecured depositors are not inclined to run. But this situation changes as  $\mu$  decreases, and is exacerbated when assets are increasingly encumbered. When secondary markets are frozen,  $\lambda = \infty$ , banks are always worse off under the covered bond regime.

Figure 3 makes clear how the dynamic adjustment of the bank's balance to ensure the quality of ring fenced assets influences systemic risk. Following the failure of the initial investment, the bank is forced to swap assets in and out of the ring fence in order to maintain the over-collateralization of the ring fence. Unsecured creditors become more jittery as a result, leading to a higher probability of a run. This situation is made worse as the secondary market becomes more illiquid, larger  $\lambda$ , which – due to the higher haircut – requires the bank to encumber more assets, leaving even less for the unsecured depositors. Although we treat  $r^D$  as exogenous and assume that banks cannot borrow further from unsecured depositor, the analysis helps clarify how an adverse feedback loop in funding markets can easily develop. Should a bank need to meet sudden liquidity needs in the face of an adverse shock to returns, secured financing is likely to be more costly and access to unsecured credit is likely to be constrained.

This analysis helps clarify the actions of the European Central Bank during the crisis. In 2009, in response to problems in the covered bond markets, the ECB purchased Euro 60 billion of covered bonds to improve the funding conditions for those institutions issuing covered bonds and improve liquidity in the secondary markets for these bonds. In terms of Figure 3, this is akin to setting  $\lambda = 0$  and engendering a lower probability of a creditor run. In the event, the action proved successful – spreads on covered bonds declined and bond issuance picked up sharply after the announcement of the program.<sup>15</sup>

### 3.3. The OTC market for covered bond products

We now endogenize the degree of illiquidity,  $\lambda$ , governing the secondary market price of covered bonds and other securities based on them. In the model, liquidity provision stems from the behavior of investors in over-the-counter (OTC) securities markets. In particular,  $\lambda$  is determined by the diffusion, or otherwise, of over-the-counter trading in covered bond products. Such trades, which are privately negotiated, can be motivated in two ways. First, covered bondholders may themselves seek levered financing and use their bonds to seek out diversification opportunities. And second, other investors in the OTC market may wish to purchase collateralized securities from one party with the intention of packaging them into a new synthetic product for onward sale as part of their proprietary trading, or speculative investment, activity.<sup>16</sup> Typically, a small number of dealer banks dominate the intermediation of such OTC securities markets.<sup>17</sup> The  $N^O$  OTC players include all covered bond holders as well as other investors.

Let  $c$  be the opportunity cost incurred by an investor when transacting over-the-counter for secured lending products. Pledging collateral blocks liquid funds from being used elsewhere. When returns on the underlying assets are high, on average, an investor has less need to pledge collateral and so the opportunity cost is low. We therefore assume that  $c$  decreases with the

<sup>15</sup>See Beirne et al. (2011) for a detailed discussion of the impact of the ECB's covered bond purchase.

<sup>16</sup>The recent popularity of covered bonds has led several leading dealer banks (such as JP Morgan and Credit Suisse) to consider establishing a standardized CDS market for covered bonds in order to enable covered bond protection to be bought and sold (see Carver (2012)).

<sup>17</sup>As Duffie (2010) notes, dealers frequently deal with other dealers. Also, in most OTC derivative transactions, at least one of the counterparties is a dealer. The bulk of investors in covered bonds tend to be banks and asset management firms. Broker dealers constitute a significant part of the former category (see Packer et al. (2007) and Shin (2009)).

expected return,  $\mu$ , of the asset being used as collateral for the covered bond, i.e.,  $c \equiv c(\mu) = e^{-\kappa\mu}$ , where  $\kappa > 0$  is a scaling for how the opportunity cost varies with returns. If  $\kappa$  is small, the rate of change of  $c$  with  $\mu$  is small. For large  $\kappa$ , the opportunity cost is near 0, for all returns. Since some synthetic covered bond products will involve the co-mingling of the ring-fenced collateral with other collateral held by investors, it is also costly to unscramble the proper nature and value of the assets underlying these products. Let  $\chi_j$  be the cost to an investor  $j$  of gathering such information.

We accommodate the OTC market in our three period structure by dividing the interval between the initial and interim dates into a countable number of sub-periods,  $s$ . OTC investors are organized in an undirected network,  $A \in \{0, 1\}^{N^O \times N^O}$ , where  $a_{ij} = 1$  implies that there are trading opportunities between investors  $i$  and  $j$ .<sup>18</sup> The set  $\mathcal{N}_i = \{j | a_{ij} = 1\}$  is the set of trading neighbors for investor  $i$ . In sub-period  $s$ , investor  $i$  seeks out (at random) another investor,  $j$ , to purchase a security, incurring opportunity cost,  $c$ , in the process. In pursuing the trade, investor  $i$  is characterized by a variable  $d_i^s \in \{0, 1\}$  that specifies whether he gathers information about the product ( $d_i^s = 0$ ) or not ( $d_i^s = 1$ ). As the analysis below makes clear, the rationale for this decision rule does not stem from a fundamental evaluation of underlying collateral quality, but rather on the fact that others also follow the rule.

If investor  $i$  gathers information, then with probability  $\tilde{q}$  he learns that collateral quality is poor and refuses the transaction. The payoff to  $i$  in this case is  $-\chi_i$ . With probability  $1 - \tilde{q}$ , the collateral underlying the covered bond product is judged to be good quality. In this case  $i$  accepts the asset, repackages it into a new synthetic product for another investor,  $k$ . In return, investor  $i$  receives one unit of cash, earning a payoff  $1 - c - \chi_i$  in the process.

On the other hand, investor  $i$  also has the option of simply accepting the claims of investor  $j$  regarding collateral quality without gathering costly information ( $d_i^s = 1$ ). In this case, the net payoff to  $i$  depends on whether investor  $k$  also behaves in the same way. Investor  $i$  does not know a priori which of its neighbors accepts the product without due diligence, but is aware of the probability,  $\bar{d}_i^{s-1} = |\mathcal{N}_i|^{-1} \sum_{k \in \mathcal{N}_i} d_k^{s-1}$ , that a randomly selected neighbor behaves in this manner.

With probability  $\tilde{q}(1 - \bar{d}_i^{s-1})$ , investor  $i$  believes that investor  $k$  will monitor and discover that the collateral underlying the security offered by  $i$  is poor. In this event,  $k$  rejects the transaction and investor  $i$  is left with the security on his balance sheet. The net payoff to investor  $i$  is thus  $-c$ . But with probability  $1 - \tilde{q}(1 - \bar{d}_i^{s-1})$ , investor  $i$  believes that  $k$  monitors and determines the collateral to be sound. In this case, trade takes place and yields  $1 - c$  for investor  $i$ .

The expected payoff to investor  $i$  in period  $s$  from gathering costly information about the security ( $d_i^s = 0$ ) is thus

$$u_i^s(0) = (1 - \tilde{q})(1 - c) - \chi_i, \quad (12)$$

and from opting to transact without due diligence is

$$u_i^s(1) = \tilde{q}(1 - \bar{d}_i^{s-1})(-c) + (1 - \tilde{q}(1 - \bar{d}_i^{s-1}))(1 - c). \quad (13)$$

The period  $s$  best response of investor  $i$  when he gets the opportunity to buy a covered bond product is accordingly,

$$(d_i^s)^* = \Theta[u_i^s(1) - u_i^s(0)] = \Theta[\tilde{q}(\bar{d}_i^{s-1} - c) + \chi_i], \quad (14)$$

where  $\Theta[\dots]$  is the Heaviside function. In order to capture the diffusion and take-up (and hence liquidity) of covered bond products, we model the dynamics, starting from an initial set

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<sup>18</sup>Investors in the OTC network thus hold portfolios of long and short contracts with counterparties, so the links capture net credit exposures between agents.

of conditions, for  $d_i$ . We follow Blume (1993) and Young (2011) in focusing on stochastic choice dynamics of a local interaction game. Each investor interacts directly with his immediate neighbors and, although each player has few neighbors, all investors interact indirectly through the chain of direct interactions.

In each sub-period,  $s$ , investors have an opportunity to revise their strategy in light of the behavior of their neighbors. Under *best-response* dynamics, each investor chooses equiprobably from among the strategies that give the highest payoff flow, given the action of his neighbors, at each revision opportunity. Under *stochastic-choice* dynamics, the probability that the investor chooses strategy  $d_i^s = 0$  over  $d_i^s = 1$  is proportional to some function of the payoffs that  $d_i^s = 0$  and  $d_i^s = 1$  achieve from the interaction of the investor with his neighbors. We therefore assume that investor  $i$  chooses action  $d_i^s = 1$  with probability

$$\Pr[d_i^s = 1] = \frac{e^{\beta_i u_i^s(1)}}{e^{\beta_i u_i^s(1)} + e^{\beta_i u_i^s(0)}}, \quad (15)$$

where  $\beta_i \geq 0$  measures the responsiveness of the investor.<sup>19</sup> The larger is  $\beta_i$  the less likely is the investor to experiment with a sub-optimal action given the actions of his neighbors. The responsiveness parameter, thus, influences the rate of diffusion, or willingness of investors to trade covered bond products, across the OTC network. In the limit  $\beta_i \rightarrow \infty$ , best response dynamics emerge as investor  $i$  places equal positive weight on all best responses and zero weight on sub-optimal actions. The stochastic choice model of equation (15) reduces to equation (14). By contrast when  $\beta_i = 0$ , choice decision is random.

In the case of a network homogenous degree  $k$ , i.e.,  $k_i = |\mathcal{N}_i| = k$ , and best-response dynamics, i.e.,  $\beta_i \rightarrow \infty$ , we can solve for the fraction of investors willing to trade covered bond products in the OTC market. Defining  $\pi(\chi) = \Pr[d_i = 1 | \chi_i = \chi]$  to be the probability that investor  $i$  takes up a derivative product without monitoring, given information gathering cost  $\chi$ , we have

$$\pi(\chi) = \sum_{m > (c - \chi/\tilde{q})k} \binom{k}{m} \bar{\pi}^m (1 - \bar{\pi})^{k-m}. \quad (16)$$

The probability that a randomly chosen neighbor of  $i$  also takes up the derivative product without monitoring is given by  $\bar{\pi}$ . In light of equation (14), the probability that  $i$  takes up the product is simply the probability that at least  $(c - \chi/\tilde{q})k$  other neighbors take up the product. Taking expectations over costs in equation (16), we obtain

$$\bar{\pi} = \sum_{m=0}^k \binom{k}{m} \bar{\pi}^m (1 - \bar{\pi})^{k-m} \Pr \left[ \chi > \tilde{q} \left( c(\mu) - \frac{m}{k} \right) \right]. \quad (17)$$

Figure 4 plots the fixed point solution  $\bar{\pi}$  from equation (17) as a function of  $\mu$ . For large  $\mu$ , there is a unique solution,  $\bar{\pi} = 1$  where all OTC participants willingly trade in secured money markets without monitoring. In particular, if investors do decide to acquire information, they find that this does not alter their valuation, of the derivative product. In other words, in this region, derivatives and repos based on covered bonds are informationally insensitive. As

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<sup>19</sup>A formal derivation for equation (15), from the utilities given by equations (12) and (13), is given by Brock and Durlauf (2001), where to the utility values  $u_i^s(1)$  and  $u_i^s(0)$  we add random stochastic terms  $\epsilon(1)$  and  $\epsilon(0)$ , respectively, which are extreme value distributed, i.e.,

$$\Pr[\epsilon(1) - \epsilon(0) = x] = \frac{1}{1 + \exp(-\beta x)}.$$

returns decreases, a second solution emerges at  $\mu = 2.4$ , where  $\bar{\pi} = 0$ , and all investors monitor and hold back from the secured money markets. Since this solution co-exists with the  $\bar{\pi} = 1$  solution, decisions by a few investors to deviate and acquire information can result in an abrupt aggregate shift in behavior, valuation and prices. As returns decrease, covered bond derivatives switch from being informationally insensitive to informationally sensitive.

The speed of diffusion, i.e., the willingness of investors to trade without due diligence, thus determines the firesale discount,  $\lambda$ . When  $\bar{\pi} = 1$ , investors believe that the underlying collateral is sound and, hence, the asset is relatively easy to sell. But, when  $\bar{\pi} = 0$ , the OTC market becomes relatively illiquid as cautious investors reject bilateral deals and require a large discount to hold the asset. The extent of the firesale depends, therefore, on how long it takes covered bond products to gain widespread acceptance among OTC investors. Following Young (2011) we define the expected waiting time as

$$t^* = \mathbb{E} \left[ \min \left\{ \sum_i d_i^t \geq \rho N, \ \& \ \forall s \geq t \ \Pr \left( \sum_i d_i^s \geq \rho N \right) \geq \rho \right\} \right], \quad (18)$$

i.e., the expected time that must elapse until at least a fraction  $\rho$  of investors take up covered bond products, and the probability is at least  $\rho$  that at least this proportion takes up these assets in all subsequent sub-periods. In other words, for covered bond products to be taken up in expectation across the network, a high proportion of investors must be willing to adopt them and stick to their choice with high probability. Accordingly,

$$\lambda = t^* \quad (19)$$

so that if investors opt to take up quickly, then the fire sale discount is lower. But if investors are reticent in taking up covered bond products and monitor first, then  $\lambda \rightarrow \infty$  as  $t^* \rightarrow \infty$ .

Our model exhibits slow price recovery, which is a consequence of the persistence of equilibrium outcomes in Figure 4. Initial conditions for  $d_i^0$  matter. To see this, consider the situation where  $d_i^0 = 1$  and  $\beta_i < \infty$  for all investors. For low realizations of returns,  $\mu$ , the system is highly sensitive to the number of investors that experiment and transition to the  $\bar{\pi} = 0$  solution – experimentation in monitoring by a few leads all others to follow suit. Liquidity in OTC markets is, therefore, fragile. The  $\bar{\pi} = 0$  solution is more stable than  $\bar{\pi} = 1$  because deviations in the expected payoffs to each investor are lower if investors are monitoring. So the solution persists as returns gradually increase. It is only after returns eventually increase to levels such that  $\bar{\pi} = 0$  no longer co-exists with  $\bar{\pi} = 1$  that market liquidity is regained. We follow Young (2011) and set initial conditions to be  $d_i = 0$  for all investors.

Figure 5 plots the probability of a commercial bank run as a function of  $\mu$ , where  $\lambda$  is given by equation (19) and the opportunity cost  $c$ , is assumed to be decreasing in expected returns. As can be seen, the probability  $q$  is decreasing as returns are increasing, with a marked discontinuity at the point where OTC market liquidity collapses ( $\mu \approx 2.4$ ). The relationship between  $q$  and  $\mu$  is shown for two values of encumbrance,  $\alpha$ . In both cases, the attempt by the bank to maintain its ring fenced assets as expected returns fall leads to a rise in the probability of a depositor run. However, the influence of greater encumbrance crucially depends on the state of the OTC market. Secondary markets are liquid when returns are high ( $\mu > 2.4$ ). In this case, higher encumbrance reduces the probability  $q$  as the bank has more liquid funds at its disposal to stave off a run. However, when returns are too low, secondary markets collapse, resulting in a higher haircut for banks, that require the bank to post more collateral in order to maintain the over collateralization of the ring fence. In this case, lower encumbrance helps reduce the probability of a run.

### 3.4. Dealer banks

Empirical studies of OTC markets point to core-periphery network structures (Figure 1), with a few large and highly connected broker-dealers in the core and many smaller dealer in the periphery. In the special case that there is only one dealer bank in the core, the network simplifies to a star (Figure 6). By virtue of their centrality dealers in the core typically have greater bargaining power, facilitating price discovery and influencing aggregate outcomes. We therefore relax the assumption of homogenous OTC networks to account for such structure and explore the consequences for financial stability.

### 3.5. Star network

In a star network, investors trade only with a single dealer at the center – the size of the dealer core is  $C = 1$ . This network is directed, in the sense that peripheral investors look to the dealer bank in determining their best-response strategies, while the dealer bank makes its decision in isolation. Labeling the dealer bank as  $i = 1$ , we have from equations (12) and (13) that it is a best-response for the dealer to trade without monitoring whenever

$$\chi_1 > \tilde{q} c. \quad (20)$$

So peripheral investor  $j = 2 \dots, N^O$  follow suit whenever

$$\chi_j > \tilde{q} (c - \Theta [\chi_1 - \tilde{q} c]), \quad (21)$$

which depends on whether the central dealer willingly enters into trades or not. Taking  $\chi_j$  to be i.i.d across all investors, the fraction of investors willing to trade is

$$\mathbf{Pr} [\chi > \tilde{q} (c - d_1^*) | \chi_1], \quad (22)$$

where  $d_1^* = 1$  if  $\chi_1 > \tilde{q} c$ , and zero, otherwise. So, whenever  $d_1^* = 1$ ,  $\lambda = 0$ . This is identical to the situation shown in Figure 3, where by acting as market-maker of last resort and buying covered bond assets, the central bank serves as de-facto central dealer. Figure 7 illustrates the case where the central dealer is far more willing to experiment (i.e., take on risky collateral) than the periphery ( $\beta_1 = 20$  and  $\beta_j = 700$ , for  $j = 2, \dots, N^O$ ).

#### 3.5.1. Core-periphery networks

Figure 7 also illustrates the consequences for systemic risk when there are several dealer banks in the core ( $C = 20$ ). As the core size increases, their influence in facilitating learning diminishes as returns decrease. Moreover, the inability of the core to reach consensus (again  $\beta_{\text{core}} = 20$ ) concerning their action to willingly trade percolates to other investors in the periphery. The OTC secured money markets are less liquid, resulting in higher run probabilities.

To the extent that experimentation by dealer banks in the core reflects willingness to innovate, our result hints at a tradeoff between financial stability and financial innovation. When returns are low, the willingness to experiment of core players makes for liquid OTC markets and lowers the probability of an unsecured depositor run, compared to a case with homogenous OTC investors. A fuller discussion on the optimal size of the core would involve weighing the gains from competition against the potential losses from increased market illiquidity and financial instability.

## 4. Policy implications

Our model provides a test-bed to consider several policy options that are currently being designed or implemented internationally to improve financial stability. These include limits to asset encumbrance, systems to manage counterparty risk, and contingent liquidity facilities at central banks.



#### 4.1. Limits to asset encumbrance

The portion of a bank's assets being ring-fenced for use as a cover pool is often called encumbrance. The greater the encumbrance, the lower the amount and quality of assets available to unsecured creditors in event of default. In Europe, it is not unusual for cover pools, in some cases, to be in excess of 60 percent of a bank's total assets. In North America, the United Kingdom and Australia, however, a consensus has emerged in favor of strict limits to encumbrance. This partly reflects the higher status accorded to depositors in these banking systems.

The greater the level of encumbrance, the higher the return that unsecured creditors will demand, given the risk of subordination. And the higher this cost, the greater are banks' incentives to finance on secured terms. Policymakers are increasingly concerned that such behavior could prove self-fulfilling and compromise financial stability.<sup>20</sup>

In our model, the amount of debt a bank can raise by issuing covered bonds is controlled by the size,  $\alpha$ , of the ring-fence. If  $\alpha$  is large, the bank can place more assets into the ring-fence and raise secured finance at a more attractive price. The converse is the case when  $\alpha$  is small. Figure 5 shows what happens to systemic risk in the case of a homogenous OTC network when maximum limits on encumbrance are either high or low. The probability of a systemic, or depositor, run declines as  $\alpha$  decreases – the smaller the cover pool, the less jittery are depositors. But, when returns are high, on average, the probability of a run is higher when fewer assets are encumbered. It suggests there could be merit in allowing regulatory limits on levels of encumbrance to vary with the business cycle. During a down-turn, there may be a strong case for enforcing maximum encumbrance limits that are set at low levels. This would help forestall self-fulfilling safety races and, potentially, enhance financial stability.

#### 4.2. Global legal entity identifiers (LEI)

The Financial Stability Board has recently established a framework for a global legal entity identifier (LEI) system that will provide unique identifiers for all entities participating in financial markets. The system, by effectively bar-coding financial transactions, is intended to enhance counterparty risk management and clarify the collateral being used by financial institutions. The LEIs name the counterparties to each financial transaction and, eventually, product identifiers (PIs), will describe the elements of each financial transaction. The aim is to establish a global syntax for financial product identification, capable of describing any instrument, whatever its underlying complexity.

Placing financial transactions on par with real-time inventory management of global product supply chains is especially relevant to the policy debate on centrally-cleared standardized OTC derivatives. This regulatory push seeks to transform the OTC network described above into a star network, in which a central counterparty at the hub maintains responsibility for counterparty risk management. If the central counterparty is not 'too-big-to-fail', then accurate information on collateral and exposures will be key to ensuring that margins to cover risks are properly set. Common standards for financial data, in the form of LEIs and PIs, would facilitate this process.

In terms of our model, the successful implementation of such a regime amounts to setting the variance of the distribution of monitoring costs to zero, leading all investors in the OTC market to have the same monitoring cost  $\bar{\chi}$ . In the case that  $\bar{\chi} = 0$ , we have that  $\bar{\pi} = 0$  is the unique solution to equation (17). All investors decide to perform due diligence on collateral, and the size of the OTC market depends on expected payoffs. With probability  $\tilde{q}$ , the covered bond product is deemed unsound and investors choose not to purchase, i.e., the payoff is zero. With probability  $1 - \tilde{q}$ , the investors regard the collateral as sound and receive  $1 - c$ . By the law of large numbers,  $1 - \tilde{q}$  reflects the fraction of investors participating within, and hence the

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<sup>20</sup>See, for example, Haldane (2012a) and Debelle (2011).

depth, of the OTC markets. Liquidity in the OTC market is driven solely by credit quality, with strategic coordination risks being minimized.<sup>21</sup> Working together with cyclical policies on the limits to encumbrance, LEIs can enhance OTC market liquidity, and hence promote financial stability.

#### 4.3. Collateral and monetary policy

In recent work, Adrian and Shin (2011) and Singh (2011) have highlighted the importance of the new private money creation process ushered in by the emergence of the shadow banking system. Central to modern credit creation is the extent to which collateral (in this case, covered bond securities) can be re-pledged or re-used in OTC deals. Like traditional money multipliers, the length of collateral chains can be thought of as a collateral multiplier, and the re-use rate of collateral as a ‘velocity’. Singh (2011) suggests that the velocity of collateral fell from about 3 at the end of 2007 to 2 at the end of 2010, reflecting shorter collateral chains in the face of rising counterparty risks. Ultimately the reduced availability of collateral has adverse consequences for the real economy through a higher cost of capital.

Singh and Stella (2012) suggest that the slowdown in credit creation via collateral re-pledging can be addressed by central banks increasing the ratio of good/bad collateral in the market – though they are mindful of the fiscal consequences. Swaps of central bank money for illiquid or undesirable assets may, thus, be an integral part of central bank liquidity facilities going forward. Selody and Wilkins (2010) caution that a flexible approach to such facilities is essential if moral hazard is to be contained. Uncertainty about the central bank’s actions, including whether, when, or not it will intervene, and at what price, may help minimize distortions in credit allocation. The Bank of England has emphasized the contingent nature of its intended support in its newly established permanent liquidity facility. Its Extended Collateral Term Repo Facility (ECTR) lends gilts (or cash) against a wide range of less liquid collateral, including portfolios of loans that have not been packaged into securities, at an appropriate price. The ECTR is only activated when, in the judgement of the Bank of England, actual or prospective market-wide stresses are of an exceptional nature.

To the extent the swapping covered bond securities for government issued securities allows collateral to be more readily deployed to other business needs, a lowering of the opportunity cost  $c$  in our model serves to capture collateral velocity. Figure 8 shows the effects of a collateral swap in a star network with the central bank at the hub, which is represented by an increase of  $\kappa$ . Systemic risk is lower under the star configuration than for a homogenous OTC network, as might be expected. But the more willing is the central bank to take risk on its balance sheet and swap good for bad collateral, the lower is systemic risk.

As a final exercise, we investigate the consequences of a contingent liquidity facility operated by the central bank. In the analysis so far, we have considered homogeneous and star network structures. By intervening in secured lending markets, the central bank effectively rewires the network structure into a star, and peripheral investors look to the central bank for guidance in deciding whether to accept covered bond collateral. More generally, a wheel-like network allows us to consider how each peripheral investor trades-off the influences of the central bank to participate in secured markets, with that of other peripheral investors who are loath to do so. The network structure is depicted in the inset of Figure 9. Here, each of the  $N^O - 1$  peripheral investors looks to the central node and another peripheral investor in reaching a decision about

We assume that the central bank’s intervention policy (swapping central bank money for

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<sup>21</sup>This same outcome is also achieved for non-zero monitoring costs as long as  $\bar{\chi} < \tilde{q}c$ . If the LEI regime only amount to a shrinking of the support of monitoring costs, then we once again recover this result if the upper-bound of costs is less than  $\tilde{q}c$ .

covered bond collateral) is contingent on returns,  $\mu$ , and is based on the following, publicly known, rule. When returns are too low, ( $\mu \leq 0.1$ ), the central bank always intervenes and buys up secured products from others without monitoring. When returns are in an intermediate band, i.e.,  $\mu \in (0.1, 0.4]$ , however, the central bank will decide to engage in such collateral swaps with a small probability. Finally, when returns are high ( $\mu > 0.4$ ), the central bank will not intervene.

Figure 9 illustrates the consequences of this policy by plotting a time-series the fraction  $\bar{\pi}$  of OTC investors who trade secured covered bond products without monitoring. The figure also shows how  $\mu$  varies sinusoidally with time. The dark vertical bands indicate when the central bank intervenes. Prior to these interventions, returns in OTC markets are very low and investor participation is declining. Once the central bank intervenes, its actions are tantamount to a lowering of the opportunity cost  $c$ , which encouraged investors who had previously dropped out, to once again engage in secured trading. This change in behavior is marked by a sharp turnaround and increase in  $\bar{\pi}$  towards unity. These “*bursty*” dynamics are similar to those described by Young (2011), where central bank intervention strengthens the strategic complementarities for trading without monitoring between the other investors.

At a later date, and in the event that the fundamental no longer warrants the acceptance of such collateral, the central bank’s refusal to accept covered bond securities as collateral induces at least some other market participants to do likewise. However, these investors learn that fundamentals are strong and update their strategies to engage in OTC trades. Such learning behavior contributes to lower systemic risk (smaller  $q$ ).

## 5. Conclusion

Following the collapse of Lehman Brothers in September 2008, and the freezing up of unsecured debt markets, banks have increasingly looked to secured debt, and covered bonds in particular, to meet funding requirements. Our paper contributes to an understanding of how these markets can affect financial stability.

While our results are merely suggestive, they support calls for dynamic limits to asset encumbrance. During periods of economic downturns, enforcing a low maximum encumbrance limit would ensure that banks have greater assets to liquidate and meet the demands on fleeing unsecured creditors. The public knowledge that banks have these assets would calm jittery creditors. Our results also have bearing on recent proposals for global LEIs, which would serve to reduce strategic risks in OTC markets and replace them with measurable credit risks. These LEIs will further serve to make financial products informationally insensitive.

Finally, our results support the actions of central banks to extend their collateral swap facilities during crisis periods as a mechanism to keep core funding markets open. But our model is silent on the moral hazard implications of such policies, particularly in situations where good collateral is swapped for less desirable collateral. But distortions may be minimized if central banks follow a flexible approach by making the extension of their support contingent.

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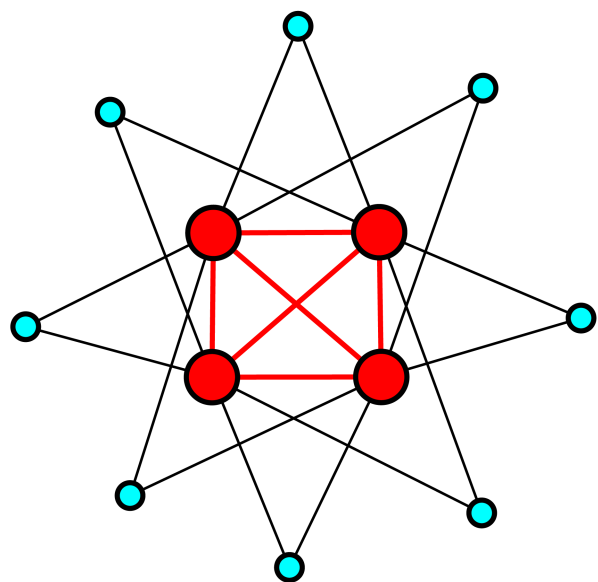


Figure 1: Example of a core-periphery OTC network with a fully connected core of four dealer banks and a peripheral set of OTC counterparties.

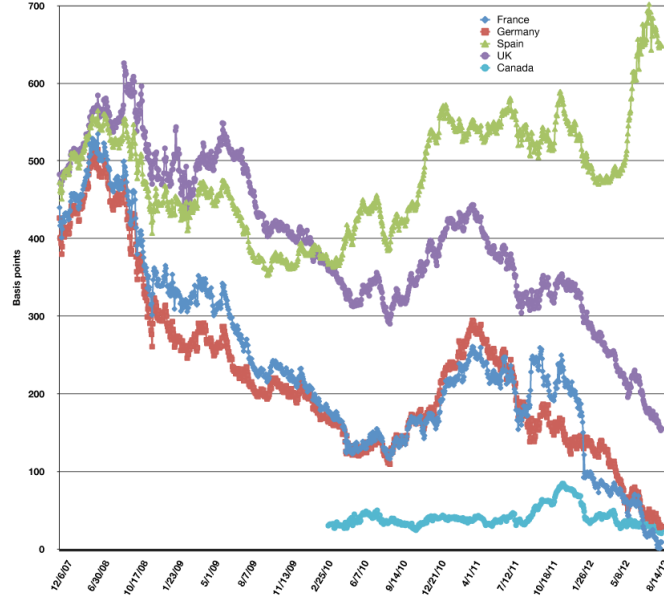


Figure 2: Spreads of covered bond prices to 5 year US Dollar Swaps.

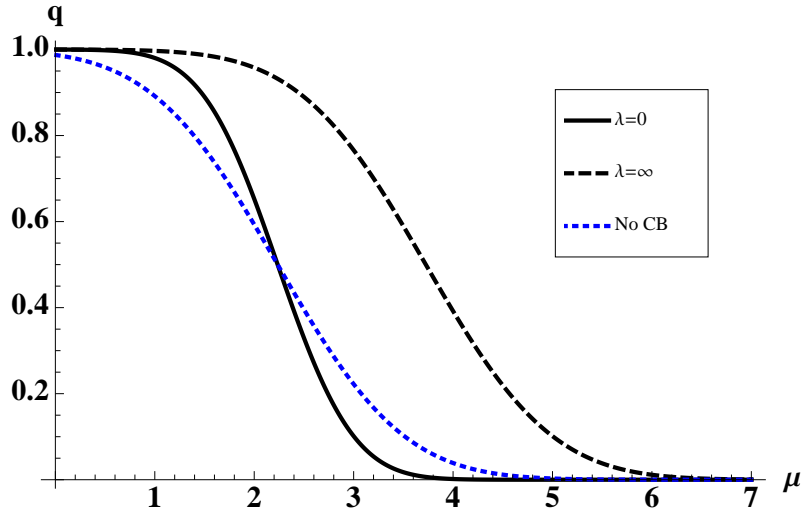


Figure 3: Probability of a crisis  $q$  as a function of returns  $\mu$  with and without covered bonds. Two values of  $\lambda$  and  $\alpha$  are considered for the covered bond regime. Additional parameters were  $r^D = 0.05$ ,  $\psi = 0.2$ ,  $\tau = 0.1$  and  $\sigma = 1$ . On the bank's balance sheet  $A^L = L^D = 1$ .



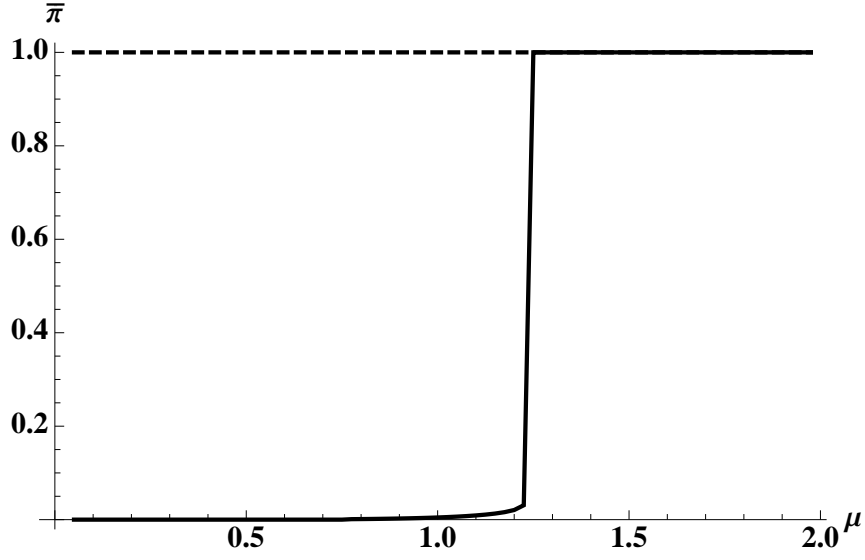


Figure 4: Fraction of OTC investors who are willing to trade covered bond products, without monitoring, as a function of returns  $\mu$ . Connectivity on the OTC network was set at  $k = 11$ , and an exponential distribution was taken for the monitoring costs where  $\bar{\chi} = 0.01$ . We set the probability  $\tilde{q} = 0.15$ .

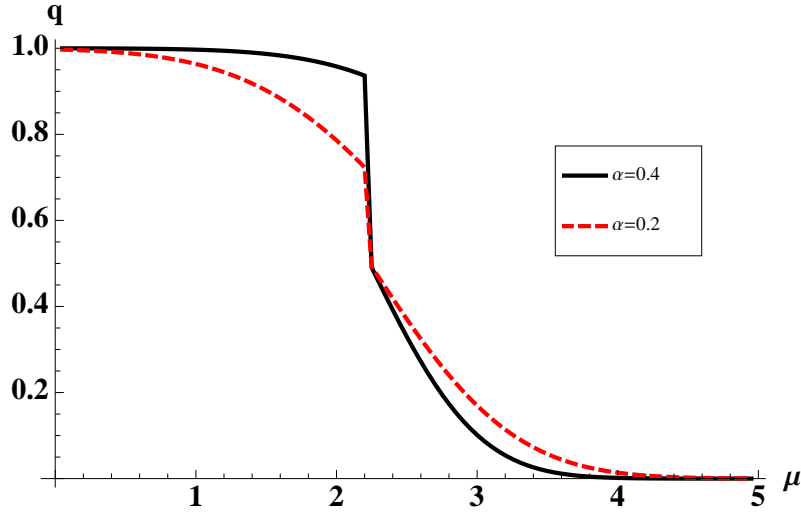


Figure 5: Probability of bank runs as a function of returns  $\mu$ . Connectivity on the OTC network was set at  $k = 11$ , and an exponential distribution was taken for the monitoring costs where  $\bar{\chi} = 0.01$ . We set the probability  $\tilde{q} = 0.15$ . Additional parameters were  $\kappa = 1$ ,  $r^D = 0.05$ ,  $\psi = 0.2$ ,  $\tau = 0.1$  and  $\sigma = 1$ . On the bank's balance sheet  $A^L = L^D = 1$ .

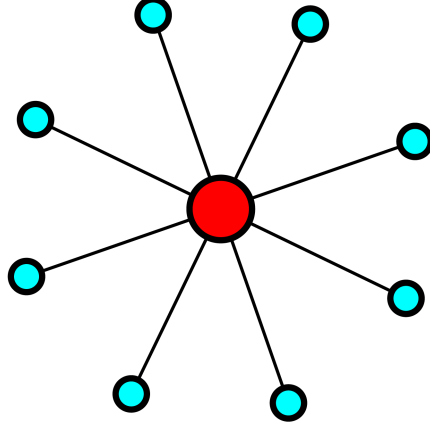


Figure 6: Example of a star OTC network.

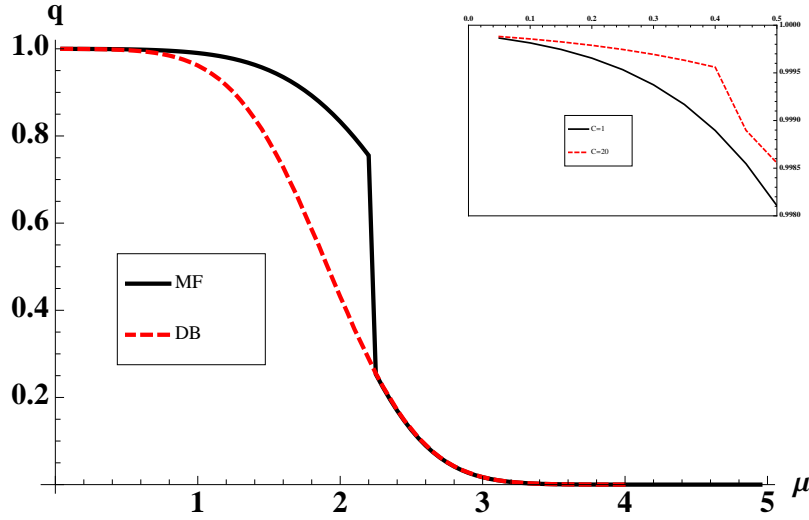


Figure 7: Probability of bank runs as a function of asset returns  $\mu$ . The solid black curve represents the theoretical mean-field result using equation (17) for investor behavior on the homogenous OTC network, where each investor has  $k = 11$  neighbors. The red curve is for a star OTC network with  $N^O = 500$  players, where the central dealer bank has  $\beta = 20$ , while the peripheral investors have  $\beta = 700$ . The inset plots  $q$  for cores of sizes  $C = 1$  and  $C = 20$ . In all cases, an exponential distribution was taken for the monitoring costs where  $\bar{\chi} = 0.01$ . We set the probability  $\tilde{q} = 0.15$ . Additional parameters were  $\rho = 0.75$ ,  $\kappa = 1$ ,  $\alpha = 0.4$ ,  $r^D = 0.05$ ,  $\psi = 0.2$ ,  $\tau = 0.1$  and  $\sigma = 1$ . On the bank's balance sheet  $L^D = A^L = 1$ .

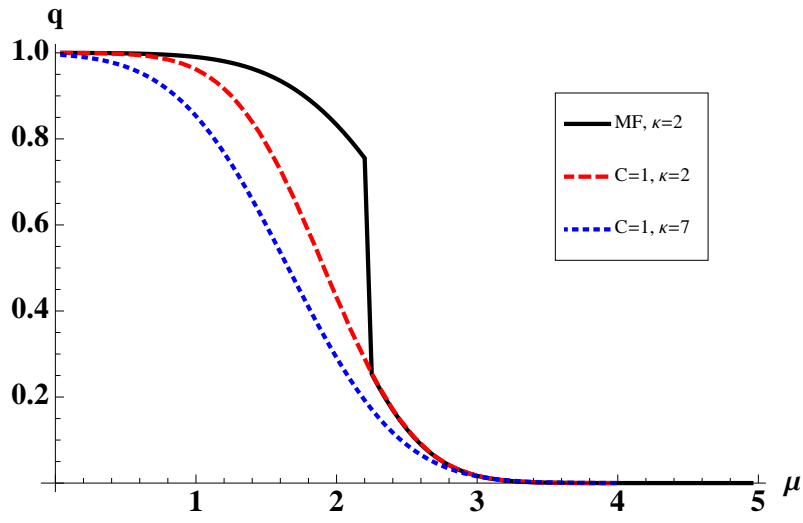


Figure 8: Probability of bank runs as a function of asset returns  $\mu$ . The solid black curve represents the theoretical mean-field result using equation (17) for investor behavior on the homogenous OTC network, where each investor has  $k = 11$  neighbors. The dashed red curve is for a star OTC network with  $N^O = 500$  players,  $\kappa = 1$ . The dotted blue curve is also for a star OTC network, but with  $\kappa = 7$ . In both cases the central dealer bank has  $\beta = 20$ , while the peripheral investors have  $\beta = 700$ . An exponential distribution was taken for the monitoring costs where  $\bar{\chi} = 0.01$ . We set the probability  $\tilde{q} = 0.15$ . Additional parameters were  $\rho = 0.75$ ,  $\alpha = 0.4$ ,  $r^D = 0.05$ ,  $\psi = 0.2$ ,  $\tau = 0.1$  and  $\sigma = 1$ . On the bank's balance sheet  $L^D = A^L = 1$ .

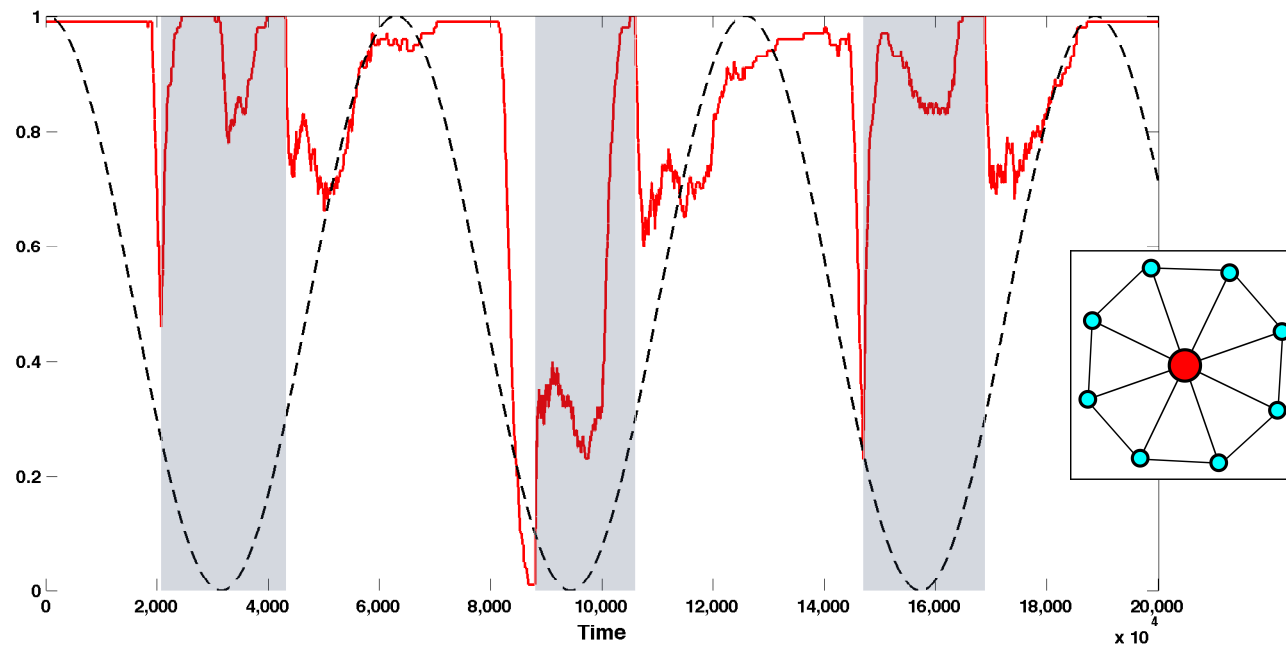


Figure 9: Time-series for the fraction of OTC investors willing to trade without monitoring. The black dashed curve depicts how  $\mu$  evolves of time, while the solid red curve gives the fraction of investors. Finally, the shaded regions give the intervals where the central hub introduced a liquidity facility and purchased covered bond products for other investors.

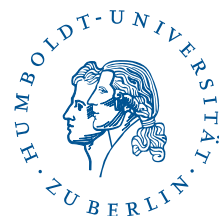
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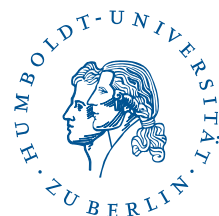
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