Preliminary and incomplete draft

Covered bonds

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Abstract

We offer a model of covered bonds that analyzes the interaction of this form of secured funding with unsecured wholesale funding. To back the issuance of covered bonds, assets are encumbered, or ring fenced, on the bank's balance sheet. This raises additional funding and finances profitable investment. However, such asset encumbrance concentrates credit risk onto wholesale investors, exacerbating the incidence of wholesale debt runs. The optimal asset encumbrance balances the bank funding channel with the risk concentration channel. We also derive implications for the pricing of covered bonds and discuss policy implications.

Keywords: asset encumbrance, bank funding, covered bonds, debt runs, fragility, global games, ring fencing, rollover risk, wholesale funding.

JEL classifications: D82, G01, G21.

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1. Introduction

The global financial crisis and sovereign debt concerns in Europe have focused attention on the issuance of covered bonds as a source of banks funding. Unsecured debt markets — the bedrock of bank funding — froze following the collapse of Lehman Brothers in September 2008, 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 bank resolution offer a favorable treatment to covered bondholders; the move towards central counterparties for over-the-counter (OTC) derivatives transactions has also increased the demand for 'safe' collateral; and covered bonds help banks meet Basel III liquidity requirements.[1]

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.[2] 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. 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.[3] Importantly, these features of covered bonds therefore shift risk asymmetrically towards unsecured creditors.

Markets for covered bonds have existed since the eighteenth century in continental Europe, and received renewed attention in advanced and emerging economies after the financial crisis of 2007–09. In the United States, where the market for mortgage-backed-

[1] See Basel Committee on Banking Supervision (2013) for details.

[2] Unlike other forms of asset-back issuance, such as residential mortgage-backed securities, covered bonds remain on the balance sheet of the issuing bank.

[3] 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.

securities (MBS) faced severe disruptions during the height of the crisis, Bernanke (2009) suggests that covered bonds are a secure and viable alternative to MBS for banks funding. Figure 1 depicts the issuance of covered bonds over the past decade by type of backed securities. In fact, covered bonds backed by mortgages has grown three-fold over this period.[4]

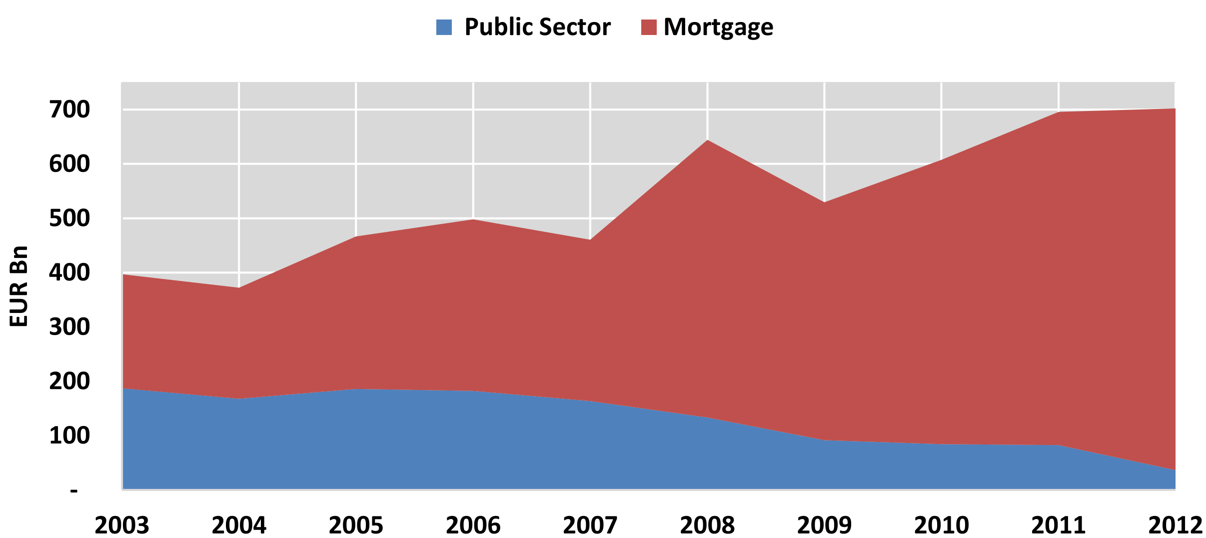

Figure 1: Issuance of covered bonds, aggregated across countries. Source: European Council on Covered Bonds

Notwithstanding their history, there is surprisingly little academic literature on covered bonds; much of which is focused on legislative differences in market structures across countries.[5] The nascent literature on the interplay between secured and unsecured funding focuses primarily on repo markets.[6] Our paper is the first to address other forms of secured funding, in particular covered bonds.

[4]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.

[5]See, for example, Packer et al. (2007) and Schwarcz (2011) for surveys on how covered bonds markets function. In a recent empirical contribution, Prokopczuk et al. (2013) investigate how market liquidity and asset quality influence the pricing of covered bonds.

[6]For example, Perotti and Matta (2014) consider short-term repo funding and unsecured short-term debt.

This paper models covered bonds and explores their implication for bank fragility. A commercial bank finances its profitable investment in high-quality assets with a mix of unsecured and secured funding. Wholesale investors hold unsecured wholesale debt, while safety-oriented investors hold covered bonds. Bankruptcy may occur after a credit shock, when some of its assets become non-performing and wholesale funding may not be rolled over. The rollover decisions of wholesale debt are modeled as a coordination game, and we adopt the global games approach as in Rochet and Vives (2004) with imperfect information about the credit shock. This allows us to derive a unique equilibrium in the rollover game that is characterized by a threshold of the credit shock above which a wholesale debt run occurs ex post. Importantly, we link this threshold to the bank's ex-ante funding choice.

The issuance of covered bonds has two opposing effects on the incidence of wholesale debt runs. First, issuing more covered bonds raises more funds from covered bond investors, which allows the bank to make more profitable investments. This **bank funding channel** raises the value of the bank's unencumbered assets and supports the rollover of wholesale debt. Second, issuing more covered bonds requires to encumber more assets on the bank's balance sheet. After a credit shock, non-performing assets in the cover pool must be replaced by unencumbered assets. This concentrates the shock on the unencumbered assets and, hence, onto wholesale investors. This **risk concentration channel** is more prominent when more assets are encumbered and supports a wholesale debt run.

We derive the optimal amount of covered bonds issuance and corresponding asset encumbrance. We provide sufficient conditions for the existence of an interior amount of asset encumbrance that balances the bank funding and risk concentration channels. While it is initially desirable to attract additional funding from covered bond investors for profitable investment, the fragility of wholesale debt becomes dominant at a certain proportion of asset encumbrance. The bank optimally refrains from further covered bond issuance. This result does not require diminishing returns to investment. Since bail-outs and deposit insurance are absent, the bank as residual claimant internalizes the impact of its funding choice.

Our model is relevant to recent policy debates on asset encumbrance.[7] The dynamic adjustment of a bank's balance sheet to ensure the quality of the cover pool increases financial fragility ex post. Moreover, the larger the pool of ring-fenced assets, and the greater the associated uncertainty, the more jittery are unsecured creditors. However, this does not necessarily imply that limits to encumbrance therefore help forestall financial crises ex ante. Indeed, as the bank funding channel suggests, covered bonds provide a cheap and stable form of bank funding. To the extent that socially profitable investment is made, the overall effect of covered bond funding can be a higher value of unencumbered assets, which are available to meet withdrawals from wholesale debt holders. More broadly, our theory suggests a general-equilibrium approach to the regulation of asset encumbrance that goes beyond the narrow focus on the risk concentration channel.

Finally, our model allows us to describe the equilibrium promised return on covered bonds. Their 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 empirically 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 percent 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.[8] An analysis of the seniority of covered bond holders relative to retail depositor insurance fund is left for future research.

[7] Haldane (2012) notes that, at high levels of encumbrance, the financial system is susceptible to pro-cyclical swings in the underlying value of banks' assets and prone to system-wide instability.

[8] Some countries do not apply encumbrance limits, while others set thresholds on a case-by-case basis.

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.[9] Our analysis models the institutional features of covered bonds in the context of rollover risk associated with wholesale funding, which relies on the ideas from the literature on global games pioneered by Carlsson and van Damme (1993). Bank runs and liquidity crises in the context of global games have previously been studied by Goldstein and Pauzner (2005) and Rochet and Vives (2004), among others, and we adapt the latter approach for our purposes. Our model is also related to recent empirical work that examines whether covered bonds can substitute for mortgage-backed securities (see Carbò-Valverde et al. (2011)).

2. Model

The economy extends over three dates $t \in \{0,1,2\}$ and is populated by a banker, a unit mass of wholesale investors, and a mass $\gamma \in (0,\infty)$ of covered bond investors. There is universal risk-neutrality and no time discounting. The banker wishes to consume at the final date, $U = C_2$, the covered bond investor wishes to consume at the initial or final date $U = C_0 + C_2$, while wholesale investors can consume at either date $U = C_0 + C_1 + C_2$. Each investor has a unit endowment at the initial date, when the penniless banker has access to investment opportunities with positive net present value.

The banker attracts funding from investors at the initial date by offering a wholesale debt contract and a covered bond contract. As in Rochet and Vives (2004), wholesale debt requires a unit deposit at the initial date and can be withdrawn at the interim or final date. The face value of wholesale debt $D \geq 1$ is independent of the withdrawal date. The banker raises $D_0 \in [0,1]$ from wholesale investors to invest the proceeds in high-quality assets (mortgages and government debt). One unit of the asset yields a finite gross return R at the final date. Liquidation at the interim date yields $\psi \in (0,1)$ of the final-date return.[10]

[9] See Packer et al. (2007) for an overview of the covered bond market prior to the global financial crisis.

[10] This discount reflects the cost of physical liquidation, the relationship-specific knowledge of the lender lost

Further funding is attracted from covered bond investors at the initial date. First, the banker ring-fences a fraction $\alpha \in [0,1]$ of assets, which is publicly observed. Second, the encumbered assets αD_0 are placed in a bankruptcy-remote vehicle, the cover pool, that remains on the bank's balance sheet. Third, these ring-fenced assets are valued marked-to-market and the final-date value of the cover pool is $CB \equiv \psi R\alpha D_0 < R\alpha D_0$. This is known as over-collateralization. The banker raises $CB_0 \geq 0$ from issuing covered bonds with face value CB and invests these proceeds in high-quality assets. Table 1 summarizes.

(cover pool)	αD_0	CB_0
(unencumbered assets)	$(1-\alpha)D_0 + CB_0$	D_0

Table 1: Balance sheet at $t = 0$

A defining feature of covered bonds is the dynamic replenishment of the cover pool. The balance sheet suffers a shock $S \in \mathbb{R}$ at the final date, which is drawn from a continuous probability distribution function $f(S)$ with corresponding cumulative distribution function $F(S)$. The banker, upon observing the realized shock S at the interim date, must maintain the value of the cover pool at all dates. For example, the banker swap out any non-performing assets in the cover pool with performing unencumbered assets. While dynamic replenishment protects covered bond investors, the entire shock is concentrated on wholesale investors. Table 2 illustrates risk concentration on unencumbered assets after a small shock $S > 0$ and in the absence of wholesale debt runs.

(cover pool)	$R\alpha D_0$	CB
(unencumbered assets)	$R[(1-\alpha)D_0 + CB_0] - S$	D
		E

Table 2: Balance sheet at $t = 2$ (for a small shock and absent wholesale debt runs)

Bankruptcy occurs if the value of unencumbered assets is insufficient to repay wholesale debt. The bank is closed and each wholesale investor receives an equal share of liqui-

when ownership is transferred (e.g., Diamond and Rajan (2001)), or an illiquidity discount (when assets are sold in a fire sale or there is limited participation, as in Allen and Gale (1994)).

dated unencumbered assets at the interim date:[11]

$$\min\left\{D\,,\,\psi\Big(R[(1-\alpha)D_0+CB_0]-S\Big)\right\}. \tag{1}$$

The banker's equity value is zero in bankruptcy because of limited liability. Furthermore, the cover pool is liquidated to repay covered bond holder. If the banker is not bankrupt, then its equity is the value of investment net of debt payments:

$$E\equiv\max\left\{0\,,R(D_0+CB_0)-S-CB-D\right\}. \tag{2}$$

The banker maximizes the expected equity value.

Rollover risk. Following Rochet and Vives (2004), the rollover decision of wholesale investors is delegated to professional fund managers indexed by $i\in[0,1]$. Managers simultaneously decide whether to roll over funding at the interim date. If a proportion $\ell\in[0,1]$ refuses to roll over, the banker liquidates an amount $\ell D/\psi>\ell D$ to serve withdrawals. Consequently, bankruptcy occurs whenever:

$$R\Big[\Big((1-\alpha)D_0+CB_0\Big)\Big]-S-\frac{\ell D}{\psi}<(1-\ell)D, \tag{3}$$

where the value of unencumbered assets is $R\Big((1-\alpha)D_0+CB_0\Big)-S$ and the banker must serve $(1-\ell)D$ of withdrawals at the final date.

Rochet and Vives (2004) argue that the decision of fund managers is governed by their compensation.[12] In case of bankruptcy, the manager's relative compensation from rolling over is negative, $-c<0$. Otherwise, the relative compensation from rolling over is the benefit $b>0$. The conservativeness ratio $k\equiv c/(b+c)\in(0,1)$ summarizes the payoff parameters.

[11]In bankruptcy, wholesale investors only access unencumbered assets. As Schwarcz (2011) suggests, wholesale investors have access to the excess value of the cover pool at the final date if and only if the bank is open.

[12]This specification ensures global strategic complementarity in the rollover decisions of fund managers. Goldstein and Pauzner (2005) analyze a bank-run game with one-sided strategic complementarity.

Dominance regions. Suppose all wholesale debt is rolled over, $\ell = 0$. Bankruptcy occurs whenever the shock is larger than a *bankruptcy threshold* $\overline{S}$:

$$\overline{S} \equiv R[(1-\alpha)D_0 + CB_0] - D. \tag{4}$$

It is a dominant strategy for fund managers not to roll over wholesale debt for $S > \overline{S}$.

Likewise, suppose no wholesale debt is rolled over, $\ell = 1$. Bankruptcy is avoided whenever the shock is smaller than a *liquidity threshold* $\underline{S}$:

$$\underline{S} \equiv R[(1-\alpha)D_0 + CB_0] - \frac{D}{\psi} < \overline{S}. \tag{5}$$

It is a dominant strategy for fund managers to roll over wholesale debt for $S < \underline{S}$. The shock takes negative values with vanishing probability, $F(0) \searrow 0$, implying that the upper and lower dominance regions are always well defined, that is $\underline{S} \geq -\frac{D}{\psi} > -\infty$ and $\overline{S} \leq R(1+\gamma) - D < \infty$ for all funding choices. Figure 2 shows the tripartite classification of the shock.

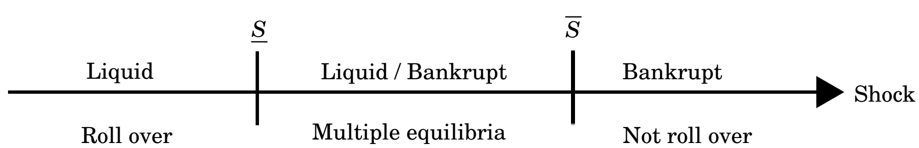

Figure 2: Tripartite classification of the shock

Information. There is incomplete information about the shock. At the interim date S is drawn according to $f(S)$ and only observed by the banker. By contrast, each fund manager i receives a noisy private signal:

$$x_i \equiv S + \epsilon_i. \tag{6}$$

The idiosyncratic noise terms ϵ_i are drawn from a continuous distribution G with support over the interval $[-\epsilon, \epsilon]$, where $\epsilon > 0$. Idiosyncratic noise is independent of the shock and i.i.d. across fund managers. The realization of the shock is publicly observed at the final date. Figure 3 shows the timeline of the model.

Initial date ($t = 0$)	Interim date ($t = 1$)	Final date ($t = 2$)
1. Asset encumbrance α 2. Issue covered bond CB_0	1. Banker learns shock S 2. Dynamic replenishment 3. Noisy signals x_i 4. Wholesale debt withdrawal ℓ 5. Asset liquidation in bankruptcy	1. Bank open if not bankrupt 2. Debt payments D and CB 3. Residual is bank equity E

Table 3: Timeline of events.

3. Equilibrium

Our solution concept is perfect Bayesian equilibrium. We solve our model by working backwards, starting with the rollover subgame between fund managers at the interim date. Each of these subgames is defined by the funding choices at the initial date: the level of asset encumbrance $\alpha \in [0,1]$, funding from covered bond investors $CB_0 \in [0,\gamma]$, the face value of wholesale debt $D \geq 1$, and funding from wholesale investors $D_0 \in [0,1]$. Proposition 1 summarizes the equilibrium in this subgame.

Proposition 1. *If private noise vanishes, $\epsilon \to 0$, then there exists a unique Bayesian equilibrium in each rollover subgame. It is characterized by a threshold of the shock S^* and a threshold of the private signal x^*. Fund manager i rolls over debt if and only if $x_i < x^*$ and bankruptcy occurs if and only if $S > S^*$:*

$$S^* = R\left[(1-\alpha)D_0 + CB_0\right] - \kappa D \in \left(\underline{S}, \overline{S}\right) \tag{7}$$

where $\kappa \equiv 1 + k\left(\frac{1}{\psi} - 1\right) \in \left(1, \frac{1}{\psi}\right)$ and $x^* \to S^*$.

Proof. See Appendix A. ■

The shock threshold varies with the funding choices as summarized in Corollary 1. Raising more funding from either wholesale or covered bond investors increases the amount of unencumbered assets at the interim date, thereby reducing the probability of default on unsecured wholesale debt for any given shock. Consequently, fund managers have more incentives to roll over wholesale debt and a wholesale debt run occurs for a smaller range of shocks. By contrast, greater asset encumbrance reduces the amount of the unencumbered assets for any given shock, which induces wholesale fund managers not to roll over funding for a larger range of shocks. Finally, a larger face value of debt means a smaller range of shocks for which all fund managers are repaid in full for a given value of unencumbered assets. This raises the incentive of fund managers not to roll over funding and debt runs occur for a larger range of shocks.

Corollary 1. *The critical shock size, at which a wholesale debt run occurs, decreases in the level of asset encumbrance and the face value of wholesale debt, while it increases in the funding raised from covered bond investors and wholesale investors.*

$$\frac{\partial S^*}{\partial \alpha} = -RD_0 \leq 0, \tag{8}$$
$$\frac{\partial S^*}{\partial CB_0} = R > 0, \tag{9}$$
$$\frac{\partial S^*}{\partial D} = -\kappa < 0, \tag{10}$$
$$\frac{\partial S^*}{\partial D_0} = R(1-\alpha) \geq 0. \tag{11}$$

Having established the equilibrium in all rollover subgames at the interim date, we now analyse the optimal choice of covered bond funding at the initial date. First, we derive the expected value of the banker's equity. For a small shock, $S < S^*$, the banker's equity is $E(S) = R(D_0+CB_0)-S-CB-D$, where $\lim_{S \nearrow S^*} E(S) = (\kappa-1)D+(1-\psi)R\alpha D_0 > 0$. Bankruptcy occurs for a large shock, $S > S^*$, so the expected equity value of the banker is given by:

$$\pi \equiv \int_{-\infty}^{S^*} E(S)\,dF(S) = F(S^*)[R(D_0+CB_0)-CB-D] - \int_{-\infty}^{S^*} S\,dF(S) \tag{12}$$

Second, we derive the participation constraint of covered bond investors. The outside option is consumption at the initial date that yields 1. Investing in covered bonds buys a claim to a fraction $1/CB_0$ of the face value CB backed by the covered pool. Absent bankruptcy, $S \le S^*$, covered bond investors are repaid in full, yielding CB/CB_0. Even in bankruptcy, covered bond investors can liquidate the cover pool to obtain CB/CB_0, provided the shock is not too large, $S^* < S \le \overline{\overline{S}} \equiv R(D_0 + CB_0) - \alpha R D_0$. However, a large shocks, $\overline{\overline{S}} < S \le \hat{S} \equiv R(D_0 + CB_0)$, also wipes out part of the cover pool, so covered bond investors only receive their fraction of its liquidation value, which is $\psi[R(D_0 + CB_0) - S]/CB_0$ for each investor. The resulting participation constraint of covered bond investors is:

$$1 \le F\left(\overline{\overline{S}}\right)\left(\frac{CB}{CB_0}\right) + \int_{\overline{\overline{S}}}^{\hat{S}} \psi \frac{R(D_0 + CB_0) - S}{CB_0}\, dF(S). \tag{13}$$

The banker chooses the level of asset encumbrance and the amount of funding from covered bonds to maximize the expected value of equity subject to the participation constraint of covered bond investors, taking the wholesale debt contract (D_0, D) as given:

$$\max_{\alpha \in [0,1], CB_0 \in [0,\gamma]} \pi(\alpha, CB_0; D_0, D) \text{ s.t. } (13)$$

Proposition 2. *If covered bond investors are relatively abundant, $\gamma \ge \psi\left[RF(R) - \int_0^R S\, dF(S)\right]$, and a regularity condition on the distribution F holds, then there exists an interior solution for the level of asset encumbrance $\alpha^* \in (0,1)$.*

Proof. See Appendix B. ■

References

Allen, F. and D. Gale (1994). Limited market participation and volatility of asset prices. *American Economic Review 84*(4), 933–55.

Bernanke, B. S. (2009). The future of mortgage finance in the united states. *The B.E. Journal of Economic Analysis and Policy 9*(3), 1–10.

Carbò-Valverde, S., R. J. Rosen, and F. Roriguez-Fernández (2011, November). Are covered bonds a substitute for mortage-backed securities? Federal Reserve Bank of Chicago Working Paper no. 2011-14.

Carlsson, H. and E. van Damme (1993). Global games and equilibrium selection. *Econometrica 61*(5), 989–1018.

Diamond, D. W. and R. G. Rajan (2001). Liquidity risk, liquidity creation, and financial fragility: A theory of banking. *Journal of Political Economy 109*(2), 287–327.

Frankel, D., S. Morris, and A. Pauzner (2003). Equilibrium selection in global games with strategic complementarities. *Journal of Economic Theory 108*(1), 1–44.

Goldstein, I. and A. Pauzner (2005). Demand deposit contracts and the probability of bank runs. *Journal of Finance 60*(3), 1293–1327.

Haldane, A. (2012, April). Financial arms races. Speech to the Institute for New Economic Thinking, 14 April, Berlin.

Basel Committee on Banking Supervision (2013). Basel iii: The liquidity coverage ratio and liquidity risk monitoring tools. Technical report, Bank for International Settlements.

Morris, S. and H. S. Shin (2003). Global games: Theory and applications.

Packer, F., R. Stever, and C. Upper (2007, September). The covered bond market. *BIS Quarterly Review*, 43–55.

Perotti, E. and R. Matta (2014). Repo funding and faster bank runs.

Prokopczuk, M., J. B. Siewert, and V. Vonhoff (2013). Credit risk in covered bonds. *Journal of Empirical Finance 21*, 102–120.

Rochet, J.-C. and X. Vives (2004). Coordination failures and the lender of last resort: was bagehot right after all? *Journal of the European Economic Association 2*(6), 1116–1147.

Schwarcz, S. L. (2011). The conundrum of covered bonds. *Business Lawyer 561*(3), 561–586.

Appendix A. Proof of Proposition 1

Vanishing private noise, $\epsilon \to 0$, is sufficient to establish the existence of a unique Bayesian equilibrium in each rollover subgame, which is in threshold strategies.[13] Each fund manager i uses a threshold strategy, whereby wholesale debt is rolled over if and only if the private signal suggests that the shock is small, $x_i < x^*$. Hence, for a given realization $S \in [\underline{S}, \overline{S}]$, the proportion of fund managers who do not roll over debt is:

$$\ell\left(S, x^*\right) = \text{Prob}\left(x_i > x^* | S\right) = \text{Prob}\left(\epsilon_i > x^* - S\right) = 1 - G\left(x^* - S\right).$$

The critical mass condition states that bankruptcy occurs when the shock reaches a threshold S^*, where the proportion of wholesale debt that is not rolled over is evaluated at S^*:

$$R\left[(1-\alpha)D_0 + CB_0\right] - S^* - \ell\left(S^*, x^*\right)\frac{D}{\psi} = \left(1 - \ell\left(S^*, x^*\right)\right)D \tag{A.1}$$

Using Bayes' rule, the posterior distribution of the shock conditional on the private signal is $S|x_i$. The indifference condition states that the fund manager who receives the critical signal $x_i = x^*$ is indifferent between rolling over and not rolling over wholesale debt:

$$k = \Pr\left(S < S^* | x_i = x^*\right). \tag{A.2}$$

Using the definition of the private signal $x_j = S + \epsilon_j$ of the indifferent fund manager,

[13] Morris and Shin (2003) show that only threshold strategies survive the iterated deletion of strictly dominated strategies. See also Frankel et al. (2003).

we can state the conditional probability as follows:

$$
\begin{aligned}
1-k &= \Pr\left(S \geq S^* | x_i = x^*\right) & \text{(A.3)}\\
&= \Pr\left(S \geq S^* | x_i = x^* = S + \epsilon_j\right) & \text{(A.4)}\\
&= \Pr\left(x^* - \epsilon_j \geq S^*\right) & \text{(A.5)}\\
&= \Pr\left(\epsilon_j \leq x^* - S^*\right) & \text{(A.6)}\\
&= G\left(x^* - S^*\right) & \text{(A.7)}
\end{aligned}
$$

Therefore, the indifference condition implies that $x^* - S^* = G^{-1}\left(1-k\right)$. Inserting the indifference condition into $\ell\left(S^*, x^*\right)$, the proportion of fund managers who do not roll over when the shock is at the critical level S^* is perceived by the threshold fund manager to be:

$$\ell\left(S^*, x_i = x^*\right) = 1 - G\left(x^* - S^*\right) = 1 - G\left(G^{-1}\left(1-k\right)\right) = k. \tag{A.8}$$

Therefore, the threshold of the shock is $S^* = R\left[(1-\alpha)D_0 + CB_0\right] - \kappa D$. If private noise vanishes, the signal threshold also converges to this value. □

Appendix B. Proof of Proposition 2

Step 1. The derivative of the banker's expected profit with respect to the funding raised from covered bonds issuance is:

$$\frac{\partial \pi}{\partial CB_0} = RF(S^*) + Rf(S^*)\left[(\kappa - 1)D + (1-\psi)\alpha R D_0\right] > 0 \tag{B.1}$$

for all feasible values of α, CB_0, D, and D_0. Therefore, the banker raises as much funding from covered bond investors as possible.

Furthermore, the participation constraint of covered bond holders can be written as:

$$CB_0 \leq F\left(\overline{\overline{S}}\right)CB + \int_{\overline{\overline{S}}}^{\hat{S}} g(S)\, dF(S), \tag{B.2}$$

where $g(S) = \psi[R(D_0 + CB_0) - S]$, which implies that $g\left(\overline{\overline{S}}\right) = CB$ and $g\left(\hat{S}\right) = 0$. Taking the derivatives with respect to the funding from covered bond investors, the left-hand side has a unit slope, while the right-hand side's slope is:

$$\frac{dRHS}{dCB_0} = f\left(\overline{\overline{S}}\right)CB\frac{d\overline{\overline{S}}}{dCB_0} - g\left(\overline{\overline{S}}\right) f\left(\overline{\overline{S}}\right)\frac{d\overline{\overline{S}}}{dCB_0} - g\left(\hat{S}\right) f\left(\hat{S}\right)\frac{d\hat{S}}{dCB_0} = 0 \tag{B.3}$$

Therefore, the left-hand side of condition B.2 increases in CB_0, while the right-hand side is constant in CB_0, so we evaluate the right-hand side at $CB_0 = 0$ without loss of generality:

$$CB_0 \leq F\Big((1-\alpha)RD_0\Big)CB + \int_{(1-\alpha)RD_0}^{RD_0} \psi[RD_0 - S]\, dF(S) \equiv RHS(CB_0 = 0) \geq 0. \tag{B.4}$$

Regarding boundary conditions, we have that $LHS \in [0, \gamma]$. What is the largest value of the right-hand side for any funding choice at the initial date? The RHS increases in D_0:

$$\frac{dRHS(CB_0 = 0)}{dD_0} = \alpha\psi RF\Big(R[1-\alpha]D_0\Big) \geq 0, \tag{B.5}$$

so it takes its highest value at $D_0 = 1$. When evaluated at $CB_0 = 0$ and the $D_0 = 1$, the right-hand side increases in α:

$$\frac{RHS(CB_0 = 0, D_0 = 1)}{d\alpha} = \psi RF\Big(R[1-\alpha]\Big) > 0, \tag{B.6}$$

so the right-hand side takes it largest value for $\alpha = 1$:

$$RHS \leq RHS(CB_0 = 0, D_0 = 1, \alpha = 1) = \psi\left[RF(R) - \int_0^R S dF(S)\right] > 0. \tag{B.7}$$

Thus, if covered bond investors are relatively abundant, $\gamma \geq \psi\left[RF(R) - \int_0^R S dF(S)\right]$, then there exists a unique interior value of $CB_0^*(\alpha) \in [0,\gamma]$ for the participation constraint of covered bond holders to bind:

$$CB_0^*(\alpha) \equiv F\Big((1-\alpha)RD_0\Big)CB + \int_{(1-\alpha)RD_0}^{RD_0} \psi[RD_0 - S]\, dF(S). \tag{B.8}$$

Increasing the level of asset encumbrance therefore raises the funding attracted from covered bond investors:

$$\frac{\partial CB_0^*(\alpha)}{\partial \alpha} \equiv \psi RD_0 F\Big((1-\alpha)RD_0\Big) > 0. \tag{B.9}$$

Step 2. Evaluating the threshold $S^*(\alpha, CB_0; D_0, D)$ at $CB_0^*(\alpha)$ yields:

$$\begin{aligned}
S^*(\alpha;D_0,D) &\equiv (1-\alpha)RD_0 - \kappa D + \alpha\psi R^2 D_0 F\Big((1-\alpha)RD_0\Big) + \psi R\int_{(1-\alpha)RD_0}^{RD_0} [RD_0 - S]\, dF(S) \\
\frac{\partial S^*(\alpha;D_0,D)}{\partial \alpha} &= RD_0[\psi RF\Big((1-\alpha)RD_0\Big) - 1] \lesseqgtr 0
\end{aligned}$$

Similarly, evaluating the expected equity value of the banker at $CB_0(\alpha)$ yields:

$$\begin{aligned}
\pi(S^*,\alpha;D_0,D) &\equiv F(S^*(\alpha))\Big[RD_0 - D + CB\Big\{-1 + RF\Big((1-\alpha)RD_0\Big)\Big\} + \psi R\int_{(1-\alpha)RD_0}^{RD_0} [RD_0 - S]dF(S)\Big] + \cdots \\
&\quad \cdots - \int_{-\infty}^{S^*} S\, dF(S) \\
\frac{\partial \pi(S^*,\alpha;D_0,D)}{\partial \alpha} &= \psi RD_0\,[-1 + RF\Big((1-\alpha)RD_0\Big)]\,F(S^*(\alpha)) \\
\frac{\partial \pi(S^*,\alpha;D_0,D)}{\partial S^*} &= f\Big(S^*(\alpha)\Big)\,[(\kappa-1)D + (1-\psi)\alpha RD_0] > 0
\end{aligned}$$

Thus, taking its effect via the funding from covered bond investors into account, the banker chooses $\alpha \in [0,1]$ to maximize his expected equity value subject to equation (B.8), which yields the following total derivative. [remainder to be typed]