J Real Estate Finan Econ
https://doi.org/10.1007/s11146-020-09747-8

Price Discovery Limits in the Credit Default Swap Market in the Financial Crisis

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Published online: 15 February 2020

Abstract
We derive the credit default swap (CDS) premium a financial institution requires to assume the default risk of fixed income instruments and the maximum premium a CDS buyer is willing to offer. These premiums are functions of the institution's capital and current risk exposure. In most cases, an institution requires an increasing premium to assume additional risk. However, we show that an under-capitalized institution that already has substantial default risk exposure would engage in risk-shifting and assume more risk at lower CDS premiums. Consistent with this, prior to the 2008 financial crisis credit default swap issuance increased substantially, as did the volume of the underlying mortgage-backed securities, but the data suggests that required CDS premiums remained constant or declined.

Keywords Credit insurance · Credit default swaps · Price discovery

Introduction

One of the main puzzles of the 2008 financial crisis, as documented below, is that the issuance of credit default swaps (CDS) on mortgage-backed securities increased substantially in the 2004–2007 period, while the premiums remained unchanged or even declined. This observation contradicts standard economic theory, which suggests

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that a CDS issuer would normally require higher premiums to issue ever more CDS since doing so creates exposure concentration risk and puts the firm at risk. We offer a detailed discussion of the CDS market in Section 2 below.

In this paper, we attempt to explain the apparent disconnect between pricing of CDS and their risk. In particular, we attempt to explain how increasing demand for CDS, which under normal circumstances should lead to an increase in the premiums charged, can lead to the opposite result of lower spreads. The core of our argument is based on risk-shifting from the CDS issuer to the firm's creditors. Importantly, CDS buyers in our model are fully informed and price-in the default risk of the CDS issuer. The model is based on a Poisson jump process of capital loss to capture security default risk with which CDS sellers face a positive probability of default and have strong risk shifting motive when capital stock is low.

The contribution of the paper is the application of the model to firms issuing CDS on mortgage-backed securities. Commentators have pointed to CDS on mortgage-backed securities issuance as one of the factors that caused, or at least exacerbated, the 2008 financial crisis. In the run-up to the crisis, from 2003 to 2007, the issuance of CDS backing mortgage securitization increased three-fold while mortgage debt doubled. The empirical evidence points to the underpricing of mortgage default risk ex ante in the private label residential mortgage backed securities (PL MBS) market in these years (Levitin, Lin, & Wachter, forthcoming). Moreover, the trading of the ABX, an index of subprime pools, often insured against default through CDS, showed no increase in risk premiums from 2006 through 2007, even as fundamentals declined. For instance, housing prices did begin their decline in mid-2006 and early subprime defaults spiked.[1] This underpricing of risk occurred, despite the fact that the ABX did trade and were transparently referenced to the underlying subprime mortgages, unlike PL MBS which were often sold over the counter. In these years, the volume of CDS issued continued to increase with no increase in the price of risk (Schwarcz, 2019).

There has been no explanation in the literature for why firms issuing CDS would continue to issue CDS without pricing in additional risk, as fundamentals observably decline. Here we develop a model of a profit- maximizing firm that issues CDS and, optimally chooses to lower the risk premium, as volume increases. The model can help explain the stylized facts associated with the financial crisis. It also has implications for mortgage default insurance issuing firms going forward and the future structure of the housing finance system.

The simple model we develop, represents a financial institution that has a valuable intermediation business that generates positive profits. The financial institution can also issue CDS, which provides immediate revenues from the CDS spread, but exposes the firm to future losses if the underlying instruments experience default or write-down. When the CDS exposure is small relative to the capital of the institution, issuing additional CDS requires an increased premium, just as standard intuition would suggest. However, if the financial institution (the CDS issuer) already has a large CDS exposure and is under-capitalized, further issuance comes at a lower premium.

[1] The ABX Index represents 20 subprime residential mortgage-backed securities and is used as a financial benchmark of the overall value and performance of the subprime residential mortgage market. See Wachter (2018) for further discussion.

The intuition behind this result is that the financial institution is likely to lose the profitable intermediation business if CDS losses become large even with the current exposure, so assuming further risk is of no consequence. Yet, if CDS losses do not materialize, the institution profits from the CDS spreads it collects.

The above risk-shifting argument is based on one key assumption – the customers of the normal intermediation business (distinct from the CDS buyers), do not consider the default risk of the financial institution. The underlying intermediation business continues to be profitable even if the financial institution's capital is below the regulatory required minimum. We justify this by appealing to the fact that often it is difficult for financial intermediary customers to observe the true financial condition of a complex firm. Empirically, firms such as Bear Sterns and Lehman Brothers were able to execute transactions up until the moment they collapsed. Similarly, buyers of auto or home insurance from AIG did not alter their purchasing choices because of a potential AIG weakness. In fact, the traditional insurance business for AIG continued to be profitable up until its collapse and continues today following a government bailout.

The assumption that the customers of the normal intermediation business (distinct from the CDS buyers) do not consider the default risk of the insurer is analogous to the moral hazard and perverse incentives problem associated with FDIC deposit insurance. Under this analogy, the contribution of our work is that the ability to continue operations regardless of default risk, whether this is due to FDIC insurance or any other reason, is sufficient to generate severe mispricing even in instruments, the CDS in our case, that are traded in competitive and transparent markets.

Importantly, the CDS buyers (distinct from normal intermediation business customers) in our model are fully informed and rational. Therefore, in our work, there is no risk-shifting from the CDS issuer to the CDS buyer. Since CDS buyers tend to be more sophisticated and better informed than the financial intermediation customers, we believe this is an important feature of our work. However, making the alternative assumption that CDS buyers are also uninformed only strengthens our main conclusions as it allows an even higher degree of risk-shifting.

In addition to the above direct risk-shifting assumption, major CDS issuers also engage in too big to fail, or too interconnected to fail, risk-shifting, as noted by Markose, Giansante, and Shaghaghi (2012). While we do not model this aspect of risk-shifting, we note that the possibility of such risk-shifting at the social level makes the negative consequences we show in our work potentially even more significant. Furthermore, Bolton and Oehmke (2011) show that CDS underpricing affects creditor behavior and potentially leads to an inefficiently high incidence of costly bankruptcies. While we do not model the societal costs of excess leverage and defaults, it is obvious from the crisis, that these can have systemic effects.

The model of risk-shifting that we develop is compatible with other explanations of the underpricing of risk in the run-up to the financial crisis. For example, Schwarcz (2019) argues underpricing of CDS occurred, because firms, which contract to make insurance payments only in future contingencies, tend to perceive lower risk at the outset of making guarantees, a behavioral phenomenon he terms "abstraction bias." In a similar vein, Min (2015) and others argue that investors in money market instruments are informationally insensitive, meaning that they do not react to new information about risk (Dang, Gorton, & Holmström, 2012). Also (including famously Robert Shiller in *Irrational Exuberance*, 2016) point to persistent expectations of continuing house price increases as a culprit behind the mispricing of risk. It is also quite possible that the underlying cause of the observed decrease in the risk premium is a shift outward of the supply curve. Such shift could occur because the sellers of CDS that are myopic. That is, they earn large bonuses for selling CDSs and do not have the incentive to consider the long run risk to the firm (Schwarcz, 2019).

While we agree that these behavioral phenomena were at play, the explanation we offer for the action of CDS issuing non-depository firms is consistent with a set of otherwise unexplained stylized facts observed in the run-up to the crisis. These include the rising share of CDS relative to RMBS and the risk adjusted declining risk premiums on RMBS, including for hard data characteristics, such as, LTV and FICO score, observable to investors, which other theories do not explain. The mechanism is also consistent, as noted, with the stable pricing of the ABX index, which was readily tradeable, through mid-2007.[2]

Alternative explanations do not account for the deterioration in the pricing of risk along with the rise in leverage over time and the rise in the share of PL MBS covered by CDS. While lack of information on loan products and the composition of residential mortgage-backed securities (RMBS) is likely to have had a part in the crisis, the fact that PL MBS pools pricing for risk declined over time relative to hard data information available on mortgage pool characteristics implies other forces beyond information asymmetries were at play along with information asymmetries.

Here we offer such an alternative explanation, which is consistent with the stylized facts. It is based on limited liability and risk shifting but unlike past explanations, it is not based on government insurance, such as, demand deposit insurance or potential bailouts. Rather, it is based on the provision of CDS by companies, which are profitable because they have an additional and related business, such as insurance or lending. The presence of government insurance or the potential for a government bailout worsens the resulting underpricing behavior, but it is not the sole cause.[3]

Our presentation of results assumes that CDS issuers and buyers agree on the riskiness of the underlying market. It is possible CDS issuers take an increase in the demand for CDS as a signal that the underlying market has become riskier. An increase in the parameter value capturing the underlying market riskiness would monotonically increase the CDS premium required. However, the effect we document remains and an increase in the CDS issuance would dampen or even negate the increase in CDS premium that should occur in response to a parameter revision. It is also conceivable that the increase in demand for CDS is for liquidity or microstructure reasons and is unrelated to a negative signal about the underlying assets. Either way, controlling for

[2] *See* Susan M. Wachter, Credit Risk Transfer, Informed Markets, and Securitization, Economic Policy Review 24(3), 2018. In January 2006, Markit Group, in collaboration with a group of major banks, launched the ABX.HE (the ABX), linked to the pricing of twenty specific home equity RMBS deals, including some of the largest deals during this period. The overall index incorporated a basket of indexes, differentiated by credit risk rating.

[3] The literature identifies the mispricing of the put option embedded in nonrecourse lending (Pavlov & Wachter, 2006; Gomes, Grotteria, & Wachter, 2018), deriving from bank managers and shareholders exploitation of mispriced deposit insurance. In the model we develop here, insurance is mispriced but not due to government backing but rather due to profit maximizing firm behavior. In a related paper, Gollier, Koehl, and Rochet (1997) shows that the optimal exposure to risk of firms with limited liability is larger than firms with unlimited liability.

the riskiness of the underlying market, the CDS premium decreases in CDS volume in the circumstances and regions we discuss below.

Our approach can be viewed as a formal treatment of many conclusions Stulz (2010) and Zingales (2008) reach on CDS research and contribution to the crisis. Specifically, their work points out that some (many) CDS issuers did not have the ability to bear the risks they took on. Our work shows that such seemingly irrational behavior is explainable and could have been predicted. Our work also points to the need for policies to respond to this specific mechanism for underpricing or risk. While the Dodd Frank Act has reformed how CDS are used, the mechanism we describe is relevant to entities that offer financial products and offer insurance to investors on those products going forward.

Section 2 provides an overview of the CDS market and, in particular, discusses how CDS premiums declined in the 2004–2006 period in the face of increasing issuance. We describe the model setup for the issuer and the buyer in Section 3. Section 4 provides the solution of the model and Section 5 concludes.

CDS Background

The key empirical observation we attempt to explain is that CDS issuance during the 2004–2007 period vastly increased, while CDS spreads were insensitive to the credit worthiness of the underlying securities, remained unchanged, and even declined. CDS is a way for a financial institution to assume the default risk of a fixed income security, such as a MBS tranche. The buyer of the CDS pays a premium to the financial institution for the assumption of default risk. Standard economic theory and intuition suggest that an increased demand for CDS leads to increased premiums. Increased demand for CDS (relative to the total fixed income market) suggests that investors are revising their default risk estimates and require more insurance. At the same time, a CDS issuer should increase the premium required to issue additional CDS because doing so puts the firm at risk. Yet, in the pre-crisis period, the CDS credit quality-adjusted spreads remained unchanged and even declined on an increasing volume. At a time of growing risk, such as the run-up to the crisis, CDS demand will grow and fuel a feedback loop of mounting risk.

Jayasuriya (2019) documents the decline in CDS spread from 2004 to 2006. There were four major issuers of CDS and for each, the CDS spread declined. For instance, for AMBAC, the CDS spread dropped from 29 bps to 11 bps from 2004 through 2006; for MBIA, the CDS spread decreased from 32 to 23 bps; and for FSA, it went from 21 to 11 bps in the same period.

At the same time, as Stanton and Wallace (2011) document, the CDS premiums were not at all sensitive to the credit quality of the underlying MBS even as measured by readily available public information.

In other words, CDS volume consistently increased during the 2004–2006 period with no change or even decline in the observable credit quality-adjusted spreads. When considering additional, unobserved credit quality, as in Arentsen, Mauer, Rosenlund, Zhang, and Zhao (2015), CDS spreads almost certainly declined.

Moreover, Arentsen et al. (2015, Table 2) document that the percentage of mortgage-backed securities (MBS) with concurrent CDS coverage increased from 26% in 2004 to

54% in 2006, with the percentage as a portion of an increasing volume of MBS securities over the same period. Similarly, Fostel and Geanakoplos (Fostel & Geanakoplos, 2012, Fig. 3) document a sharp increase in CDS issuance through the middle of 2007. The total volume of CDS issuance for MBS more than tripled in the 2004–2006 period and remained high even through the first half of 2007, when the signs of a potential mortgage-related crisis became clear. Particularly striking is the finding of Arentsen et al. (2015) that loans packaged in MBS that had CDS available substantially under-performed other securitized loans. Not only were financial institutions taking on more risk at lower premiums, but they were also apparently doing so with inadequate screening of the MBS they insured.

While we do not take a position on the contribution to the systemic risk of CDS providers, the literature does point to the outsize role of CDS issuing insurance firms in the crisis in the US. Bernal, Gnabo, and Guilmin (2014) show that the insurance industry is the most systemically risky financial sector in the US from 2004 to 2012 and specifically riskier than the banking sector.

In the aftermath of the crisis, the 2009 Dodd-Frank Wall Street Reform Act (DFA) required enhanced regulation of CDS in an attempt to mitigate such risks. Specifically, the DFA requires bank counterparty exposure (which includes exposure via CDS issuance) to be reported and monitored, for example, through stress tests. Nonetheless, financial intermediaries that issue investor guarantees against default, along with other products, continue to exist and may expand depending on the future of housing finance reform, as discussed below. The financial institution, that we model here, could apply to a government sponsored enterprise (GSE) which intermediates the mortgage payment from the borrowing households in a mortgage backed security (MBS) or private guarantors which also guarantee returns to MBS investors. These entities, as they grew larger, could be incentivized to underprice their guarantee fee.

Model Setup

Financial Institution

In this section we develop a simple model of a financial institution that has only two distinct sources of revenue: traditional financial intermediation and issuance of credit default swaps (CDS). The traditional intermediation represents a profitable business (positive expected profit), consistent with the notion that financial institution charters or brands are valuable and, once obtained, represent positive NPV projects. Specifically, we assume the risk-neutral change in the capital stock due to the cash flow generated from the traditional lending business is:

$$dX = (\mu - \Omega)dt + \sigma dz \tag{1}$$

This is a standard continuous time process for the firm's value, where X is a Gaussian Markov process and denotes the current capital of the firm, which without loss of generality is normalized to be zero at the minimum capital requirement, μ is the expected arithmetic growth in capital when the lender is in business, Ω denotes the risk premium required by investors in the company, σ is the volatility of capital flows from normal business operations. μ, Ω, and σ are assumed to be constants, with dz. representing a standard Brownian process. With the risk premium adjustment, Ω, Equation (1) is the risk-neutral process for capital, X.

We choose an arithmetic Brownian motion for the lender's capital changes to allow for the possibility of negative levels of capital (below the minimum capital requirement). Lenders/insurers do not cease operations the moment their capital falls below their minimum requirements. Instead, they continue operations through borrowing from other financial institutions or central banks.

More importantly, long-standing financial institutions are able to continue operations and earn income even with capital below the minimum capital requirement. To some extent this reflects the correct belief that the franchise still has value and shareholders may contribute additional capital over time to mitigate the shortfall. Even if shareholders decide to abandon the business, it is very likely that the underlying profitable insurance or financial services will continue, perhaps after restructuring, government bailout, or sale.

In addition to the traditional financial intermediation business, the financial institution can issue credit default swaps (CDS) which pay certain premium continuously but expose the capital of the institution to potential default with some probability which we model as a Poisson jump. By adding the collected premium and deducting potential loss modeled as a Poisson jump, we incorporate CDS issuance into the capital process. Adding CDS to the traditional lending modifies the process for capital as follows:

$$dX = (\mu + Ck - \Omega)dt + \sigma dz - Cgdq \tag{2}$$

where C denotes the total issuance of CDS, k denotes the CDS premium continuously collected by the issuer, g denotes the exposure of the lender in case the underlying security defaults or experiences a substantial write-down, and dq denotes the Poisson jump process with jump probability λ. The premiums collected are simply the total amount of CDS issued, C, multiplied by the premium collected, k. Similarly, the loss in case of a CDS claim is the total amount of CDS issued, C, multiplied by the exposure of the issuer in case the underlying security defaults, g. This specification assumes that the loss per CDS contract is independent of the number of contracts issued.

As noted, the financial institution can be interpreted to be a government sponsored enterprise (GSE) which intermediates the mortgage payment from the borrowing households in a mortgage backed security (MBS) to the MBS investors, collecting fees for both issuing MBS through securitization, and fees for the guarantee of return to the investor. The amount C is the total balance of an MBS pool, and the rate k is the difference between the gross mortgage interest rate and the MBS coupon rate, or the G-fee collected by a GSE. The value g is the interest rate payment required to be delivered to the investors in case households cannot make the mortgage payment.

The majority of CDS on MBS are structured as pay-as-you-go securities. Under this structure, the CDS issuer covers losses in the case of default as in standard CDS, but also in the cases of partial write-down of the underlying security. In other words, if the underlying security experiences a write-down of 5%, then the issuer pays the buyer 5% of the notional amount remaining at the time of write-down. We assume such relatively small write-down are handled by the diffusion process in Equation (2). The jump process in Equation (2) is meant to represent relatively less frequent and substantial events in which a substantial value of the underlying security is written down. Nevertheless, if partial write-downs are of particular importance in a specific market, the proposed model can be calibrated to accommodate this through higher probability of a jump and small jump size.

The total CDS issuance, C, in Equation 2 is not a state or choice variable. Instead, our solution computes the required premium, k, as a function of the CDS to be issued. In other words, we provide the entire supply curve for the CDS to be issued. This approach allows us to demonstrate how the required premium, k, changes with respect to the quantity issued.

The above specification assumes there is only one asset on which CDS are issued. This can be easily generalized by increasing the jump intensity and reducing the jump size. Under such specification, a jump would represent an event in any one asset covered by the CDS. The jumps would occur more often, but the losses would be lower. Such changes to our parametrization do not materially impact our main conclusions.

The institution is allowed to pay dividends to shareholders only if its capital exceeds the minimum capital requirement, normalized to zero in this case. If the capital falls below the minimum capital requirement, the institution is not allowed to pay dividends. Instead, the shareholders can either contribute capital to the institution or cease operations.

The exact form of the dividend policy, especially the required capital contributions, is not crucial for our model. However, some contribution from shareholders, current or new, that is proportional to the size of the capital shortfall is necessary for our conclusions. Absent such required contribution, shareholders would have no incentive to contribute to the firm and the firm's capital could become infinitely negative. Requiring shareholders to contribute capital if they wish to continue operations is a way to ensure that there is an optimal abandonment boundary, below which shareholders optimally end the business.

Notice that the requirement to contribute capital in our model does not violate the limited liability for shareholders and is actually more realistic than the alternative that shareholders are not required to contribute regardless of the capitalization of the insurer. First, the capital contributions are required only if shareholders choose to continue operations. At each point in time, the shareholders can choose to liquidate the business, in which case they have no requirement for further capital contributions. Therefore, the capital contributions are required only if the institution continues operations and are discontinued at the endogenous abandonment boundary. Second, no institution that has the option to end the business and default would be allowed to operate with infinitely large capital deficit. Either government regulators or market participants would force a financial institution to either rise additional equity or discontinue operations. Third, while we describe the capital contributions in our model as contributions from current shareholders, the model makes no distinction between contributions from current or new shareholders. If some or all capital contribution comes from new shareholders then existing shareholders are diluted, which is indistinguishable from them making a cash contribution but retaining their original ownership share.

For simplicity, we assume that dividends are paid at the rate $r X$, where r is the risk free rate of interest and where X can be positive (dividends) or negative (contributions), as long as the lender is in business. As discussed above, the exact form of the dividend policy is not essential. However, this particular form allows a substantial simplification in the solution, allowing us to obtain an implicit equation for the solution as discussed below. Appendix A provides the solution for any dividend policy, which needs to be fully solved numerically.

Valuation of the Financial Institution

In order to value the financial institution that issues CDS along with traditional lending business, the standard Hamilton-Jacobian-Bellman equation in the continuous time finance literature leads to the following value function a risk-neutral financial institution *V.*

$$rV(X)dt = rXdt + E(dV) \tag{3}$$

We apply the Ito's Lemma to the expected differential of the firm value in the presence of a Brownian shock to capital accumulation and a Poisson jump due to default as follows.

$$E(dV) = \left((\mu + Ck - \Omega)\frac{\partial V}{\partial X} + \frac{\sigma^2}{2}\frac{\partial^2 V}{\partial X^2} \right) dt - \lambda(V(X) - V(X - Cg))dt \tag{4}$$

This provides the following differential equation for the firm value, *V*:

$$rV(X) = \begin{cases} rX + (m + C\,k)\dfrac{\partial V}{\partial X} + \dfrac{\sigma^2}{2}\dfrac{\partial^2 V}{\partial X^2} - \lambda V(X), & \xi \leq \mathrm{X} \leq \xi + C\,g \\ rX + (m + C\,k)\dfrac{\partial V}{\partial X} + \dfrac{\sigma^2}{2}\dfrac{\partial^2 V}{\partial X^2} - \lambda(V(X) - V(X - C\,g)), & \xi + C\,g \leq X \end{cases} \tag{5}$$

where $m = \mu - \Omega$ and ξ is the abandonment boundary at which shareholders optimally discontinue operations. The bottom branch of Equation (5) corresponds to the differential equation that holds when one jump of X in magnitude Cg will still leave the capital of the institution above the abandonment value, while the top branch corresponds to the differential equation that holds when one jump takes the capital below the abandonment boundary. The abandonment boundary, ξ, is endogenous and corresponds to the value of X at which $V(X) = 0$. Note that the bottom branch of Equation (5) captures the cases when capital is large enough to withstand one jump. Furthermore, the probability of two or more jumps in any fixed time interval $(t, t + \tau)$ declines at a power of two in τ, so it tends to zero when h becomes small (Merton, 1976, p. 128). Therefore, there is no need to consider capital levels that can survive two or more jumps as separate cases.

The solution to Equation (5) is of the following functional form:

$$V = \begin{cases} \dfrac{r(m + Ck)}{(r + \lambda)^2} + \dfrac{r}{r + \lambda}X + A_1\exp(b_1 X) + A_2\exp(b_2 X), & \xi \leq X \leq \xi + Cg \\ \dfrac{m + Ck - \lambda Cg}{r} + X + F\exp(hX), & \xi + Cg < X \end{cases} \tag{6}$$

where A_1, A_2, F, b_1, b_2, and h are arbitrary constants. Substitute the value function from Equation (6) into Equation (5), one branch at a time. The top branch provides the following expression for b_1 and b_2:

$$b_{1,2} = \frac{1}{\sigma^2}\left(-m - Ck \pm \sqrt{(m + Ck)^2 + 2\sigma^2(r + \lambda)}\right)$$

The bottom branch provides an implicit equation for h:

$$r + \lambda - \lambda e^{-C\ h\ g} = (m + C\ k)h + \frac{\sigma^2 h^2}{2} \tag{4}$$

which we solve numerically.[4] Two solutions exist, negative and positive. When there is a perturbation of the capital stock away from the steady state, a negative h suggests a concave value function and will bring the capital stock back to the steady state, while the positive solution is unstable. The equation has two solutions, we take the negative one. Therefore, the solution to the differential equation given in (5) is the function given in Equation (6) and the expressions for b_1, b_2, and h.

This leaves us with the constants A_1, A_2, F, and ξ, which we solve using the value matching and smooth pasting conditions at the abandonment boundary, ξ, and at the abandonment boundary plus one jump, $\xi\cdot\ +C\ g$. Specifically, we use the following conditions to obtain F, A_1, and A_2:

$$\left\{V_1\Big|_{X=\xi} = 0, \left(\frac{d}{dX}V_1\right)\Big|_{X=\xi} = 0, V_1\big|_{X=\xi+C_g} = V_2\big|_{X=\xi+C_g}\right\}, \{F, A_1, A_2\}$$

and to obtain ξ:

$$\left\{\left(\frac{d}{dX}V_1\right)\Big|_{X=\xi+C_g} = \left(\frac{d}{dX}V_2\right)\Big|_{X=\xi+C_g}\right\}, \xi$$

where V_1 and V_2 denote the value functions as defined by Equation (6).

Equation 5 shows the determinant of the value of the financial institution. The left side is the flow value, which should be equal to the 4 terms on the right side due to no arbitrage in equilibrium. The first term is the risk-free return of the firm capital. The second term is associated with the expected capital gain from the traditional lending business m and the insurance business Ck. The third term is associated with the uncertainty in the growth of capital and normal business operation. The fourth term is the expected capital loss due to security default, which is the arrival rate of default multiplied by the gap between the values before and after the Poisson jump. The upper branch shows the value after jump close to the abandon boundary is 0 due to business termination. The bottom branch shows the value after a jump distant from the abandon

[0] Two solutions exist, negative and positive. When there is a perturbation of the capital stock away from the steady state, a negative h suggests a concave value function and will bring the capital stock back to the steady state, while the positive solution is unstable.

boundary is the continuation value with capital net of the insurance payment. The zero value at and below the abandon boundary leads to the risk shifting motive in the CDS pricing.

Equation 6 shows the closed-form solution to equation 5. Note that when C increases, the domain of capital belonging to the upper branch becomes larger. Compared with the value distant from the abandon boundary, the value near the abandon boundary has 3 terms associated with the level of firm capital. The linear term is about the traditional lending business. Two exponential terms with one increasing and the other decreasing in capital creates introduces convexity and concavity in the value function. Because any security default drives the capital below the abandon boundary, the expected return includes the expected capital growth net of risk premium (mu - omega) and the collected insurance premium Ck, discounted at the risk-free rate adjusted with the termination rate (r + lambda) (which is equal to the arrival rate of the Poisson jump).

While we can only obtain numerical solutions to the abandonment boundary, the value function in Equation (6) is informative nonetheless. Absent jumps ($\lambda = 0$), the first two terms of both branches represent simply the present value of the business in perpetuity. Specifically, they represent the value of the underlying business and the value of the capital at hand. The remaining terms capture the value of the abandonment option.

CDS Buyers

CDS buyers in our model, unlike the intermediation business customers, are fully aware of the current capital level of the financial institution and its abandonment boundary. Therefore, they correctly infer the probability of default on the CDS and adjust the CDS premium they are willing to pay accordingly.[5] In other words, the CDS customers consider the same process for capital, X, as the institution. However, they take the abandonment boundary, ξ, as determined by the institution's optimization problem. In this sense, their optimization is easier, as they treat the abandonment boundary as exogenous.

In what follows we analyze the situation of a risk neutral CDS buyer who matches the expected benefits with the expected cost of the contract. As we explain below the premiums thus obtained represent a lower bound for the premium the buyer would be willing to pay taking into account risk aversion, hedging demands, or agency conflicts.

The CDS buyers pay the CDS premium, Ck, continuously, and receive Cg in case of a jump. If the issuer defaults in case of a jump, then the CDS buyer does not receive full payment but receives a partial payment. We assume the insurer uses whatever capital is left above the abandonment boundary to pay the outstanding CDS claims before terminating operations. In other words, the CDS buyer has a senior claim and the issuer pays as much as possible on the CDS claim before it goes out of business. Our results do not change materially under an alternative assumption that the lenders to the issuer have a senior claim, in which case the CDS owners do not receive anything in the case of default. In fact, our main findings are even stronger under this alternative scenario.

[0] Note that the CDS premium is not risk premium. It is akin the premium charged on any insurance policy.

We summarize the value of the CDS buyer's claim, W, with the following Bellman equation:

$$rW(X)dt = -kCdt + E(dW) \tag{7}$$

In this setting, the risk-free return on the CDS buyer claim equals the instantaneous premium payment plus the expected change in the value of the claim.

As we show in the Appendix A, for the zero-NPV CDS premium, $k = g\lambda$, and for large levels of capital, X, the value of the CDS buyer claim is zero, as expected. As the issuer's capital, X, declines, the value of the claim to the buyer becomes negative. The CDS buyer would only enter the CDS contract if they have a hedging demand, just like any other insurance product.

Moreover, we demonstrate that the CDS premium they are willing to offer would also rationally decline as the CDS exposure of the issuer increases. Figure 5 depicts the value function, W, for a CDS buyer, as a function of issuer's capital, X, for various levels of CDS exposure. In this case, we compute the value function for a CDS premium set at the zero expected profit level, $k = \lambda g$. For high levels of issuer capital, X, the value function for the buyer is zero, as expected. However, for low levels of capital, the value function for the buyer declines in recognition of the possibility of counterparty default. This decline is most significant for issuers who have high CDS exposure. We further compute the CDS premium, k, that the buyer is willing to pay to maintain zero value of their contract. Figure 6 depicts the offer premium as a function of CDS exposure of the issuer for various levels of issuer capital. When the CDS exposure is low relative to the issuer capital, the buyer is willing to offer the actuarially fair premium of $k = \lambda g$. However, as the CDS exposure of the issuer increases relative to its capital, the buyer recognizes the possibility of issuer default and is willing to offer lower and lower premiums for the CDS.

Results

In this section we graphically present the main insights coming out of the model. For all the numerical solutions reported below we use the parameter values presented in Table 1.

Figure 1 depicts the value function for the financial institution for various levels of CDS issuance, C. If the lender does not issue any CDS, $C = 0$, then the value function represents a typical convex curve reflecting the abandonment option value, the value of the ongoing business, and the current capital, X. The curve is convex near the abandonment boundary and approaches a straight line for higher levels of capital. As the lender starts issuing CDS, i.e., $C > 0$, two things happen. First, the abandonment boundary is higher and the value function has convex and concave parts. The increase of the abandonment boundary is significant and concerning from a policy point of view. Not only is the lender riskier because of the CDS they issue, but also they are likely to abandon the business at increasingly smaller capital deficits. Simply put, the lender transfers more and more of the CDS risk to its creditors.

Figure 2 depicts the abandonment boundary for various levels of CDS issued. Clearly, as the CDS book increases, so does the abandonment boundary. This result

Table 1 Parameters used for the numerical solutions

Parameter	Typical Value
Risk-free rate, r	.05
Size of jump, g	.5 (If a jump occurs, 50% of the face value of the CDS is lost).
Jump intensity, λ	.05 (Expected jump arrival = 20 years)
Risk-adjusted positive drift in capital due to operating business, $m = \mu - \Omega$	1
Volatility of capital due to operating business, σ	1
CDS issuance, C	Varies, needs to be non-negative
CDS premium, k	Endogenous

Table 1 reports the base parameter values used to generate the numerical solutions reported in the paper

is important, as it suggests that CDS issued not only make it more likely for the capital to fall below the abandonment boundary but also shifts the abandonment boundary. These two effects work together to increase the probability of business failure with CDS issuance.

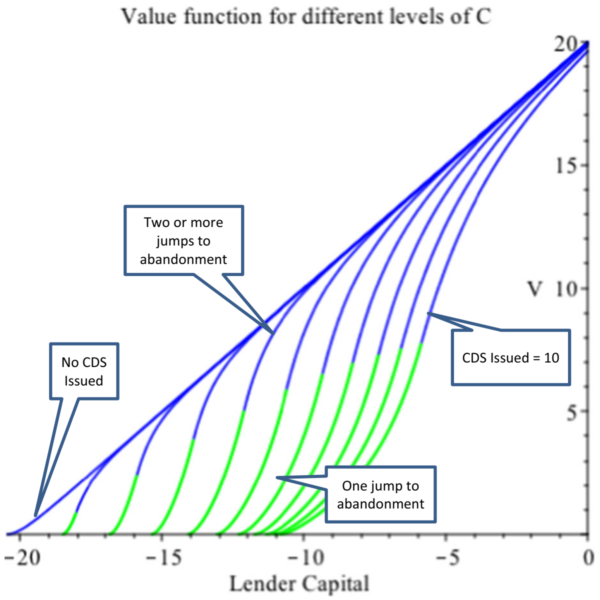

Fig. 1 Institution Value Function. Depicts the value function for the lender/insurer as determined by the numerical solution of Equation (6). The horizontal-axis depicts the current lender capital. Only negative values are shown, although the function extends over all positive values as well. As capital increases, the value function approaches a 45-degree line and the abandonment option becomes infinitely small. Each curve on the graph represents one single value function computed for a specific level of CDS issued. The highest value function depicts the solution with no CDS issued. The lowest value function depicts the solution with 10 units of CDS issued. The lower portion of each value function is based on the upper branch of Equation (6) (low capital) and the upper portion of the value function is based on the lower branch of Equation (6) (high current capital). The two functions are matched with value-matching and smooth pasting at the level of capital that is exactly one jump away from abandonment

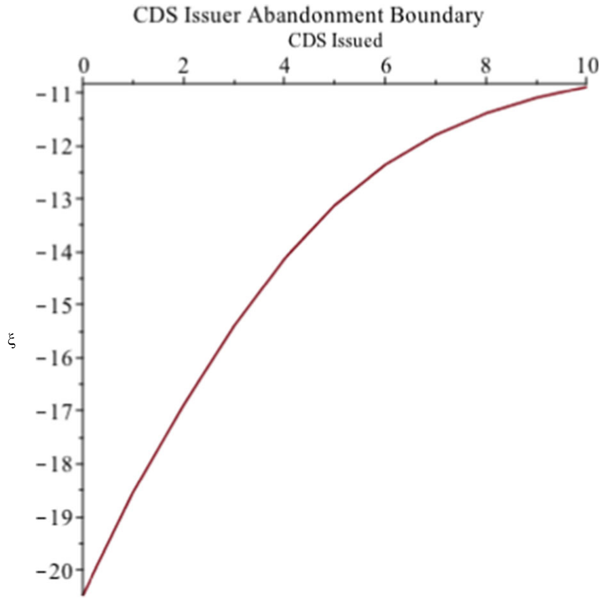

Fig. 2 Abandonment Boundary as a Function of CDS Issued. Depicts the abandonment boundary as a function of CDS issued. As the CDS book increases, the abandonment boundary increases

Next, we solve for the required CDS premium, k, to induce the lender to issue CDS. Note that if the continuously collected premium, $k = \lambda g$, issuing a CDS has zero expected profit (denoted as zero-NPV on the graph). This is the actuarially fair premium where the amount collected just compensates for the expected loss. However, the institution in our model would not be willing to issue CDS at this premium even if it were risk-neutral. The reason is that this is a zero expected return project that nonetheless introduces volatility, which, in turn, puts the valuable underlying business at risk. In other words, while the issuer is zero-profit as a firm (Equation 3), the CDS instrument needs to have positive profit. Therefore, λg represents a lower bound for the required CDS premium.

We solve for the required premium, k, as follows. We consider a lender who has no CDS on their books and is considering issuing new CDS in the amount C. The scenario we envision is that a client approaches the lender with a request for CDS in that amount. We then find the premium a lender requires to issue the CDS so that its total firm value remains unchanged. Specifically, we solve for k such that $V(X, 0, 0) = V(X, C, k)$. The left hand side of this equation does not actually depend on k, as the lender CDS exposure is 0, as indicated by the second argument. For a fixed C, the right-hand side is a monotonically increasing function of k. For $k = \lambda g$, any issuance of CDS is value-decreasing, $V(X, 0, 0) > V(X, C, k)$, because the price of the CDS just offsets the expected future losses and includes no compensation for putting the positive profits from normal operations at risk. Therefore, there is a unique k that preserves the firm value, $V(X, 0, 0) = V(X, C, k)$.

Figure 3 depicts the required premium for different levels of current lender capital, X, and for a range of new CDS exposure, C. For all levels of capital, the required premium initially increases in CDS exposure, C, as one might expect. This reflects the required compensation for the additional risk a lender faces from issuing CDS. However, after a certain CDS level, the lender requires lower premiums to increase the size of the CDS to

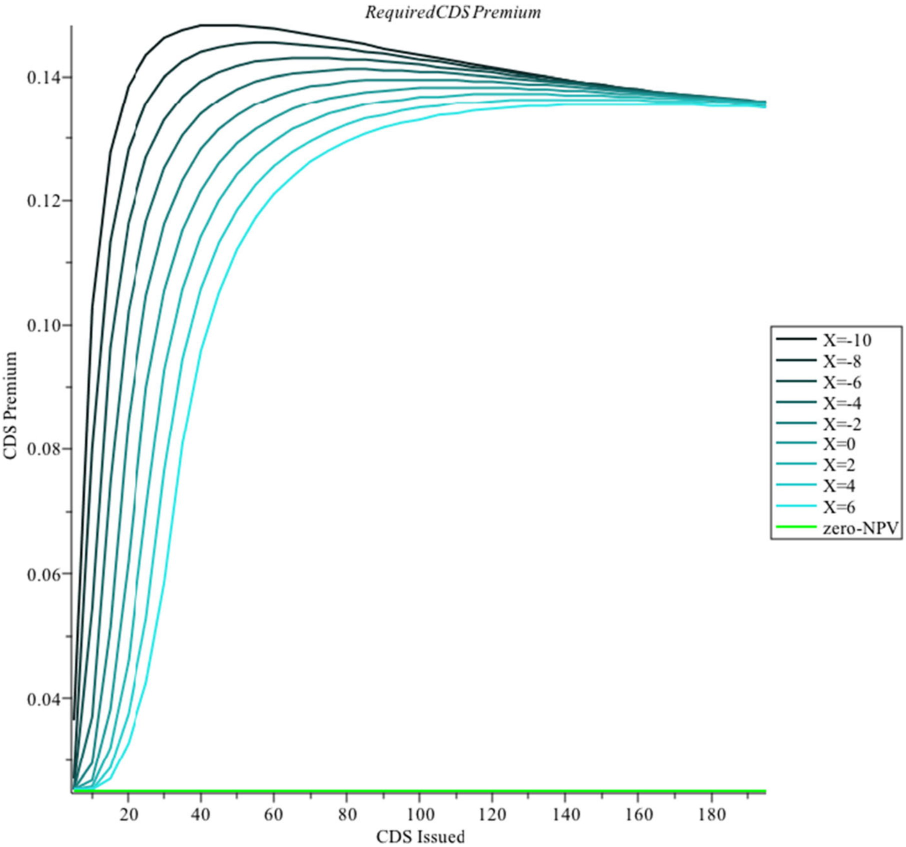

Fig. 3 Required average CDS premium. Depicts the CDS premium, k, that a lender/insurer requires to issue a certain level of CDS, depicted on the horizontal axis. This is the required premium to move from no CDS issued to CDS issued as depicted on the horizontal-axis. Each line depicts the CDS premium required for different levels of current capital. The required CDS premium increases with the size of the CDS to be issued in all cases when the size of the CDS is small relative to the current capital level. However, when the size of the CDS to be issued increases relative to the current level of capital, the required premium starts to decline. This occurs early if current level of capital is low ($X = -10$). Even for relatively higher levels of capital, say $X = 0$, the required premium declines past a certain CDS book size

be issued. In other words, the lender charges a relatively lower premium to take on relatively more risk. Importantly, even well-capitalized financial institutions, even ones with capital above the regulatory minimum requirement, normalized at zero in this solution, start to require lower premiums to issue more CDS after a certain point.

The flat line on the bottom of Fig. 3 depicts the actuarially fair CDS price that just offsets expected future losses ($k = \lambda g$). As discussed above, the financial institution we are considering needs to charge a price above that minimum to not only offset future expected losses but also compensate for the risk CDS issuance poses to the normal profitable operations.

An alternative, and more general, way to compute the required CDS premium is to consider the cost of issuing additional CDS conditional on a certain level of CDS already on the books. This is the marginal cost of issuing more CDS, as opposed to the average premium depicted in Fig. 3. Specifically, we can solve for the required k such that $V(X, C, k) = V(X, C + \Delta C, k + \Delta k)$, where ΔC and Δk denote the increase in CDS exposure and the change in the CDS premium, respectively. For small additional issue of CDS, the change in the average premium is given by the derivative of the curves depicted in Figure 3, $\frac{\partial k}{\partial C}\Big|_{V=constant}$. To derive the premium on the new issue, consider the total premium charged, as depicted on Figure 3, before and after the new issue:

$$Ck + k_{NewIssue}\Delta C = (C + \Delta C)(k + \Delta k) \tag{8}$$

The left-hand side of Equation (7) is the premium on the existing CDS, k, times its size, C, plus the premium on the new issue, $k_{NewIssue}$, times its size, ΔC. This weighted average needs to equal the premium, $k + \Delta k$, on the new CDS quantity, $C + \Delta C$. Simplify Equation (8):

$$k_{NewIssue} = k + \Delta k + C\frac{\Delta k}{\Delta C} \tag{9}$$

Figure 4 shows the premium required on a new issue, $k_{NewIssue}$, as a function of the CDS already on the books. The required premium on a new issue rises quickly at first for all levels of capital, as the total required average premium on the entire book needs to increase as shown in Figure 3. However, after the inflection point on each curve depicted in Figure 3, the required premium on the new CDS issue starts to decline. Importantly, after a certain CDS portfolio size, the premium required on the new issue is lowest for the least capitalized firm. While we do not model the competitive behavior of insurers here, it is reasonable to assume that the issuer offering the lowest premium gains the most market share. In other words, the least capitalized insurer is willing to issue CDS at the lowest premium and likely gains market share. This further pushes the under-capitalized insurer on their declining required premium curve, both average and marginal, giving them a further competitive advantage.

Combining the findings reported in Figures 3 and 5 it is clear that for any level of capital there is a certain level of CDS exposure for the issuer beyond which both the minimum required premium and the offered premium decline with additional CDS exposure. In other words, as the CDS issuance increases beyond a certain level, both issuers and buyers require lower CDS premiums.[6]

Beyond the risk-transfer concerns the above findings highlight, they offer the disturbing possibility that as the market receives negative signals about the value of the underlying asset, institutions are able and willing to issue CDS at declining rates. The negative signal certainly would induce rational investors to acquire more CDS. In a normal market, this would increase the CDS premium, which, in turn, would dampen the lending markets and ultimately cool down the underlying asset markets. However, since the CDS premiums decline rather than increase in the face of increased demand for CDS, we see a large increase in the volume of CDS issuance, but the premium

[0] In our illustration, the offer rate is lower than the ask rate in all cases. This is intuitive because the issuer needs to be compensated for putting the underlying business at risk, while the buyer needs to be compensated for the credit risk of the issuer. If taken literally, our results suggest that there would be no CDS transactions. We note, however, that from a modelling point of view this can be easily overcome. For instance, the buyer may have some hedging demand for the CDS and be willing to pay a premium in excess of the one depicted in Figure 6. Or, the buyer may be risk-averse, which would also induce them to offer a higher premium than what we compute.

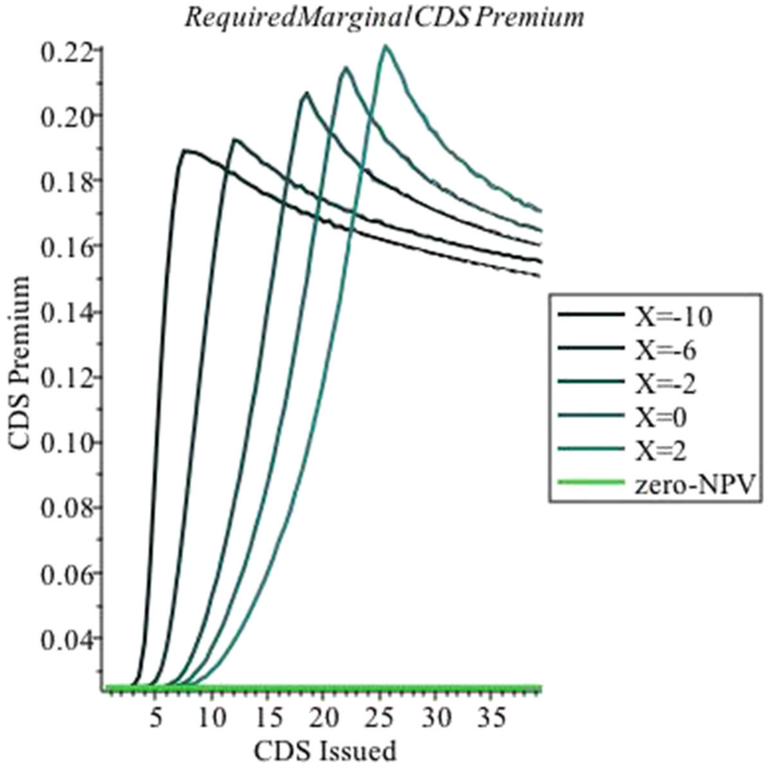

Fig. 4 Required CDS premium on new issue as a function of existing CDS book. Depicts the CDS premium, $k_{NewIssue}$, that a lender/insurer requires to issue a new CDS, conditional on already having a certain level of CDS issued. The horizontal axis depicts the CDS already issued. Each line depicts the CDS premium on new issue required for different levels of current capital. The required CDS premium on new issues increases with the size of the CDS already issued in all cases when the size of the CDS is small relative to the current capital level. However, when the size of the CDS already issued increases relative to the current level of capital, the required premium starts to decline. This occurs early if the current level of capital is low ($X = -10$). Even for relatively higher levels of capital, say $X = 0$, the required premium declines past a certain CDS book size

remains constant or declines. Therefore, the signal that is sent to the lending market is one of encouragement, making cheap financing easily available and relaxing lending standards. In other words, as the CDS market expands, and likely becomes riskier, less capitalized firms gain market share. Put together, our model suggests that risk-shifting occurs not only at the individual firm level but also likely at a market-wide level.

This is consistent with the events that preceded the 2008 financial crisis. CDS premiums declined through mid-2007 across all markets, CDS issuance increased tremendously, and lending spreads in the underlying mortgage market declined in response.

Conclusion

The apparent disconnect between the demand for CDS on mortgage-backed securities prior to the financial crisis and the pricing of those securities is often cited as one of the main contributing factors to the overall mispricing of mortgage-related investments.

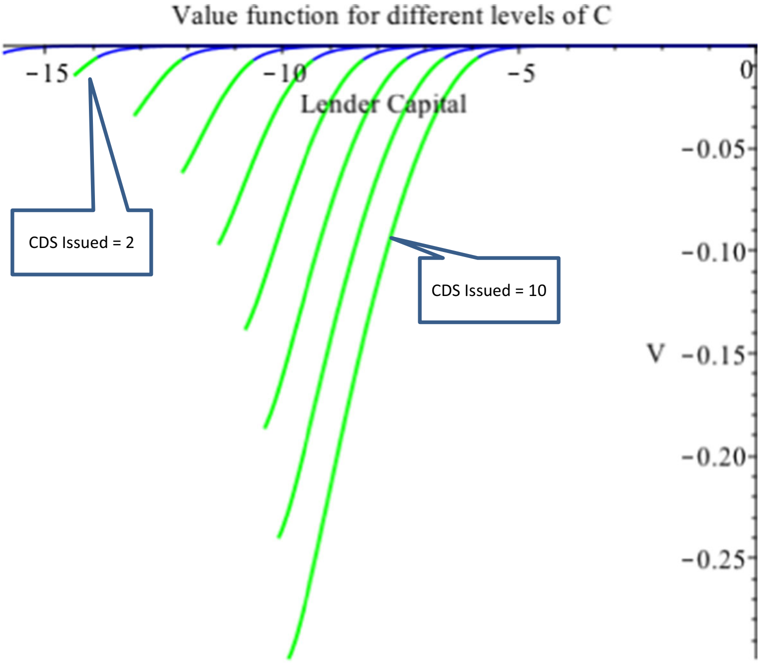

Fig. 5 Value function for CDS buyer. Depicts the value function for the CDS buyer as a function of issuer capital at various levels of issuer exposure. For high levels of issuer exposure, the value of the CDS to the buyer is zero, as expected. However, as the issuer capital declines, the value of the CDS contract to the buyer declines because the buyer recognizes the possibility of CDS default. The decline occurs for higher levels of capital and is steeper if the issuer is under-capitalized

The explanations for this disconnect are often rooted in investor information asymmetries (Lin et al.). In addition, the literature offers agency conflict explanations, based on the undercapitalization of the firm, for the underpricing of risk. In this paper, we formalize an agency based explanation in a simple model of a financial institution with profitable ordinary business and a CDS issuance business.

For a given amount of CDS issuance and a given amount of capital owned by a financial institution, we observe a non-monotonic relationship between CDS issuance and marginal/average CDS premium. Two pricing motives, risk compensation and risk shifting, are balancing each other, and two forces depend on the relative importance of the traditional lending business and the insurance business through CDS issuance to the accumulation of firm capital. When traditional lending business dominates the insurance business, the concern that firm capital will drop below the abandon boundary is minimal. The pricing motive of risk compensation to the traditional business explained above is dominant and the CDS premium of an additional unit of CDS is increasing. As the amount of CDS issuance increases, the probability that the firm capital going below the abandon boundary (probabilistically after a Poisson jump occurs) and the probability of business ceasing increase, and the pricing motive of risk shifting grows stronger. With no limited liability constraint, the marginal CDS premium should keep going up, as the loss in case of security default is never wiped out. However, with a limited liability constraint imposed (firm value cannot go below zero), the marginal CDS premium would decrease because there is no downside risk that exists in the

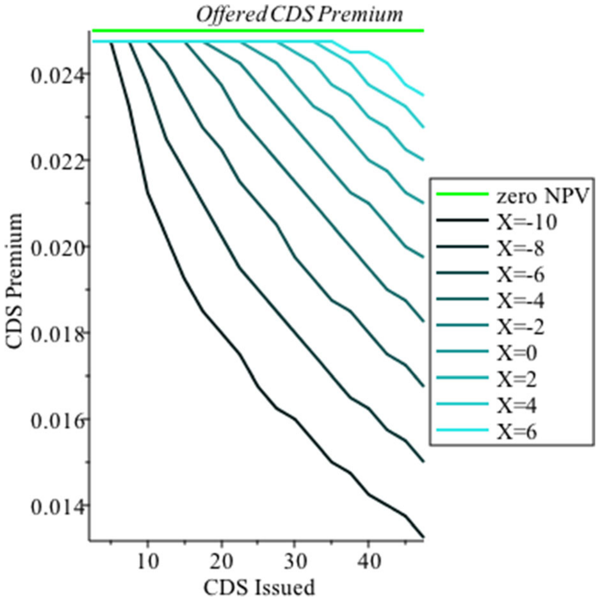

Fig. 6 CDS offer premium. Depicts the maximum CDS premium the buyer is willing to offer as a function of the issuer capital and the CDS already issued. For low levels of CDS issued, the maximum offer is at the zero-NPV, actuarially fair, premium. (The graph shows the offer curves slightly below the zero-NPV line for presentation purposes). Past a certain level of CDS issued, the maximum premium a buyer would offer declines with the CDS already issued. This decline occurs earlier and is steeper for under-capitalized issuers

unlimited liability case and such potential loss in case of the security default would not be priced in or compensated by the collected premiums. The inflection point we see in CDS premium balances the forces of risk compensation and risk shifting.

This inflexion point shows that after a certain level of CDS has been issued, financial institutions would require lower and lower CDS premiums for issuing more CDS. In other words, as the demand for CDS increases its price drops. While this is a typical conclusion of any production function with fixed costs, it is highly unusual for financial contracts that have no fixed cost but have increasing variable costs (risk).

Even more strikingly, as the total CDS issuance in the market place increases, less capitalized issuers gain market share, replacing well-capitalized firms. Thus, there is risk-shifting not only within individual firms, but also between competing CDS issuers.

We further show that rational and fully informed CDS buyers recognize the possibility of issuer default and correctly reduce the premium they offer for CDS. Therefore, past a certain level of exposure, both the issuers and the buyers of CDS require lower and lower premiums.

The above findings have significant policy implications. First, when the CDS market is small relative to the overall capitalization of CDS issuers, the pricing functions behave as expected. Increases in demand for credit protection through CDS generate increasing CDS premiums. This, in turn, would appropriately affect the MBS pricing and send a correct signal to the underlying real estate markets.

Once the CDS market becomes significant relative to the overall capitalization of the issuers, then the above mechanism breaks down and CDS pricing declines with increase in CDS demand. When this occurs, the underlying MBS and real estate markets receive a signal that appears to indicate low (and falling) overall risk, while the actual risk is increasing. This suggests that, first and foremost, the CDS issuance needs to be kept small relative to the capitalization of each firm. Second, the market share of firms needs to be monitored to ensure that if under-capitalized firms start gaining market share, their activity is curtailed either through direct regulation or through increasing the required capital contributions in case of capital shortfalls.

Appendix

Differential equation with a general dividend policy

The risk-neutral, no-arbitrage condition for the value of the lender, *V*, under a general dividend policy, δ, is:

$$rV(X)dt = \delta X dt + E(dV).$$

The Ito's Lemma for the jump-diffusion processes remains unchanged:

$$E(dV) = \left((\mu + Ck - \Omega)\frac{\partial V}{\partial X} + \frac{\sigma^2}{2}\frac{\partial^2 V}{\partial X^2}\right)dt - \lambda(V(X) - V(X - Cg))dt.$$

This provides the following differential equation for the lender value, *V*:.

$$rV(X) = \begin{cases} \delta X + (m + C\,k)\dfrac{\partial V}{\partial X} + \dfrac{\sigma^2}{2}\dfrac{\partial^2 V}{\partial X^2} - \lambda V(X), & \xi \le X \le \xi + C\,g \\ \delta X + (m + C\,k)\dfrac{\partial V}{\partial X} + \dfrac{\sigma^2}{2}\dfrac{\partial^2 V}{\partial X^2} - \lambda(V(X) - V(X - C\,g)), & \xi + C\,g \le X \end{cases}$$

This system of equations can only be solved numerically.

Valuation of the CDS Buyer's Claim

Applying Ito's Lemma for jump-diffusion processes while the issuer is in business, $>\xi$, we obtain:

$$E(dW) = \left((\mu + Ck - \Omega)\frac{\partial W}{\partial X} + \frac{\sigma^2}{2}\frac{\partial^2 W}{X^2}\right)dt + \lambda(\min(Cg, \max(X - \xi, 0)) - W)dt$$

Note that the second part above has (-*W*) because the CDS buyer receives a payout but the claim expires in case of a jump. Substitute this into Equation (7) to obtain the following differential equation for the value of the CDS claim, *W*, while the issuer is in business, $X > \xi$:

$$rW(X) = -kC + \left((\mu + Ck - \Omega)\frac{dW}{dX} + \frac{\sigma^2}{2}\frac{\partial^2 W}{X^2}\right) + \lambda(\min(Cg, \max(X - \xi, 0)) - W)$$

Simplify:

$$\begin{cases} (r+\lambda)W(X) = -k\,C + \left((m+Ck)\dfrac{dW}{dX} + \dfrac{\sigma^2}{2}\dfrac{\partial^2 W}{X^2}\right) + \lambda\, g\, C, & \textit{if } X > Cg+\xi \\ (r+\lambda)W(X) = -k\,C + \left((m+Ck)\dfrac{dW}{dX} + \dfrac{\sigma^2}{2}\dfrac{\partial^2 W}{X^2}\right) + \lambda(X-\xi), & \textit{if } \xi < X < Cg+\xi \end{cases}$$

The solution to this equation is:

$$W(X) == \begin{cases} \dfrac{(g\lambda-k)C}{r+\lambda} + B_1\exp(pX), & \textit{if } X > Cg+\xi \\ \dfrac{(X-\xi)\lambda^2 + ((X-\xi)r+m)\lambda - Ckr}{(r+\lambda)^2} + B_2\exp(pX) + B_3\exp(qX), & \textit{if } \xi < X < Cg+\xi \end{cases}$$

where B_1 and B_2 are arbitrary constants, ξ is the abandonment boundary as determined by the issuer optimization, and

$$p = -\frac{C\,k + m + \sqrt{C^2k^2 + 2C\,k\,m + 2(\lambda+r)\sigma^2 + m^2}}{\sigma^2} < 0$$

$$q = -\frac{C\,k + m - \sqrt{C^2k^2 + 2C\,k\,m + 2(\lambda+r)\,\sigma^2 + m^2}}{\sigma^2}$$

Determine B_1, B_2, and B_3 with value-matching and smooth-pasting at $X = Cg + \xi$ and at value-matching to zero at the abandonment boundary, $X = \xi$:

$$B_3 = \frac{-p\left(-\dfrac{(g\lambda-k)C}{r+\lambda} + \dfrac{(C\,g-2\xi)\lambda^2 + ((C\,g-2\xi)r+m)\lambda - Ckr}{(r+\lambda)^2}\right) - \dfrac{\lambda}{r+\lambda}}{(p-q)\exp(-q(Cg-\xi))} < 0$$

$$B_2 = \frac{\dfrac{\lambda}{r+\lambda} - qB_3\exp(-q\xi)}{p\exp(-p\xi)}$$

$$B_1\exp(-p(Cg-\xi)) = \frac{(C\,g-2\xi)\lambda^2 + ((C\,g-2\xi)r+m)\lambda - Ckr}{(r+\lambda)^2} +$$

$$+B_2\exp(-p(Cg-\xi)) + B_3\exp(-q(Cg-\xi)) - \frac{(g\lambda-k)C}{r+\lambda}$$

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