Credit Derivatives: Capital Requirements and Strategic Contracting*

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Abstract

How do non-publicly observable credit derivatives affect the design contracts that buyers may offer to signal their own types? When credit derivative contracts are private, how do the different rules of capital adequacy affect these contracts? In this paper we address these issues and show that, under Basel I, high-quality banks can use CDO contracts to signal their own type, even when credit derivatives are private contracts. However, with the introduction of Basel II the presence of private credit derivative contracts prevents the use of CDO as signalling device if the cost of capital is large. We also show that a menu of contracts based on a basket of loans characterized by different maturities and a credit default swap conditioned on the default of the short term loans can be used as a signalling device. Moreover, this last menu generates larger profits for high-quality banks than the CDO contract if the cost of capital and the loan interest rates are sufficiently high.

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1 Introduction

Bank loans have usually been considered as illiquid assets. This is mostly explained by the private information banks have about the quality of their loans: since this information is not easily verifiable, potential buyers are reluctant to take risk on such assets.

The recent advent of credit derivatives, however, has provided banks with a whole range of flexible instruments for selling loans and transferring loan risk. For example, pure credit derivatives, such as plain vanilla credit default swaps (CDS) allow banks to buy protection on a single exposure or on a basket of exposures; portfolio products, such as Collateralized Debt Obligations (CDO), enable banks to sell risks from their entire loan portfolio[1]. One main advantage of these new instruments over traditional forms of credit risk transfer is their flexibility, that helps to mitigate informational problems.

In this paper we investigate the problem faced by a bank that, because of asymmetric information in the credit risk transfer market, needs to signal its quality. In line with current market practice[2], we assume that credit derivative trades are not made public (i.e. credit derivatives are private contracts and outside investors are unable to observe all the credit derivatives positions of the banks) so that the protection buyer cannot make a commitment to a specific partial protection level to signal its type. In fact, any protection buyer who purchases partial protection upon its loans with a protection seller can, at the same time, hedge the rest with another protection seller, without the first being informed. We also assume that banks are subject to minimum regulatory

[1]BBA (2002), and BIS (2003, 2005) surveys show that the volume of trade in credit derivatives has known a huge increase shortly. To date, credit derivatives are traded almost exclusively on single names CDS: defaults events for corporations that also have publicly traded bonds outstanding; CDO, RMBS and "classical" ABSs experienced some success in recent years.

[2]As reported by BIS (2005): "About two-thirds of the surveyed banks disclose only the aggregate notional size of their positions. [....] In addition, when national accounting rules require the disclosure of financial guarantees, the total amount guaranteed through credit derivatives is disclosed, even if the bank does not make a more comprehensive disclosure of its position".

capital requirements and that bank capital is costly. This induces banks to prefer to hold risk-free rather than risky assets even if they are risk neutral and to attribute a cost to the capital required by loans.

These, according to our opinion, reasonable assumptions suggest two research questions, which, to our knowledge, have not yet been considered in the literature. First, how does the presence of credit derivatives, which are not public, affect the design of the contracts that protection buyers may offer to signal their own types? Second, when credit derivative contracts are private, how do the different institutional settings (namely, the presence of different regulatory capital requirements) influence these contracts? In this paper we present a simple model which addresses these questions.

The overall structure of our model is roughly as follows. We assume that banks are of different types, and vary in their ability to screen borrowers. There exist "high" type banks that are able to screen their borrowers and choose only "good" loans, and "low" type banks that are unable to do so. In our model there is a one-to-one relation between a bank's ability and the riskiness of its credit portfolio, i.e. banks of diverse type have different loan pools. Protection sellers do not know the true type of the protection buyer (simply "the buyer" from now on), and therefore face an adverse selection problem.

As previously mentioned, the definition of minimum capital requirements is important in our analysis because it may affect the contract design. Much of the initial activity in the credit risk transfer market was in response to inconsistencies in the regulatory framework for bank capital allocation (see Jones (2000)). In this paper *we focus* on capital requirements which prevent regulatory arbitrage and help to reduce both the probability of bank default and the expected deadweight costs associated with bank insolvency. The less intrusive capital adequacy rule suggested by regulators in pursuit of this objective and used in the paper is that bank capital must cover losses due to loan defaults with a given probability (see BCBS (2005) commonly known as Basel II).

In order to solve the adverse selection problem, we consider first the contract most used both in the literature and by practitioners to solve the adverse selection problem: the CDO menu where the protection buyer transfers a portion of the risk of the portfolio in one or more tranches to the protection seller and retains the other portion. The key aspect of this mechanism is that the risk transferred and the risk retained are of different seniority and, usually, the protection buyer holds the equity tranche (i.e. the most junior tranche). As DeMarzo and Duffie (1999) show, the protection buyer's retention of the subordinate block reduces the total lemon's premium by creating an incentive to align its interests with those of the protection seller.

In our work, we obtain the same result of DeMarzo and Duffie (1999) if credit derivatives are public contracts. However, we show that the contract design changes when banks cannot credibly commit to make public the contracts they sign and there are capital requirements.

When CDOs are public contracts and there are no capital requirements for CDOs (as under Basel I[3]) high type banks signal their own type by retaining the equity tranche. CDO contracts sustain a separating equilibrium, since to sign this contract is more costly for a low type bank than for a high type one, because loans in the former type's portfolio have higher probability to default. When CDOs are subject to capital requirements (as under Basel II[4]), to sign this contract is even more costly for a bank which retains the equity tranche, since it has to allocate enough bank capital to cover its losses and

[3]This situation is in line with current practice and current regulation. Indeed under Basel I (BCBS (1988)) in some jurisdictions CDOs are considered as a portfolio loan sales and banks face almost no capital requirement for holding the equity tranche.

[4]Basel II (BCBS (2005)) requires that all first loss positions of CDO (i.e. the equity tranche) must be deducted from bank capital.

therefore to satisfy capital requirements. As a result, when the cost of capital is increasing, low type banks have lower incentive to mimic high type banks[5]. This implies that the amount of the equity tranche that sustains the separating equilibrium is decreasing in the cost of capital. Namely, when the cost of capital goes to infinite the equity tranche which sustains the separating equilibrium is (almost) zero and so does capital requirements.

When credit derivative contracts are private, a low type bank is able to secretly cover the equity tranche and avoid to allocate bank capital to cover losses or satisfy capital requirements. Therefore, the cost of capital is not affecting the incentive to mimic high type and the equity tranche that sustains the separating equilibrium does not depend on the cost of capital. When the equity tranche is independent on the cost of capital, the separating contract induces the high type bank to hold a large amount of capital in order to prevent default and satisfy capital requirements. It follows that if the cost of capital is sufficiently large, then the separating equilibrium is not sustainable, because high type would prefer to hedge the equity tranche than to retain the risk and face the cost of capital. This case suggests a potential effects that the introduction of Basel II may have on the CDO market.

In summary, we show that, first, the separating CDO contract depends upon the presence of capital requirements and whether credit derivatives are private or public; second, when credit derivatives are private contracts, the CDO contract cannot be used as a signalling device if the cost of capital is large enough.

Given these results we investigate if there are other contracts that could be preferable than CDOs to solve the adverse selection problem when credit derivatives are private contracts and there are capital requirements. The contract we propose is quite new in

[5]However, this situation is only theoretical given the presence of credit derivative contracts that are not publicly observable.

the literature of financial innovation and is based on a basket of loans characterized by different maturities and a credit default swap conditioned on the default of the short term loans. This financial contract is such that the protection buyer pays a premium to the protection seller in exchange for a contingent payment by the counterpart if short term loans default. A plain vanilla conditioned on the default of the short term loans is a commitment to buy, at a fixed price, an insurance contract (a credit default swap) on the rest of the basket after the default. For sake of simplicity, we call this menu of contracts the FTD menu because is similar in spirit to the a first-to-default contract.

The FTD menu signals the quality of the bank in a different way with respect to the CDO. With a FTD menu, the bank is signalling its type by committing to buy "new" insurance if short term loans default. Hence, through a FTD, a bank signals its type by paying a state dependent premium and not by varying the quantity of insurance it buys. If the interest rate on the loans is large enough to cover the premiums paid to insure the loan portfolio in all the states, it turns out that a bank which signs a FTD menu has no capital at risk and therefore no capital requirements to satisfy.

In this case, if the cost of capital is sufficiently large, then the FTD menu guarantees higher profits than the CDO menu to the protection buyer, because only the former contract allows a bank to signal its type without facing the cost of capital.

In summary, the paper presents two main results. When credit derivatives are private contracts and there are capital requirements, CDO contracts cannot always be used to generate a separating equilibrium. Second, the CDO menu is not always the best contract to sustain a separating equilibrium (as instead shown by DeMarzo and Duffie (1999) in a framework with public observability of contracts) and different contracts like FTD menu can be successfully used as signalling devices.

The paper is organized as follows. The next section describes the related literature. In Section 3 we present the basic model and we analyze the benchmark case with symmetric information. In Section 4 we consider the asymmetric information case and we present our results. Section 5 concludes.

2 Related literature

The tremendous development in credit derivative markets has received the attention of both regulators and policy makers. Most international and national supervisors have published reports on the topic (e.g. IMF (2002), BIS (2003, 2005)). These reports are rather similar in tone. On one hand they emphasize the benefits of credit derivatives in terms of risk sharing and diversification gains. On the other hand, there is common concern that credit derivatives may have implications for financial stability. In creating new markets for credit risk, credit derivative instruments may (i) have an impact on asymmetric information problems existing between borrowers and lenders (see Duffee and Zhou (2001) and Morrison (2005)) and (ii) create new problems in the credit markets (see Kiff, Michaud and Mitchell (2003) for a review of almost all the potential implications of credit risk transfer markets because of the asymmetric information problems in the credit markets). Most of the arguments however, are on a purely informal basis, which is due to the lack of theoretical work on these issues. A recent exception is Morrison (2005) who shows that if credit derivative trades are not published so that the protection buyer cannot make an ex-ante commitment to a specific protection level, banks have a moral hazard incentive to fully hedge their exposition and therefore cease to monitor. This behavior has the negative effect of causing disintermediation and thus reducing welfare. In our paper we show that the extensive flexibility provided by credit derivative products allows a solution to the adverse selection problem created by both the opacity of bank loans and the fact that credit derivatives are private contracts[6].

Even ignoring the capital requirement issue and the contract observability problem, the theoretical literature on credit derivatives and asymmetries of information problem is limited and borrows from optimal contract design to solve the adverse selection problem. In their model DeMarzo and Duffie (1999) include general securities whose payoffs may be contingent on arbitrary public information such as CDO contracts. DeMarzo and Duffie focus on liquidity problems with asymmetric information. More precisely, they have shown that, in line with Leland and Pyle (1977) pooling and sharing may be optimal when the protection buyer has superior information. They argue that the sharing process allows the protection buyer to concentrate the "lemon's premium" on the small first-loss or equity tranche and create a relatively large, low-risk senior tranche. Also, the protection buyer's retention of the subordinate tranche reduces the total lemon's premium by creating an incentive for the buyer to align its interests with those of the protection seller. In our model we also consider this kind of contract design and derive the characteristics of this contract when a buyer cannot credibly commit to retain part of the risk because credit derivatives are private contracts, an aspect not addressed in the previous paper.

Duffee and Zhou (2001) demonstrate that the problem of adverse selection may be overcome by drawing up credit derivatives with a smaller maturity than that of the underlying asset[7]. The key assumption in their model is the hypothesis that the bank's information advantage changes over the time and, in particular, is greater close to the

[6]Chiesa (2005) shows that Morrison's (2005) problem could be solved using an optimal credit risk transfer instrument, i.e. transferring exogenous risk. In this way the bank lowers the amount of capital that it must put at stake for finding incentive-compatible to monitor/screen the loans it originates.

[7]Moreover, Duffee and Zhou (2001) show that the mechanism proposed by Gorton and Pennacchi (1995) to reduce the moral hazard problem associated with the loan sales is broadly applicable to any mechanism that transfers loan risk outside of the bank, including credit derivatives.

maturity date of the loan. One of the contract we present is similar in spirit to the one proposed by Duffee and Zhou (2001). Nevertheless our approach is different, because we neither assume that the bank's information advantage decreases over time, nor that there is perfect observability of credit derivative contracts.

3 The model

3.1 Assumptions

Let us consider a market where there is a bank (buyer) operating in the local loan market which may hedge its expositions in the OTC credit derivative market by selling credit risk to other banks (protection sellers). By definition, the OTC market is characterized by private contracts i.e. details of trades are not made public.

Buyers and sellers are both risk neutral and, for simplicity, the riskless interest rate is zero. The (protection) buyer belongs to one of two different types: high-type (denoted by h) and low-type (denoted by l). Both types vary only with respect to the quality of their loan pools for the credit risk on which the bank seeks protection. The quality of the pools is assumed to depend on borrowers' ability to repay loans. Since the probability of loan default depends on the ability of the bank to discern its borrowers, the buyer's quality can be represented by the probability that its borrowers repay loans. This probability is greater for a high-type buyer than for a low-type. Let p_i for $i = \{h, l\}$ be the probability of success for loans repayment, then $0 \leq p_l < p_h \leq 1$, where p_l and p_h are the probability of loan success held by a low-type and a high-type buyer, respectively.

The model incorporates three dates: 0, 1 and 2. On date 0, the buyer holds a portfolio of two commercial loans with fixed size: I_1 and I_2. I_1 matures on date 1 while I_2 matures on date 2. Both credit lines can default only at the maturity date and are uncorrelated[8]. Making a loan of amount I a buyer $i = \{h, l\}$ obtains an expected profit $\pi_i = p_i (1 + \mu) I - I$, where μ is the interest rate, which is the same for both types. Hence, sellers cannot infer buyers' types from the interest rate.[9] Moreover, we assume that $\mu \leq 1$; this assumption allows us to simplify our analysis and in our opinion is sufficiently mild not to undermine the generality of our results. We assume that $\pi_h > \pi_l \geq 0$ that is both types of loans have non negative net-present-value (NPV)).

Banks finance the portfolio of loans with deposits. Therefore, losses will push the bank toward insolvency if it has not enough capital to cover them. Because of either deadweight costs generated by insolvency or capital requirements, the bank, even if risk neutral, cares about risk and holds capital as a buffer to cover losses or to satisfy capital requirement. We assume that bank capital is invested in a short term asset and is not used to finance the portfolio of loans. Moreover, although bank shareholders are risk neutral, the cost of capital, denoted by ρ, is assumed to be greater[10] than the cost of deposits that is normalized to zero[11]

These assumptions simplify the model considerably because we do not need to explicitly model the bank's capital structure and capital adequacy rules in details but we refer more generally to the bank capital needed to prevent default with a given probability

[8]The key aspects of the paper are not based on diversification opportunities; the assumption that there are no other assets in the bank's portfolio allows to present our results in a very simple framework focussing on the use of credit derivatives to cover exposures.

[9]This assumption is in line with the statement of Duffee and Zhou (2001), according to which there is not a one-to-one relation between the interest rate charged by a bank and the quality of borrowers. Indeed, the interest rate charged on a loan depends on the overall relationship existing between the bank and its borrowers and also on the bank's and borrowers' bargaining power. Moreover, the bank's choice of interest rate is also affected by the presence of informational asymmetries between borrowers and the bank itself. Regarding this topic, we recall the works about credit rationing by Jaffee and Russel (1976) and Stiglitz and Weiss (1981).

[10]See Dewatripont and Tirole (1993), Froot and Stein (1998) and Gorton and Winton (1998) for explicit models of why ρ might be positive.

[11]Introducing a positive flat deposit insurance premium would reduce the spread with the cost of capital but this extra cost will be reflected in the cost of loans without altering our results.

α. We assume that[12] $\alpha > p_h$ and this implies that the bank capital has to cover all the losses.

Here we focus on the case in which banks use credit derivatives in order to reduce capital requirements and therefore the cost of capital. The credit derivative market we consider is characterized by the presence of different types of contracts. At time 0, the buyer simultaneously offers to purchase credit derivative contracts from the sellers[13]. Since there are many sellers, we assume that the buyer faces a competitive market. At the time of the proposal, the buyer's type is private information. Hence, we assume that the buyer has full bargaining power and makes a take-or-leave-it offer to a seller.

The buyer may offer a number of different contract menus:

- a credit default swaps basket (the *CDS basket*), that hedges the credit risk of the portfolio I_1 and I_2;

- a collateralized debt obligation[14] (CDO) on the portfolio I_1 and I_2, and an insurance contract to cover the counterpart's losses up to a certain amount L (the *CDO menu*);

- a first-to-default basket and a plain vanilla CDS contract over I_2 conditioned on the default of the first asset I_1 (the *FTD menu*). The first-to-default basket is a financial contract in which the protection buyer pays a premium to the protection seller in exchange for a contingent payment by the counterpart if asset I_1 defaults. In case of a default by I_1 the contract ends. The other contract in the menu is a commitment at time

[12] Under Basel II α is set at 99.9%.

[13] We assume that protection sellers are not subject to capital requirements because, as in line with empirical evidence, they are largely insurance companies or hedge funds.

[14] Most specifically, the CDO contracts traded in the market are Asset Backed Securities where the bank sells part of its loan portfolio to a special purpose vehicle which refinances itself through the issue of bonds. Payoffs are tranched with claims on the poll separated into different degrees of seniority in bankruptcy and timing of default. The equity (or junior) tranche is the residual claim and has the highest risk. The mezzanine tranche comes next in priority. The senior tranche has the highest priority and is often AAA rated. Usually the bank buys the equity tranche which absorbs all default losses up to its par value, before other tranches have to bear any further losses. For a more detailed description see Das (1998).

$t = 0$ to buy, at a fixed price, a plain vanilla contract on I_2 at time $t = 1$, conditional on the default of the first asset, I_1.

In our model, the credit event is identified with a failure to pay at the maturity date. The credit event payment is defined as the difference between the nominal value plus the accrued interest and the recovery value of the defaulted loan. For simplicity, we assume here that the recovery value is equal to zero, so that the credit event payment will be equal to the nominal value plus the accrued interest of each loan ($I_1(1+\mu)$ in $t = 1$ and $I_2(1+\mu)$ in $t = 2$). Moreover, all the cash flows (including payment of the premiums) occur at the maturity of the contracts. Finally, let $0 < q < 1$ be the percentage of high-quality banks among the protection buyers.

3.2 The benchmark case: symmetric information

If a bank is issuing a portfolio of loans (I_1, I_2) its maximum loss with a confidence level α is $I_1 + I_2$ given our assumption that the recovery rate is zero (i.e. capital requirements are $I_1 + I_2$). Under this framework, in order to prevent default (or satisfy capital requirements) the bank has to guarantee loans losses with bank capital equal to $I_1 + I_2$. The expected profits of a bank of quality $i = \{h, l\}$ will be:

$$\pi_i \left(I_1 + I_1\right) = \left(1 - p_i\right) \left(I_1 + I_2\right)(1 + \mu) - \left(I_1 + I_2\right) - \rho(I_1 + I_2) \text{ with } i = h, l \qquad (1)$$

where $\rho(I_1 + I_2)$ is the required remuneration for the bank capital buffer that guarantees loan losses. In order to reduce loan losses and therefore the capital buffer, the bank can sign credit derivatives.

When the buyer's type is common knowledge, then the lowest premium that a risk neutral seller is willing to accept is the fair premium. Hence, the lowest premium in order to fully insure a bank of type i with loan I_j by means of a plain vanilla CDS contract is:

$$\Phi_i(I_j) = (1 - p_i)\, I_j(1+\mu) \text{ with } i = h, l \text{ and } j = 1, 2. \tag{2}$$

Signing a *CDS basket* contract on the bank's loan portfolio, the expected profits of a buyer of type i are:

$$\pi_i(I_1 + I_1) = \mu(I_1 + I_2) - \Phi_i(I_1) - \Phi_i(I_2) \;\text{ with } i = h, l \tag{3}$$

Observe that loan losses are completely covered by the CDS basket and therefore there are no capital requirement and no costs of capital. Since by assumption the NPV of the loans is positive for both types $i = h, l$, it follows that expected profits are positive.

It is straightforward to note that, with complete information, the full coverage CDS basket is a first-best contract.

4 Asymmetric information

4.1 Pooling equilibria.

In any pooling equilibrium the minimal premium that a risk neutral seller is willing to accept in order to sign a plain vanilla contract that fully hedges the counterpart against the credit risk of the loan I_j is:

$$\Omega(I_j) = q(1 - p_h)\, I_j(1+\mu) + (1-q)(1-p_l)\, I_j(1+\mu) \; with \; j = 1, 2. \tag{4}$$

Signing a full coverage plain vanilla credit derivative, a buyer of type i obtains the following expected profit:

$$\pi_i(I_j) = \mu I_j - \Omega(I_j) \text{ with } i = h, l \text{ and } j = 1, 2. \tag{5}$$

As usual, it is easy to find the pooling equilibrium where both types of buyers sign the same contract. In particular, it is straightforward to check that there exists a pooling equilibrium such that buyers of both types sign the CDS basket. The seller's beliefs are such that, if a full coverage CDS basket is offered, the buyer is a high-type with probability q; if any contract different than a full coverage CDS basket is offered, then the buyer is a low-type with probability 1. It is clear that high-type banks' profits are lower than their profits in a game with complete information and the lower the number of high-type banks in the market, the stronger is the incentive to signal their own type. We devote the next section to analyze separating equilibria.

4.2 Separating equilibria

In this section we prove the existence of separating equilibria such that, at time zero, a high-type buys one of the two menus of contracts (CDO or FTD) presented above and the low type buys the full coverage CDS basket[15]. First we consider the two menus separately. Then we determine which separating contract is preferred by high-type banks; this depends on how the cost of capital, ρ, and the interest rate, μ, vary.

In order to overcome the multiplicity of perfect Bayesian equilibria, we only consider separating equilibria which satisfy the intuitive criterion proposed by Cho-Kreps (1987)

[15]We do not consider explicitly the plain vanilla credit derivative swap on a basket with partial coverage. In fact, we already know from DeMarzo and Duffie (1999), and it is easy to show that the same holds in our framework, that this contract provides less profit to the protection buyers than the CDO contract.

for a signalling game (denoted "CK perfect Bayesian equilibria"). Given that we employ this refinement concept several times, it is worth giving an informal intuition of how it works. Consider that a buyer makes an out-of-equilibrium proposal and consider any conjecture that it has about how the seller reacts. If it happens that, given the seller's most optimistic conjecture (the seller believes that the proposer is high-type bank with probability one), a high-type bank finds it optimal to deviate while the low-type does not, then the intuitive criterion imposes to assign probability 1 that the proposer of such a contract is a high-type bank.

First, we determine the conditions under which we have a separating equilibrium such that high-type banks choose CDOs to signal their own type. Later we consider the FTD menu.

4.2.1 Separating equilibrium with CDO

With a CDO contract the protection buyer sells its basket portfolio (I_1, I_2) to the protection seller and guarantees the payment, in case of default, of a fraction of the loss suffered by the buyer of the portfolio (the protection seller). We consider a small modification to the CDO contract described above. In our contract the protection buyer pays L to the protection seller when the default of at least one loan occurs and the amount L does not depend on the size of the loss suffered by the protection seller. Given that both parties are risk neutral, a flat refund leads to the minimum size of loss that the high-type has to sustain in order to signal its own type. Therefore, this contract, minimizing the amount of the required capital is preferred by a protection buyer to any other contract with variable payment. In this section we assume that the buyer can offer to the seller either a plain vanilla CDS basket credit derivatives or a CDO menu, but not a FTD menu.

To understand the role of observability of credit derivative contracts and capital requirement on the signalling contract we consider first the case when credit derivatives are public contracts and there are no capital requirements or the cost of capital is zero (but the bank still has an incentive to transfer credit risk).

Proposition 1 *When credit derivatives are public contracts and banks are not subject to capital requirements, there exists a unique CK separating perfect Bayesian equilibrium such that high type banks sell $(I_1 + I_2)$ loans in exchange for a fixed amount of money and commit to pay in case of default of any of the underlying assets an amount $\hat{L} = \frac{(I_1+I_2)(1+\mu)}{(p_h+p_l)}$. Low type banks sign full coverage plain vanilla derivative contracts. The adverse party's beliefs are such that if full coverage plain vanilla default swap or a CDO with $L < \hat{L}$ are offered, then the bank is a low-type with probability one. If a CDO with $L \geq \hat{L}$ is offered, then the bank is high-type with probability one.*

Proof. See the appendix. ■

When CDO are public contracts and there are no capital requirements high type banks signal their own type by retaining the equity tranche. CDO contracts sustain a separating equilibrium, since to sign this contract is more costly for a low type bank than for a high type one, because loans in the former type's portfolio have higher probability to default[16]. In this case the CDO menu is a first best contract for the high-type (given the assumption of risk neutrality).

The CDO contract which sustains a separating equilibrium changes when credit derivatives are public contracts and there are capital requirements, as stated in the following proposition:

[16] As stressed above, this situation is in line with current practice and current regulation (Basel I). The potential presence of private contracts is not relevant because the high type has no incentive to cover the equity tranche.

Proposition 2 *When credit derivatives are public contracts and banks are subject to capital requirements, there exists a unique CK separating perfect Bayesian equilibrium such that high type banks sell* $(I_1 + I_2)$ *loans in exchange for a fixed amount of money and commit to pay in case of default of any of the underlying assets an amount* $\hat{L} = \frac{(p_h - p_l)(I_1+I_2)(1+\mu)+\rho(p_h(I_1+I_2)(1+\mu)-(I_1+I_2))}{(p_h^2-p_l^2)+\rho p_h^2}$. *Low type banks sign full coverage plain vanilla derivative contracts. The adverse party beliefs are such that if full coverage plain vanilla default swap or a CDO with* $L < \hat{L}$ *are offered, then the bank is a low-type with probability one. If a CDO with* $L \geq \hat{L}$ *is offered, then the bank is high-type with probability one.*

Proof. See the appendix. ■

When credit derivatives are public contracts (or banks can credibly commit to retain the equity tranche risk) and there are capital requirements, the equity tranche L depends on the cost of capital ρ and is decreasing in this parameter. The intuition behind this result is simple: higher is the cost of capital, lower are the incentives for the low-type banks to mimic the high-type banks and draw up these contracts. On the contrary, when $\rho = 0$ (there is no cost of capital) the amount of equity tranche that sustains the separating equilibrium is the same as in the case of public contracts with no capital requirements[17]. However, when $\rho > 0$ CDO contracts are no longer first best contracts.

When credit derivative contracts are private, and therefore banks can hedge the equity tranche without the counterpart of the CDO contract being informed[18], then the equilibrium, when it exists, turns out to be the same as in Proposition 1, that is when the credit derivative contracts are public and there are no capital requirements.

[17]This case is more in line with Basel II that requires that all first loss positions must be deducted from bank capital. But it is only a theoretical case because protection buyers in current practice cannot commit to hold the equity tranche.

[18]BIS (2005) indicates that banks issuing CDO have then transferred the equity tranches to hedge funds.

Nevertheless, this time the equilibrium exists only if the cost of capital ρ is not too high[19].

Proposition 3 *When credit derivatives are private contracts and banks are subject to capital requirements, if* $\rho \leq \frac{(p_h^2-p_l^2)(1+\mu)}{(p_h+p_l)-p_h p_l(1+\mu)}$*, then there exists the unique* CK *separating perfect Bayesian equilibrium described in Proposition 1. If* $\rho > \frac{(p_h^2-p_l^2)(1+\mu)}{(p_h+p_l)-p_h p_l(1+\mu)}$*, then there exists no separating equilibrium in which high type banks sign CDO contracts and low-type banks sign plain vanilla contracts.*

Proof. See the appendix. ■

The intuition behind this result is the following. A bank that sells its loans partially insures the counterpart by committing to pay an amount $\hat{L}$ in case of default of any of the underlying assets. Since the probability of sustaining a default is lower for the high types than for the low-types, then there exists an amount of refund L such that low-type banks prefer to sign a CDS basket, while high-type banks prefer to sign a CDO menu. In the appendix we show that the minimum refund $\hat{L}$ which supports a separating equilibrium (and the unique one satisfying the intuitive criterion) induces a positive capital requirement, i.e. the bank has to allocate capital in order to avoid insolvency because it has to pay $\hat{L}$ to the adverse party when the loan defaults. Therefore, the larger the cost of capital ρ, the smaller the profits of a high-type bank when it signs a CDO menu. In particular, if $\rho > \frac{(p_h^2-p_l^2)(1+\mu)}{(p_h+p_l)-p_h p_l(1+\mu)}$, then high-type banks prefer to hedge the equity tranche as a low type and therefore, in this case, there is not a separating equilibrium. If $\rho \leq \frac{(p_h^2-p_l^2)(1+\mu)}{(p_h+p_l)-p_h p_l(1+\mu)}$, then a high-type prefers to incur the cost of capital rather than to hedge the equity tranche. Low-types do not over-insure their exposure using both CDS basket and CDO menu (i.e. trying to mimic high-types) because the

[19]This result indicates that the potential effect of the introduction of Basel II and the presence of high costs of capital would be a reduction of the use of CDO contracts in order to reduce capital requirements.

premium they receive for the refund $\hat{L}$ is lower than the fair value (they receive $(1-p_h^2)\hat{L}$ but the expected value of their payment is $(1-p_l^2)\hat{L}$). Therefore, if a low-type over-insures its exposition, it reduces its expected profits[20]. As a result, our separating equilibrium does not require that a bank has not secretly hedged its portfolio using other contracts.

It is also worth noting that the refund $\hat{L}$ does not depend on the cost of capital ρ (while the existence itself of the separating equilibrium does), because we assume that credit derivatives are private contracts. Since a bank can hedge the refund $\hat{L}$ without the counterpart being informed, the cost of capital does not enter in the self selection constraint of the low type (see the appendix) and therefore, the amount of equity tranche that sustains the separating equilibrium is the same as in the case of public contracts without capital requirements.

4.2.2 Separating equilibrium with first to default contracts

In this subsection we show that high-type banks may also use the FTD menu of contracts to signal their own types. By signing a FTD menu, a high-type bank credibly signals its quality in a way that is distinct from signing a CDO menu. In fact, in the last case the high-type bank sells its portfolio of loans and the signalling device is obtained by partially insuring the buyer of the portfolio in case of default. In the former case, the high-type bank buys protection and is therefore the insured party. In this case, a bank signals its own type by accepting a stochastic payment for the insurance. The bank will pay a new premium to insure against a second default, if and only if a default of one of assets has already occurred. In this way, a high-type bank signals its own type with a contract that provides partial coverage, such that it is not the amount of coverage, but the amount of the payment (i.e. the premium paid for the insurance), that varies

[20]Clearly the high-type bank is not over-insuring its portfolio using CDS basket because anyone buying that insurance is assumed to be a low-type bank.

across different states of the world. Again, since the probability of having a first default is higher for low type (since $1 - p_l > 1 - p_h$), then there exists a premium large enough to deter low-types to sign a FTD menu.[21]

Assuming that a protection buyer can only propose either a FTD menu or a CDS basket credit derivative contract, the following proposition holds:

Proposition 4 *If* $\mu \geq \frac{(1-p_l)I_1+(1-p_h p_l)I_2}{p_l(I_1+p_h I_2)}$ *or* $\rho \leq \frac{(p_h-p_l)}{p_l}$, *then there exists a unique CK separating perfect Bayesian equilibrium such that:*

(i) high type banks sign a first-to-default basket contract paying a premium $\hat{\Psi}_{0,h}(I_1, I_2) = (1 - p_l)(I_1 + p_h I_2)(1 + \mu)$, *and a plain vanilla contract on* I_2 *conditioned on the credit* I_1 *default, paying a premium* $(1 - p_h) I_2(1 + \mu)$*;*

(ii) low type banks sign full coverage plain vanilla derivative contracts and pay the fair premium.

The protection seller's beliefs are such that the protection buyer is a high type bank with probability one if and only if it proposes to sign a FTD menu with $\Psi_{0,h}(I_1, I_2) \geq \hat{\Psi}_{0,h}(I_1, I_2)$. *If the protection buyer proposes to sign a plain vanilla contract or a FTD menu contract with* $\Psi_{0,h}(I_1, I_2) < \hat{\Psi}_{0,h}(I_1, I_2)$, *then the protection seller believes that the bank is low-type with probability one.*

Proof. See the appendix. ■

Note that the premium paid at time $t = 0$ for the first-to-default is larger than the fair premium that would be equal to $(1 - p_h)(I_1 + p_h I_2)(1 + \mu)$. The high type pays this larger premium in order to prevent low type banks form mimicking its behavior and therefore the difference between the premium paid and the fair one is the cost that high type bank faces in order to signal its type.

[21] This is a typical signalling device in the literature on asymmetric information. For instance, in Diamond (1993) a borrower can decide to execute an (inefficient) short term contract in order to signal he is not afraid to turn again to the credit market.

The premium paid at time $t = 1$ to hedge loan I_2 in case of I_1 default, is equal to the fair premium for the high-types. In fact, we restrict our analysis to renegotiation-proof contracts. In a separating equilibrium only high-type banks sign a FTD menu. Therefore at time $t = 1$ in the case of I_1 default, there is complete information on the buyer type and therefore the unique renegotiation-proof premium that the buyer pays to hedge asset I_2 is equal to $(1 - p_h) I_2(1 + \mu)$.[22]

The capital requirement induced by a FTD menu can be positive or zero, depending on the level of the interest rate. As we show in the appendix, if $\mu \geq \frac{(1-p_l)I_1+(1-p_h p_l)I_2}{p_l(I_1+p_h I_2)}$, then profits are large enough to pay the premium of the plain vanilla credit default swap on I_2 when I_1 defaults and therefore there is no need of bank capital because the bank faces no losses. If $\mu < \frac{(1-p_l)I_1+(1-p_h p_l)I_2}{p_l(I_1+p_h I_2)}$, a high-type bank which signs the FTD menu faces losses in some state of the world. Therefore, in this case in order to satisfy capital requirements, the bank has two choices: (i) to cover this exposure with a plan vanilla contract (paying a premium as a low type) or (ii) to hold capital. The bank selects the second solution and chooses to not hedge the loss it faces (when I_1 defaults and it has to hedge again credit I_2) if and only if the cost of capital is relatively low, i.e. $\rho \leq \frac{(p_h - p_l)}{p_l}$.

The high-type bank has no incentive to over-insure its portfolio issuing more than one FTD menu. To buy insurance is costly for a high type bank and therefore this strategy increases profits only if in this way the bank reduces its capital. For the same reason, the high-type bank has no incentive to over-insure its portfolio using a CDS basket. The effect would be a reduction of expected profits since anyone buying that insurance contract is assumed to be low-quality bank. Low-type banks do not over-insure their

[22]We may have different separating contracts if the premium paid at time $t = 1$ can be larger than $(1 - p_h) I_2(1 + \mu)$. If we assume that a buyer can commit at time $t = 0$ to pay a premium larger than $(1 - p_h) I_2(1 + \mu)$ to the seller in order to insure I_2 in case of I_1 default, then there exists equilibria in which buyer's profits are higher. But consistently with the assumption that the buyer has full bargaining power, we assume that these contracts could be renegotiated at time $t = 1$.

exposition because the overall cost of purchasing any of the contracts (either CDS or FTD menus) is equal to their expected profits.

Our separating equilibrium does not require that adverse parties know that a bank has not secretly hedged its portfolio using other contracts. When a high-type bank buys a FTD menu, it commits to buy a plain vanilla contract at time $t = 1$ in case of default of the first asset. This commitment is ex-post incentive compatible as a result of the solvency or capital requirement constraint. The FTD menu is a costly contract for the high-type banks since they pay an insurance premium that is higher than the fair premium. In particular, the premium paid at time $t = 0$ is $(1-p_l)(I_1+p_h I_2)(1+\mu)$ while the fair premium of a first-to default contract is equal to $(1-p_h)(I_1+p_h I_2)(1+\mu)$. Hence, a FTD menu is not a first best contract when $\rho = 0$. Moreover neither the premium paid at time $t = 0$ nor the premium eventually paid at time $t = 1$, depend on the cost of capital ρ. Again, this occurs since we have assumed that buyers can privately sign credit derivatives and therefore the cost of capital does not influence the self-selection constraint of the low-type banks.

The equilibrium described in Proposition 4 is not unique if we enlarge the set of possible contracts that a buyer can offer to the seller. High-type banks, as we have shown above, can signal their own type using either a FTD menu or a CDO menu. Hence, it is worthwhile analyzing the conditions under which a high-type buyer would prefer to signal its own type by means of a FTD rather than a CDO menu.

4.3 Signalling contracts: a comparison

Assuming that a protection buyer can propose a FTD menu, a CDO menu or a CDS basket credit derivative contracts, the following proposition holds:

Proposition 5 *If* $\mu \geq \frac{(1-p_l)I_1+(1-p_h p_l)I_2}{p_l(I_1+p_h I_2)}$ *and* $\rho \geq \frac{(p_h^2-p_l^2)(1+\mu)(I_1+p_h I_2)}{(I_1+I_2)(p_h+p_l)-p_h p_l(I_1+I_2)(1+\mu)}$, *then a high-type buyer prefers to signal its own type by drawing a FTD menu than by drawing a CDO menu of contracts.*

Proof. See the appendix. ■

The intuition for this proposition is the following. In proposition 4 we prove that if $\mu \geq \frac{(1-p_l)I_1+(1-p_h p_l)I_2}{p_l(I_1+p_h I_2)}$, then with the FTD menu the bank has not to allocate any capital at risk and it faces no cost of capital. In contrast, in order to sustain a separating equilibrium, the CDO menu always induces a positive capital requirement and the bank faces a positive cost of capital. Therefore, ρ only affects the profits of high-type buyers when they sign a CDO menu and not when they sign a FTD menu. It follows that there exists a cost of capital ρ large enough to make the FTD menu more profitable than the CDO menu for high-type buyers.

DeMarzo and Duffie (1999) show that the CDOs are optimal contracts in presence of asymmetric information when contracts signed in the credit markets are publicly observable. We proved that CDOs still can be used to solve the adverse selection problem when contracts are private. However, Proposition 5 shows that if ρ and μ are high enough the FTD contract not only Pareto dominates the CDO contract (since it faces no cost of capital), but also guarantees higher profits to the buyers.

In our analysis the bank holds capital in order to prevent default. Also for regulators it is important that banks avoid default and this is one of the reasons they introduced capital requirements. Recently, the BCBS (2005) proposed capital requirements based on Value-at-Risk. More specifically, bank capital must cover losses due to loan defaults with a given probability $\alpha = 99.9\%$. This definition is very similar to the approach we used above for determining bank capital. The main difference is that in our analysis we include also intermediation margin (i.e. μ), while it is not clear under Basel II if this element is included[23].

More specifically, if the bank buys protection by selling its portfolio of loans with a CDO it is receiving the margin of its portfolio and in case the loans default it has to pay L. This implies that the level of capital that the bank has to hold in order to avoid default is L minus the margin. Under Basel II it is not clear if the margin could be immediately included in the bank capital. Nevertheless, as the following proposition shows, it is easy to extend our results to the case where capital requirement is equal to the maximum loss of a bank's asset portfolio with a given confidence level α without including the margin.

Proposition 6 *If the capital requirement is based on the total losses without including margins, and:*

$$\rho \in \left[\frac{(p_h^2 - p_l^2)(I_1 + p_h I_2)(1 - p_l)}{(I_1 + I_2) - (1 - p_h)(p_h + p_l) I_2}, (p_h - p_l) \right], \tag{6}$$

then the high-type buyers prefer to signal their own type by signing a FTD menu than a CDO menu.

Proof. see the appendix. ■

In this case also the FTD menu induces the bank to hold capital (indeed the margin of the first loans cannot be used to cover the premium payment of the plain vanilla contract on the second loan), but this requirement is lower than the capital requirement of the CDO menu[24]. Indeed, for the FTD menu the maximum loss is only the fair premium for hedging I_2 if I_1 defaults, i.e. the expected loss, $(1 - p_h)(1 + \mu) I_2$; for the

[23] See Suarez and Repullo (2004) and Elizalde and Repullo (2005) for a discussion of this issue.

[24] Capital requirements for FTD in the BCBS (2005) document are specified in paragraph 207 page 36. The BCBS (2005) document is not explicitly considering contract like the commitment to buy protection on the other loan if the first loan defaults. In our framework we recognize the capital relief also for this contract.

CDO menu the maximum loss is the amount L that is equal to $\frac{(I_1+I_2)(1+\mu)}{(p_h+p_l)}$ and it is always larger than $(1-p_h)(1+\mu)I_2$.

Therefore, as before, it follows that there exists a cost of capital ρ large enough to make the FTD menu more profitable than the CDO menu for high-type buyers (but not too large otherwise there is no separating equilibrium).

Finally, it is worthwhile to note that under[25] Basel I in some jurisdictions CDOs are considered as a portfolio loan sales and banks face almost no capital requirement for holding the equity tranche (i.e. for this contract ρ is almost equal to zero). As we show above, if $\rho = 0$ for CDO menu then the high type bank is still able to signal its type by signing a CDO menu with $L = \hat{L}$. In this case the CDO menu is a first best contract for the high-type (given the assumption of risk neutrality). This result may be one reason of why CDO contracts have experienced some success in recent years. Nevertheless, Basel II requires that all first loss positions must be deducted from bank capital[26]. Therefore, under Basel II, if the cost of capital is positive ($\rho > 0$) CDO contracts are no longer first best contracts. Moreover, if credit derivatives are private contracts and the cost of capital is relatively high they are Pareto dominated by the FTD menu or they are not separating contracts.

A limitation of our model is that we consider credit derivatives that apply only to a basket of two loans. The extension to a larger basket would greatly complicate our model and we prefer to leave this issue to further research. Nevertheless, we expect that our main idea holds even in a more general framework. The key point is that, as soon as the FTD menu has a capital requirement that is lower than the CDO menu, there exists a cost of capital that will make this menu of contracts better than the CDO[27].

[25]See Basel Committee on Banking Supervision (1988).

[26]See BCBS (2005).

[27]This result is enforced if we consider that, as shown by Franke and Krahnen (2005) the equity tranche bears more than 96-98% of the credit risk of the loan portfolio under the CDO.

A case not explicitly considered in our analysis is when the low-type banks can select loans with a negative NPV. It is easy to show that even under this assumption the results will be qualitatively unchanged. More specifically, both FTD and CDO menus allow the high-type to signal its own type. The only significant difference is that in any separating equilibrium the low-type banks do not fund loans with a negative NPV and do not enter the credit derivative markets.

A second case related to our analysis but not explicitly considered is the moral hazard problem that arises when the protection buyer signs a full coverage plain vanilla contract and therefore has an incentive to stop monitoring the borrower. In our framework it is possible to show that with a FTD menu in which underling assets have different maturities the same conclusion does not hold necessarily. If a bank signs a FTD menu then, in the event of an asset default, it must sign another contract to cover the exposure of the remaining loans. Hence, if the cost of monitoring is not too high, the bank has an incentive to monitor the portfolio. It is straightforward to extend this result to the case where CDO menu is used to provide the incentive to monitor.

5 Concluding Remarks

A major concern of both policy makers and regulators is the effect of credit derivatives on the performance of credit markets. We show that the existence of a credit derivative market together with capital requirements for credit risk induces an adverse selection problem because low-type banks may cover their exposure with credit derivatives. Hence, the introduction of a credit derivative market does not necessarily always benefit the economy and increase social welfare.

The use of classical signaling contracts able to solve the problems that arise from the opacity of the loan portfolios of banks is precluded in such market because (i) the retention of a part of the risk increases banks' capital requirements and (ii) credit derivatives are private contracts and are not explicitly made public by banks (at least some of them). This last point makes the use of contracts based on partial coverage more difficult, because protection buyers are unable to commit to a specific level of protection that is ex-post incentive compatible.

To our knowledge this is the first paper in the academic literature to consider rigorously the implications for the design of credit derivatives contracts of these two characteristics: capital requirements and private credit derivative contracts.

Our main result is that, when the cost of capital is not too high, there may nonetheless exist a separating equilibrium where high-type banks signal their own type by signing derivative contracts. First, we show that a CDO menu is (still) a contract that solves the adverse selection problem, even if the buyer cannot commit itself to not hedge the risk by holding the equity tranche (because credit derivative contracts are private). Nevertheless, in our framework unlike DeMarzo and Duffie (1999) CDOs are not always second best contract in presence of asymmetric information. In fact, our second contribution is to prove that if the cost of capital and the interest rate are sufficiently high, then high-type banks prefer to signal their own type by drawing a FTD menu than by drawing a CDO menu.

We believe that this second result is especially interesting for two main reasons. First because it suggests a potential contract design that is able to solve the adverse selection problem when Basel II is implemented (under Basel I we showed that CDOs are first best contracts). Second, it shows that theoretical predictions may change whether credit derivative contracts are publicly observable or not. Since the assumption that contracts are not publicly observable seems much more plausible, our result suggests that the analysis of the presence of private contracts in the credit market may deserve further investigation.

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Appendix

Proof of Proposition 1: With a CDO contract a bank sells its loans I_1 and I_2 to the adverse party. The maximum price that the counterpart accepts to pay is equal to the expected profits of the loans minus the expected payment it receives in case of default of any of the underlying assets. When credit derivatives contracts are public, to sustain a signaling equilibrium the CDO contract has to satisfy the following self-selection constraint for the low-type, that is:

$$p_h(I_1+I_2)(1+\mu)+(1-p_h^2)L-(1-p_l^2)L-(I_1+I_2)\leq \tag{7}$$

$$(I_1+I_2)(1+\mu)-(1-p_l)(I_1+I_2)(1+\mu)-(I_1+I_2),$$

where the left hand side is the expected profit of a low-type bank that deviates and signs a CDO contract: namely, $p_h(I_1+I_2)(1+\mu)+(1-p_h^2)L$ is the fixed amount of money the bank receives by selling the CDO, and L is the equity tranche (which is paid with probability $(1-p_l^2)$). The right hand side of the above inequality is the expected profit of a low-type which signs a full coverage plain vanilla and pays its fair premium. Condition (7) implies:

$$L\geq\frac{(I_1+I_2)(1+\mu)}{p_h+p_l}\equiv\hat{L}. \tag{8}$$

Hence, it follows that there exists a separating CDO contract such that high-type banks sell loans I_1 and I_2 in exchange for an amount of money equal to $p_h(I_1+I_2)(1+\mu)+(1-p_h^2)L$ and commit to pay $\hat{L}$ in case of the default of any loan. Low type banks sign full coverage plain vanilla contracts paying the fair premium $(1-p_l)(I_1+I_2)(1+\mu)$. The equilibrium beliefs are such that the loans buyer believes that the bank is high-type if and only if it offers to sign a CDO with $L\geq\hat{L}$. It believes that the bank is low type with probability one if either a CDO contract with $L < \hat{L}$ or a plain vanilla contract is offered. It is easy to check that these beliefs satisfy the intuitive criterion. To check uniqueness, note that in any separating equilibrium where the equity tranche offered by the high-type bank is equal to $\tilde{L} > \hat{L}$, there exists $\hat{L} \leq L < \tilde{L}$ such that if a high-type deviates offering a CDO contract with this equity tranche, then by the intuitive criterion a seller should assign probability one that the proposer is a high-type. ■

Proof of Proposition 2: When credit derivatives contracts are public but there are capital requirements, the self–selection constraint for the low-type is the following:

$$\begin{aligned} & p_h(I_1+I_2)(1+\mu)+(1-p_h^2)L-(1-p_l^2)L-(I_1+I_2)+ \\ & \qquad +\rho\left(\min\left\{0,p_h(I_1+I_2)(1+\mu)+(1-p_h^2)L-L-(I_1+I_2)\right\}\right)\leq \\ & \qquad\qquad (I_1+I_2)(1+\mu)-(1-p_l)\left(I_1+I_2\right)(1+\mu)-(I_1+I_2). \end{aligned} \tag{9}$$

The capital that the bank has to provide is the maximum loss, that is the difference between the money the bank receives by selling the loans and the sum of the loans and the equity tranche, if this difference is negative, zero otherwise.

First, we look for the maximum penalty L such that there is no need for capital, that is:

$$p_h(I_1+I_2)(1+\mu)+(1-p_h^2)L-L-(I_1+I_2)\geq 0, \tag{10}$$

which implies:

$$L\leq \frac{p_h(I_1+I_2)(1+\mu)-(I_1+I_2)}{p_h^2}\equiv \tilde{L} \tag{11}$$

Condition (9) when condition (10) is satisfied implies:

$$p_h(I_1 + I_2)(1 + \mu) + (1 - p_h^2)L - (1 - p_l^2)L - (I_1 + I_2) \leq \tag{12}$$
$$(I_1 + I_2)(1 + \mu) - (1 - p_l)(I_1 + I_2)(1 + \mu) - (I_1 + I_2)$$

that is,

$$L \geq \frac{(I_1 + I_2)(1 + \mu)}{p_h + p_l} \equiv L'. \tag{13}$$

Simple calculation shows that $L' > \tilde{L}$ and therefore there is no possibility of sustaining a separating equilibrium without inducing a need for capital.

Hence, whenever it exists an equity tranche which sustains a separating equilibrium, it has to be large enough to induce a loss. Namely we have:

$$L \geq \frac{(p_h - p_l)(I_1 + I_2)(1 + \mu) + \rho(p_h(I_1 + I_2)(1 + \mu) - (I_1 + I_2))}{(p_h^2 - p_l^2) + \rho p_h^2} \equiv L''. \tag{14}$$

Condition (14) implies a positive capital requirement for low-type if:

$$\mu < \frac{p_h + p_l - p_h p_l}{p_h p_l}, \tag{15}$$

which is always true given that we assume $\mu \leq 1$. Moreover condition (15) also guarantees that $L'' \leq \frac{(I_1+I_2)(1+\mu)}{p_h+p_l} \equiv \hat{L}$, where $\hat{L}$ is the amount of the equity tranche that high-type banks pay when credit derivatives are public contracts and banks are not subject to capital requirements. Note that, for $\rho = 0$ we have $L' = \hat{L}$,while for $\rho \to \infty$ we have that L' tends to $\frac{p_h(I_1+I_2)(1+\mu)-(I_1+I_2)}{p_h^2}$ and the loss $p_h(I_1 + I_2)(1 + \mu) + (1 - p_h^2)L - L - (I_1 + I_2)$ tends asymptotically to zero.

Since L is such that the self-selection constraint (9) holds as an equality, it follows immediately that the high-type's incentive compatible constraint is satisfied: in fact, this constraint holds true if and only if:

$$p_h(I_1+I_2)(1+\mu)-(I_1+I_2)+\rho\left(p_h(I_1+I_2)(1+\mu)+(1-p_h^2)L-L-(I_1+I_2)\right) \tag{16}$$

$$\leq (I_1+I_2)(1+\mu)-(1-p_l)(I_1+I_2)(1+\mu)-(I_1+I_2), \tag{17}$$

where the left hand side is the expected profit of a high-type which offers the CDO contract and the right hand side is the expected profit of a high-type which deviates and offers to the counterpart a full coverage plain vanilla, paying the low-type fair premium. Comparing inequality (9) with inequality (16) and noting that:

$$(1-p_h^2)L-(1-p_l^2)L<0, \tag{18}$$

we conclude that the incentive compatibility constraint for the high-type is satisfied. To conclude there exists a separating equilibrium such that high type banks sign CDO contract with the commitment to pay an amount L'' in case of default of any of the underlying assets. Low type banks sign full coverage plain vanilla (paying their fair premium) and the counterpart's beliefs are such that the bank is high type with probability one if a CDO contract with $L \geq L''$ is offered, and it is low-type with probability one if either a CDO contract with $L < L''$or a plain vanilla contract is offered. The proof of the uniqueness of the CK separating perfect Bayesian equilibrium follows the same argument as in Proposition 1.

Proof of Proposition 3: When credit derivative contracts are private contracts, the self-selection constraint for the low-type depends on its decision to (secretly) hedge the equity tranche. In fact, if the low-type issues a CDO contract it can either retain the equity tranche or hedge the equity tranche (because credit derivatives are private contracts). In the first case, it faces capital requirement; in the second case, the position will be completely hedged and therefore capital requirements will be zero. In the first case, the self-selection constraint for the low-type is:

$$
\begin{aligned}
&p_h(I_1+I_2)(1+\mu)+(1-p_h^2)L-(1-p_l^2)L-(I_1+I_2)+ \\
&+\rho\left(\min\left\{0,p_h(I_1+I_2)(1+\mu)+(1-p_h^2)L-L-(I_1+I_2)\right\}\right)\leq \\
&(I_1+I_2)(1+\mu)-(1-p_l)\left(I_1+I_2\right)(1+\mu)-(I_1+I_2)
\end{aligned}
\tag{19}
$$

In the second case, the self-selection constraint for the low-type is:

$$
\begin{aligned}
&p_h(I_1+I_2)(1+\mu)+(1-p_h^2)L-(1-p_l^2)L-(I_1+I_2)\leq \\
&(I_1+I_2)(1+\mu)-(1-p_l)\left(I_1+I_2\right)(1+\mu)-(I_1+I_2),
\end{aligned}
\tag{20}
$$

where $(1-p_l^2)L$ is the premium the low type has to pay in order to hedge the equity tranche L. In this case the bank has no losse and therefore no capital requirements. It is straightforward to note that low type bank's profits are equal or higher hedging the equity tranche and therefore the second constraint is more binding. Condition (20) implies:

$$
L\geq\frac{(I_1+I_2)(1+\mu)}{p_h+p_l}\equiv\hat{L}. \tag{21}
$$

High-type bank equilibrium profits are:

$$p_h(I_1 + I_2)(1 + \mu)+ \tag{22}$$
$$\rho \left(\min \left\{0, 0, p_h(I_1 + I_2)(1 + \mu) + (1 - p_h^2)\hat{L} - \hat{L} - (I_1 + I_2)\right\}\right)$$

The equity tranche $\hat{L}$ implies a positive capital requirements for the high-type if:

$$p_h(I_1 + I_2)(1 + \mu) - p_h^2 \frac{(I_1 + I_2)(1 + \mu)}{p_h + p_l} - (I_1 + I_2) < 0, \tag{23}$$

that is, if:

$$(1 + \mu) < \frac{(p_h + p_l)}{p_h p_l}, \tag{24}$$

which holds by assumption that $\mu < 1$.

The high-type bank can also either (i) hedge the equity tranche paying the premium as a low-type, or (ii) not hedge the equity tranche and faces the cost of capital ρ. High type prefers to not hedge $\hat{L}$ if:

$$p_h(I_1 + I_2)(1 + \mu) - (I_1 + I_2)+ \tag{25}$$
$$\rho \left(p_h(I_1 + I_2)(1 + \mu) - p_h^2\hat{L} - (I_1 + I_2)\right) \geq$$
$$p_h(I_1 + I_2)(1 + \mu) + (1 - p_h^2)\hat{L} - (1 - p_l^2)\hat{L} - (I_1 + I_2),$$

that is, if:

$$\rho \leq \frac{(p_h^2 - p_l^2)(1 + \mu)}{(p_h + p_l) - p_h p_l(1 + \mu)} \equiv \widehat{\rho}. \tag{26}$$

By (25) and the self-selection constraint of the low-type, it turns immediately out that the self-selection constraint for the high-type is satisfied.

It is easy to check that the equilibrium beliefs are consistent with the equilibrium strategies and the out-of-equilibrium beliefs satisfy the intuitive criterion. Uniqueness follows from the usual argument: in any separating equilibrium where the equity tranche offered by the high-type bank is equal to $\overline{L} > \hat{L}$, there exists $\hat{L} \leq L < \overline{L}$ such that if a high-type deviates offering a CDO contract with this equity tranche, then by the intuitive criterion a seller should assign probability 1 that the proposer is a high-type.

■

Proof of Proposition 4: In a separating equilibrium, the high-type buyer offers a first-to-default contract which satisfies the following maximization problem:

$$\max_{\{\Psi_{0,i}(I_1,I_2)\}} \{\mu (I_1 + I_2) - \Psi_h (I_1, I_2) - (1 - p_h)\Phi_h (I_2) + \rho(\min (0, \mu (I_1 + I_2) - \Psi_h (I_1, I_2) - \Phi_h (I_2)))\} \tag{27}$$

s.t.:

$$\Psi_h (I_1, I_2) + (1 - p_h) \Phi_h (I_2) - (1 - p_h) (I_1 + I_2) (1 + \mu) \geq 0 \tag{28}$$

$$\mu (I_1 + I_2) - \Psi_h (I_1, I_2) - (1 - p_l)\Phi_h (I_1) + \rho(\min (0, \mu (I_1 + I_2) - \Psi_h (I_1, I_2) - \Phi_h (I_2)) \leq \mu (I_1 + I_2) - (1 - p_l)(I_1 + I_2)(1 + \mu). \tag{29}$$

where the maximum loss of the bank who buys protection is the difference between the margin on loan portfolio $\mu (I_1 + I_2)$ and the maximum premium that a protection buyer can pay, that is the premium $\Psi_h (I_1, I_2) + \Phi_h (I_2)$ that the bank pays in case of the default of the first loan (the worst event). Indeed, with a FTD menu the loss of the first default is covered by the first to default contract whose premium is $\Psi_h(I_1, I_2)$ and the loss of the second loan is covered by a CDS contract whose premium is $\Phi_h(I_2)$.

Condition (28) is the participation constraint for the (protection) seller, and condition (29) is the self-selection constraint for the low-type buyer. It is straightforward to note that the buyer wants to minimize the premiums. Since the equilibrium is separating and the buyer has full bargaining power, at time $t = 1$ the premium paid to hedge I_2 in case of I_1 default is[28]:

$$\Phi_h(I_2) = (1 - p_h) I_2(1 + \mu) \tag{30}$$

Case 1:

Let assume that:

$$\mu(I_1 + I_2) \geq \Psi_h(I_1, I_2) + \Phi_h(I_2) \tag{31}$$

In this case the bank faces no loan losses and has always money to pay the two premiums.

Substituting (30) into condition (28) and into condition (29) it is easy to check that condition (29) is more binding. Hence in equilibrium:

$$\Psi_h(I_1, I_2) \geq (1 - p_l)(I_1 + p_h I_2)(1 + \mu) \equiv \hat{\Psi}_h(I_1, I_2). \tag{32}$$

Note that high type is able to signal itself by buying a premium that is larger than the fair premium (that would be $(1 - p_h)(I_1 + p_h I_2)(1 + \mu)$).

The buyer's expected profits are:

$$\mu(I_1 + I_2) - (1 - p_l)(I_1 + p_h I_2)(1 + \mu) - (1 - p_h)(1 - p_h) I_2(1 + \mu), \tag{33}$$

[28]Equivalently, if the plain vanilla over I_2 conditioned on I_1 default is signed at time $t = 0$, the buyer cannot credibly commit to pay a premium higher than $\bar{\Psi}_h(I_2) = (1 - p_h) I_2(1 + \mu)$. In fact, given its bargaining power, it is able to renegotiate the terms of the contract at time $t = 1$.

and therefore the high-type buyer prefers to sign a first-to-default as a high-type, than signing a plain vanilla contract as a low-type if:

$$\mu\,(I_1+I_2)-(1-p_l)(I_1+p_hI_2)(1+\mu)-(1-p_h)\,(1-p_h)\,I_2(1+\mu)\geq$$
$$\mu\,(I_1+I_2)-(1-p_l)(I_1+I_2)(1+\mu),$$

that is:

$$(p_h-p_l)(I_2)(1+\mu)(1-p_h)>0, \tag{34}$$

which holds by assumption. Finally, we have to check under which condition, assumption (31) holds true. Substituting $\hat{\Psi}_h\,(I_1,I_2)$ and $\Phi_h\,(I_2)$ in (31) we obtain the following condition:

$$\mu\geq\frac{(1-p_l)I_1+(1-p_hp_l)\,I_2}{p_l(I_1+p_hI_2)}=\widehat{\mu}. \tag{35}$$

Equilibrium beliefs are consistent with the equilibrium strategies and satisfy the intuitive criterion. For any separating equilibrium where the high-type offers a FTD contract with the pair $(\Psi_h\,(I_1,I_2)\,,\,\Phi_h\,(I_2))$ such that $\Psi_h\,(I_1,I_2)>\hat{\Psi}_h\,(I_1,I_2)\,,$ then there exists a deviating proposal $(\Psi'_h\,(I_1,I_2)\,,\,\Phi_h\,(I_2))$ with $\Psi_h\,(I_1,I_2)>\Psi'_h\,(I_1,I_2)\geq\hat{\Psi}_h\,(I_1,I_2)\,,$ such that, by the intuitive criterion, a seller has to assign probability one that the proposer is a high-type bank.

Case 2:

If condition (35) does not hold, then the bank buyer needs capital to pay the premium to hedge I_2 and therefore it faces a positive cost of capital.

In this case the low-type bank which deviates and signs a first-to-default contract, can draw up a credit derivative contract in order to hedge its position. Let X be the amount a low-type bank receives in case of credit I_1 default and $(1-p_l)X$ the premium paid in equilibrium to hedge X. To avoid the cost of capital, the low-type signs a credit derivative contract such that:

$$\mu\left(I_1+I_2\right)-\Psi_h\left(I_1,I_2\right)-(1-p_h)I_2(1+\mu)+X-(1-p_l)X=0, \tag{36}$$

or,

$$X=\frac{(1-p_l)(I_1+p_hI_2)(1+\mu)+(1-p_h)I_2(1+\mu)-\mu\left(I_1+I_2\right)}{p_l}. \tag{37}$$

Since the low-type banks pay a fair premium, it turns out that the self-selection constraint is the same as in Case 1 and again they face no capital requirement.

Hence, in equilibrium, high-type banks decide to not hedge their position if and only if the expected cost of capital is lower than the cost of hedging, that is if:

$$\begin{aligned}&\rho((1-p_l)(I_1+p_hI_2)(1+\mu)+(1-p_h)I_2(1+\mu)-\mu\left(I_1+I_2\right))\leq \\ &(p_h-p_l)\frac{(1-p_l)(I_1+p_hI_2)(1+\mu)+(1-p_h)I_2(1+\mu)-\mu\left(I_1+I_2\right)}{p_l},\end{aligned} \tag{38}$$

that is, only if:

$$\rho\leq\frac{(p_h-p_l)}{p_l}\equiv\tilde{\rho}. \tag{39}$$

Finally, the usual arguments apply to verify the consistency of the beliefs and the uniqueness of the CK equilibrium. ■

Proof of Proposition 5: First of all, recall that if $\rho>\rho'$, then the equilibrium described in Proposition (3) does not exist. If $\mu\geq\widehat{\mu}$ and $\rho\leq\rho'$, then a high-type buyer makes larger profits signaling its own type by drawing a first-to default contract (and a plain vanilla conditioned on I_1 default) than by drawing a CDO if:

$$p_h(I_1+I_2)(1+\mu)-(I_1+I_2)+\rho\left(p_h(I_1+I_2)(1+\mu)-p_h^2(\frac{(I_1+I_2)(1+\mu)}{p_h+p_l})-(I_1+I_2)\right) \tag{40}$$

$$\leq \mu\,(I_1+I_2)-(1-p_l)(I_1+p_hI_2)(1+\mu)-(1-p_h)^2(1+\mu)I_2$$

where in the first row of the above formula we indicate the profits for hedging loan portfolio with CDO and in the second row for hedging the loan portfolio with the FTD menu. The above formula can be rewritten as:

$$\rho(\frac{(I_1+I_2)\,(p_h+p_l)-p_hp_l(I_1+I_2)(1+\mu)}{(p_h+p_l)})\geq(p_h-p_l)(1+\mu)\,(I_1+p_hI_2) \tag{41}$$

or,

$$\rho\geq\frac{(p_h^2-p_l^2)(1+\mu)\,(I_1+p_hI_2)}{(I_1+I_2)\,(p_h+p_l)-p_hp_l(I_1+I_2)(1+\mu)}\equiv\bar{\rho}, \tag{42}$$

noticing that the denominator is positive if and only if $(1+\mu)<\frac{(p_h+p_l)}{p_hp_l}$, which holds by assumption. Finally, it is easy to check that $\bar{\rho}<\rho'$ if and only if $p_h<1$. ■

Proof of Proposition 6: The fact that capital requirements are based on total loss and margins are not considered is not affecting the binding self–selection constraint of the low-type (20) for the CDO contract. Therefore the amount L that the protection buyer has to guarantee in order to signal its type is still $\hat{L}$. The same applies for the FTD menu: the premium paid for the FTD is $\hat{\Psi}_h\,(I_1,I_2)$ and the premium paid for the plain vanilla conditioned on I_1 default is $\Phi_h\,(I_2)$.

Under the new definition of capital requirement, the required capital for the FTD menu, (i.e. the maximum total loss) is:

$$VaR^{ftd} = \Phi_h\left(I_2\right) \equiv (1-p_h)I_2(1+\mu), \tag{43}$$

that is the fair premium that the buyer has to pay to hedge its exposition on I_2 if the loan I_1 defaults.

The required capital for a CDO is simply the equity tranche:

$$VaR^{CDO} = L \equiv \frac{(I_1+I_2)(1+\mu)}{(p_h+p_l)} \tag{44}$$

and it is easy to show that $VaR^{ftd} < VaR^{CDO}$.

In case a high type bank signs the CDO menu, it prefers not to hedge the equity tranche $\hat{L}$ if:

$$\begin{gathered} p_h(I_1+I_2)(1+\mu)-(I_1+I_2)+\rho\left(\hat{L}\right) \geq \\ p_h(I_1+I_2)(1+\mu)+(1-p_h^2)\hat{L}-(1-p_l^2)\hat{L}-(I_1+I_2), \end{gathered} \tag{45}$$

that is if:

$$\rho \leq p_h^2 - p_l^2. \tag{46}$$

In case a high type bank signs the FTD menu, it decides to not hedge its position if and only if the cost of capital is lower than the cost of hedging, that is if:

$$\begin{gathered} \rho((1-p_h)I_2(1+\mu)) \leq \\ (p_h-p_l)(1-p_h)I_2(1+\mu) \end{gathered} \tag{47}$$

or:

$$\rho \leq (p_h - p_l). \tag{48}$$

If $\rho \leq (p_h - p_l)$, then a high-type buyer makes larger profits signaling its own type by drawing a FTD menu than by drawing a CDO menu if:

$$\begin{aligned} & p_h(I_1+I_2)(1+\mu) - (I_1+I_2) - \rho\left(\frac{(I_1+I_2)(1+\mu)}{p_h+p_l}\right) \\ \leq \; & \mu\,(I_1+I_2) - (1-p_l)(I_1+p_hI_2)(1+\mu) - (1-p_h)^2(1+\mu)I_2 - \rho\,((1-p_h)(1+\mu)I_2)) \end{aligned} \tag{49}$$

which can be rewritten as:

$$\begin{aligned} \rho\left(\frac{(I_1+I_2)(1+\mu)}{p_h+p_l} - (1-p_h)I_2(1+\mu)\right) \geq \\ (p_h-p_l)(1-p_l)(1+\mu)\,(I_1+p_hI_2) \end{aligned} \tag{50}$$

or,

$$\rho \geq \frac{(p_h^2-p_l^2)(1-p_l)\,(I_1+p_hI_2)}{(I_1+I_2)-(p_h+p_l)(1-p_h)I_2} \tag{51}$$

■