To Pool or not to Pool?
Security Design in OTC Markets

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Abstract

This paper studies the optimality of pooling and tranching for a privately informed security originator facing buyers endowed with market power (perhaps due to liquidity shortages). Contrary to the standard result that pooling and tranching are optimal practices, we find that selling assets separately may be preferred by originators as it weakens buyers' incentives to inefficiently screen them. Our results can shed light on observed time-variation in the practice of pooling and tranching in financial markets, in particular, the dramatic decline in the size of the ABS market following the most recent financial crisis.

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1 Introduction

Following the most recent financial crisis, origination volume of asset-backed securities (ABS) dropped dramatically and remained far below pre-crisis levels — in 2015, issuance volume of ABS in the U.S. was 60% lower than it was in 2006. In contrast, the total issuance volume in fixed income markets was 3% higher in 2015 than in 2006.[1] At the same time, market participants and banks have been pointing to decreased liquidity across various markets, assigning blame to lower inventories and new regulations affecting financial institutions.[2] Since a large theoretical literature supports the conventional wisdom that pooling and tranching are efficient in the presence of asymmetric information (see, e.g., Farhi and Tirole 2015, among many others),[3] the dramatic decline in the size of the ABS market might warrant further explanation.

This paper studies the optimality of pooling and tranching under asymmetric information when security originators face a market where liquidity or capital is scarce and buyers endowed with such liquidity or capital have market power. In our model, an issuer possesses private information about the quality of multiple assets he wishes to sell, which creates an adverse selection problem. Our setup captures two key features of over-the-counter (OTC) markets, where structured products are typically originated and traded. First, OTC trading is often highly concentrated,[4] implying that liquidity shocks affecting a few players can give rise to liquidity shortages and thereby concentrate market power in the hands of a few institutions. This environment deviates from the settings typically considered in the existing literature on pooling and tranching, where buyers are competitive and deep-pocketed. Second, agents settle deals tête-à-tête in these markets and do not disclose all transactions and balance sheet positions. The resulting opacity limits the issuer's ability to commit to retaining net-exposures to the risks of the underlying assets, as side-transactions possibly involving derivatives are always possible. To capture this friction, we consider an environment where

[1]The issuance volume of CDOs in 2015 was 80% lower than in 2006, according to the Securities Industry and Financial Markets Association, http://www.sifma.org/research/statistics.aspx.

[2] For example, Jamie Dimon notes in the letter to shareholders dated April 8, 2014: "There already is far less liquidity in the general marketplace... The likely explanation for the lower depth in almost all bond markets is that inventories of market-makers' positions are dramatically lower than in the past... Inventories are lower - not because of one new rule but because of the multiple new rules that affect market-making, including far higher capital and liquidity requirements and the pending implementation of the Volcker Rule.

[3]Farhi and Tirole (2015) argue that one of the two "central and recurring insights of the literature" is that "... tranching is optimal. The creation of debt-like securities alleviates buyer concerns about the seller's ability to foist a lemon, and seller concerns about the seller's curse. It further minimizes incentives for information acquisition. Tranching thus boosts liquidity, the value of assets and welfare."

[4]See Cetorelli et al. (2007), Atkeson, Eisfeldt, and Weill (2012), Li and Schürhoff (2014), Begenau, Piazzesi, and Schneider (2015), Hendershott et al. (2015), Di Maggio, Kermani, and Song (2017), and Siriwardane (2017).

signaling through retention is infeasible.[5] In this setting we find that — counter to the conventional wisdom — the separate sale of assets may be optimal, both socially and privately. In particular, when buyers with market power are expected to screen the privately informed issuer, he might find it optimal to separately sell several imperfectly correlated risky assets and reduce the extent to which he is being screened, thereby sustaining greater trading volume and improving the social efficiency of trade.

The existing literature on security design has already identified circumstances under which, in "centralized" markets, an issuer may prefer not to pool assets. However, our paper is the first to show that liquidity shortages among major institutions participating in OTC markets might be an important driver of the observed dramatic declines in ABS issuances, concurrent with an increase in the volume of assets sold separately. DeMarzo (2005) uses the signaling through retention model of DeMarzo and Duffie (1999) with price-taking (i.e., competitive) buyers to show that pooling assets of different qualities decreases profits for the issuer since profits are a convex function of quality. By pooling assets the issuer loses the ability to signal assets' idiosyncratic quality to the market, resulting in lower profits. Yet, DeMarzo (2005) shows that pooling and issuing debt on a pool is optimal due to risk diversification, a channel that dominates the former channel and allows to reduce residual risks as well as the information sensitivity of the security being issued. In contrast to DeMarzo (2005) whose setup can be thought of as a centralized market where (price-taking) buyers compete for the asset, we model an issuer who cannot credibly signal the quality of her assets and who faces a buyer endowed with market power, as is more natural in opaque over-the-counter markets.

The closest setup to ours is that of Biais and Mariotti (2005), who build a model where the security design stage is followed by a stage where either the issuer or the prospective buyer chooses a mechanism (i.e., a price-quantity menu) for selling the designed security. The paper shows that in both cases issuers with low quality securities participate in the market, whereas high quality issuers might not (despite the gains to trade). In particular, when the buyer chooses the mechanism, he effectively screens the issuer, trading off higher volume with lower issuer participation. In contrast, when the issuer chooses the mechanism, the setup is equivalent to one with multiple competitive buyers. Biais and Mariotti (2005) show that issuing debt on a risky asset is optimal in both cases, since the debt contract's low information sensitivity helps to avoid market exclusion. However,

[5] Leland and Pyle (1977) and DeMarzo and Duffie (1999) highlight how adverse selection problems can be alleviated when issuers can credibly signal the quality of their securities by retaining some fraction of the assets. See also Williams (2016) and Hartman-Glaser (2017).

Biais and Mariotti (2005) do not consider the situation where the issuer may want to sell separately multiple assets and thus do not speak to the optimality of pooling and tranching.

Axelson (2007) studies a security design problem with multiple assets where the designed security is (centrally) traded through a uniform price auction among several informed buyers. In contrast to our setting, buyers have superior information relative to the issuer and prices are determined by the marginal bidder who is indifferent between buying the asset or not. The uninformed issuer then aims to minimize underpricing associated with a standard winner's curse. Axelson (2007) finds that pooling several assets and issuing debt on these assets is optimal for the issuer when competition among buyers is low or when the signal distribution is continuous, whereas selling assets separately is preferred when competition is high and the signal distribution is discrete, contrasting with our results. The latter result arises in the uniform price auction setting because for a given number of buyers the probability that the pivotal bidder has the highest possible signal when a single asset is sold is higher than the probability that the pivotal bidder has the highest possible signal when a pool of assets is sold. From a social perspective, pooling is not harmful in Axelson (2007) since social surplus is merely redistributed to the buy side, as high quality pools are simply traded at a discount. In contrast, in our model, high quality pools may not be traded at all in equilibrium (due to the buyer's optimal screening strategy), thereby preventing the realization of gains to trade and lowering the efficiency of trade.

Another paper studying the decision to pool assets is Farhi and Tirole (2015), who study whether an issuer bargaining with a single buyer prefers to sell the asset as a whole or separate the information sensitive part of the asset from the riskless part. The main focus of their paper is to study how this choice affects information acquisition by both parties. As an extension, Farhi and Tirole (2015) consider splitting an asset viewed as a bundle of an information sensitive part and a riskless part into smaller bundles. Yet, they assume that the information sensitive securities issued on these smaller bundles are all perfectly correlated, as they are fractions of the same risky asset. In contrast, our paper considers the decision to pool different risky assets when assets are less than perfectly correlated.

In the next section, we describe the environment of our model. In Section 3, we study a simple case where the originator must decide whether to issue a security on a pool of two assets with binomially distributed payoffs or issue one security for each asset. We show how the presence of a buyer with market power changes the optimal security design relative to a benchmark case with competitive buyers. We generalize our main results by allowing for continuous payoff distributions in Section 4. Finally, Section 5 discusses the robustness of our results in several alternative environments and the last section concludes.

2 Model

Suppose an issuer has $n \geq 2$ assets to sell, each with future payoff X_i for $i \in \{1, 2, ..., n\}$. We consider the security design problem where the issuer must decide whether to offer the n assets separately or bundle some of them together and offer either an equity or a debt stake on the pool. As is standard in the security design literature (see, e.g., Biais and Mariotti 2005), we assume that the issuer does not possess private information at the security design stage, which helps to capture the above-discussed notion that signaling through retention is often infeasible in opaque markets. Yet, the issuer finds out the future realizations of $X_1, \ldots, X_n$ before trading occurs and is thereby informed about the value of the security he is offering for sale.

We consider two opposite scenarios to highlight the importance of market power in the decision to pool or not the assets. As argued above, changes in market power may be interpreted as resulting, for example, from liquidity shortages. In the first, benchmark case, we assume several deep-pocketed competitive buyers. If multiple buyers offer an identical price that is accepted by the issuer, the asset is randomly allocated among these highest bidders. This competitive case can be interpreted as one where there is excess liquidity in the market. In the second case, we assume the presence of only one buyer with sufficient liquidity to purchase the securities that are up for sale.[6] In both cases, buyers do not know the realizations of X_i before trade occurs, but they know the composition of the pool, that is, which random payoffs X_i are bundled together, and the type of security issued.

As is common in the security design literature, we assume that trade creates a surplus since the issuer is impatient or faces liquidity needs, which is modeled through a lower discount factor ($\delta < 1$) for the issuer than for the buyer(s) (whose discount factor is normalized at 1). Thus, the issuer's reservation value for a security with future payoff v is δv, in case he is unable to sell it, while the buyers' valuation is v. The timing of the game goes as follows. First, the issuer chooses the number of assets to bundle in a pool, as well as a security type. Second, the issuer becomes informed about the realizations of each X_i. Third, the buyer(s) offer(s) their price(s) to the issuer

[6] We show in Appendix B that this second case is equivalent to one with multiple homogenous buyers that face position limits (e.g., due to capital requirements) constraining total demand to be marginally below the total supply of assets for sale.

in a take-it-or-leave manner. Fourth, the issuer decides whether or not to accept these offer(s). Finally, the payoffs are realized.

3 Two assets with binomially distributed payoffs

To simplify the exposition of our main results, we first study optimal security design assuming that each X_i is binomially distributed: each asset i produces a payoff $X_i = \varphi_i \sigma$ where φ_i is an independent random variable that takes the value 1 with probability $(1 - q_i)$ and the value 0 otherwise. If the issuer bundles the first k assets together the total payoff from the pool is given by $v_k \equiv \varphi_1 \sigma + \cdots + \varphi_k \sigma$. If the issuer decides to sell equity on this pool of k assets, the payoff is thus simply v_k. In contrast, if he decides to issue debt with a face value of $D\sigma$, the payoff from this security becomes $v_k^D \equiv \min\{v_k, D\sigma\}$.

In this section, we further simplify the intuition by focusing on the case where there are only two assets to sell (we relax the $n = 2$ assumption and the discrete distribution assumption in later sections). To emphasize how the solution to the security design problem differs based on buyers' market power we solve for the issuer's problem in two separate cases — we first consider a market with competitive buyers and then switch our focus to a market with a monopolistic buyer. We end the section with a numerical example that further highlights the differences between the two cases.

3.1 Competitive (deep-pocketed) buyers

An issuer has two assets he wants to sell in a market populated with several identical unconstrained prospective buyers. First, we derive the quoted price and the ex-ante profits of each agent if the issuer offers a security with an arbitrary payoff v. Since buyers are effectively competing in quotes à la Bertrand, the issuer is then able to extract all the trade surplus. Accordingly, all buyers offer a price p equal to their valuation of the issued security, which is equal to the conditional expected value of its payoff:

$$p = \mathbb{E}[v|\delta v \leq p], \tag{1}$$

where $\{\delta v \leq p\}$ is the event that the offer is accepted (i.e., the offered price is higher than the reservation value of an accepting issuer type). The buyers' ex-ante profit at this price is characterized as $B(p) = 0$ while the issuer's ex-ante profit is characterized as $S(p) = (1 - \delta) \Pr(\delta v \leq p) \mathbb{E}[v|\delta v \leq p]$, which is also equal to the realized social surplus.

In order to solve for the issuer's optimal security, we compare the case where he does not pool the assets and instead sells them separately to the case where he pools the assets before selling them.

Selling assets separately. Suppose the issuer designs two securities, each associated with only one asset offering a payoff $v_1^i = \varphi_i \sigma$. In response to this decision, buyers might offer two types of prices in exchange for security i: (a) if all buyers offer $p_1^i < \delta\sigma$, trade happens only when $v_1^i = 0$, and (b) if at least one of the buyers offers $p_1^i \geq \delta\sigma$, trade always happens. As shown above, the buyers' possible price offers and the associated profits depend on $\Pr(\delta v_1^i \leq p_1^i)$ and $\mathbb{E}[v_1^i|\delta v_1^i \leq p_1^i]$, which in this case simplify to:

	$p_1^i \geq \delta\sigma$	$0 \leq p_1^i < \delta\sigma$
$\Pr(\delta v_1^i \leq p_1^i)$	1	q_i
$\mathbb{E}[v_1^i\|\delta v_1^i \leq p_1^i]$	$(1-q_i)\sigma$	0

In equilibrium, competition drives each buyer to offer to pay the highest possible price $p_1^i = (1-q_i)\sigma$ whenever this price is sufficiently large for all issuer types to accept it:

$$(1-q_i)\sigma \geq \delta\sigma \Leftrightarrow \delta \leq \delta_1^i \equiv 1 - q_i. \tag{2}$$

This higher price is thus offered whenever the gains from trade $1-\delta$ are high enough, or whenever the asset is of relatively good quality in expectation, that is, whenever q_i, the probability of a low realized payoff, is low.

We define δ_1^i as the threshold on the discount factor δ below which a security that only includes asset i is sold to competitive buyers at the high price $p_1^i = (1-q_i)\sigma$. When $\delta < \delta_1^i$ for $i = 1, 2$ the issuer can sell each of the two assets at high prices and collect a total expected profit of $(1-\delta)(1-q_1)\sigma + (1-\delta)(1-q_2)\sigma = (1-\delta)(2-q_1-q_2)\sigma$, which is the sum of the profits from the individual sales. The issuer's profit for other regions of δ can be derived analogously.

When the two assets are traded separately, the issuer might prefer to use a debt security instead of an equity security on any of the two pools. It is, however, easy to show that issuing debt with face value $D\sigma$ where $D \in (0,1)$ is suboptimal in this simple case.[7] With binary payoffs (which we will relax later), the issuer selling an equity security on one asset does not do better by selling a debt security on that same asset.

[7] If that were the case, buyers would offer a price of $\delta D\sigma$ in exchange for the asset i whenever $(1-q_i)D\sigma \geq \delta D\sigma$. This condition would not depend on D since the level of $\mathbb{E}[v_1^D|\delta v_1^D \leq p_1^D]$ would change with D proportionally. Given that the issuer's profit would then increase in D, for any δ satisfying this condition, the optimal face value of the debt would be σ, that is, $D = 1$, which is identical to issuing equity on the asset.

Selling a pool of two assets. Having solved for the profits of an issuer trying to sell the two assets separately, we now consider the case where the issuer pools the two assets together and sells an equity claim whose payoff is $v_2 = \varphi_1\sigma + \varphi_2\sigma$. Since v_2 now has three possible realizations, buyers might now offer three types of prices p_2 in exchange for the pool: (a) if $p_2 < \delta\sigma$, trade happens only when $v_2 = 0$, (b) if $\delta\sigma \le p_2 < 2\delta\sigma$, trade happens only when $v_2 \in \{0, \sigma\}$, and (c) if $p_2 \ge 2\delta\sigma$, trade always happens, that is, when $v_2 \in \{0, \sigma, 2\sigma\}$. The values of $\Pr(\delta v_2 \le p_2)$ and $\mathbb{E}[v_2|\delta v_2 \le p_2]$ are summarized in the following table for each scenario:

	$p_2 \ge 2\delta\sigma$	$\delta\sigma \le p_2 < 2\delta\sigma$	$0 \le p_2 < \delta\sigma$
$\Pr(\delta v_2 \le p_2)$	1	$1-(1-q_1)(1-q_2)$	$q_1 q_2$
$\mathbb{E}[v_2\|\delta v_2 \le p_2]$	$(2-q_1-q_2)\sigma$	$\frac{(1-q_1)q_2+(1-q_2)q_1}{1-(1-q_1)(1-q_2)}\sigma$	0

In equilibrium, competition drives each buyer to offer to pay the highest possible price $p_2 = (2-q_1-q_2)\sigma$ whenever this price is sufficiently large for all issuer types to participate in the trade:

$$(2-q_1-q_2)\sigma \ge 2\delta\sigma \Leftrightarrow \delta \le \delta_{22} \equiv \frac{2-q_1-q_2}{2}. \tag{3}$$

We define δ_{22} as the threshold on the discount factor δ below which a security that includes both assets is sold to competitive buyers at the highest price $p_2 = (2-q_1-q_2)\sigma$. More generally, we define δ_{kj} as the threshold on the discount factor δ below which trade of a pool of k-assets occurs with the $j+1$ lowest issuer types participating (accounting for the lowest type with a zero paying asset). Specifically, if condition (3) is violated, buyers quote the intermediate price $p_2 = \frac{(1-q_1)q_2+(1-q_2)q_1}{1-(1-q_1)(1-q_2)}\sigma$ whenever it is high enough to convince an issuer whose security is worth $v_2 \in \{0, \sigma\}$ to participate in the trade:

$$\frac{(1-q_1)q_2+(1-q_2)q_1}{1-(1-q_1)(1-q_2)}\sigma \ge \delta\sigma \Leftrightarrow \delta \le \delta_{21} \equiv \frac{q_1+q_2-2q_1q_2}{q_1+q_2-q_1q_2}. \tag{4}$$

Note that since buyers are competitive in the current setting, the highest possible price is quoted whenever both conditions for high (3) and intermediate (4) prices hold simultaneously. The intuition behind these inequalities is similar to that in the case with pools of one asset. Higher gains to trade, consistent with a lower issuer discount factor δ, lead to higher participation. Moreover, it can be shown that the second threshold is higher than the first one, meaning that lower gains to trade are needed to sustain trade at lower prices. Note also that the threshold δ_{22} for a pool of two assets is the average of the two thresholds δ_1^i when assets are sold separately. (When $q_1 = q_2$ this threshold is equal to the threshold for the sale of one asset.) As a result, there is no region of δ for which the separate sale of two assets leads to high prices being offered while pooling does not.

Finally, we consider the benefits of designing a debt security on the pool of assets. As pointed out, for example, by DeMarzo (2005) and Dang, Gorton, and Holmstrom (2015), debt securities have lower information sensitivity than equity securities, and might reduce the inefficiencies of trade associated with asymmetric information. If the issuer designs a debt security on the pool of two assets with a face value of $D\sigma$, he knows that the price offered by the competitive buyers will be equal to the expected value of the security, conditional on the possible valuations of the participating issuers. Since a debt issuer values the pool of assets δv_2, he is willing to sell the debt security on the pool at a given price p_2^D and retain the residual claim worth $\delta(v_2 - \min\{v_2, D\sigma\})$ to him only if:

$$p_2^D + \delta(v_2 - \min\{v_2, D\sigma\}) \geq \delta v_2. \tag{5}$$

The price offered by competitive buyers is thus the highest price that satisfies: $p_2^D = \mathbb{E}[v_2^D | \delta v_2^D \leq p_2^D]$, where $v_2^D \equiv \min\{v_2, D\sigma\}$. Moreover, since debt is equivalent to equity whenever v_2 is below $D\sigma$, we focus on situations where issuing a debt security differs from issuing an equity stake, taking into consideration the buyers' price offer. Thus, we look for cases where $p_2^D = \mathbb{E}[v_2^D | \delta v_2^D \leq p_2^D] \geq \delta D\sigma$. The expected value of the debt security, as a function of D, is summarized in the following table:

	$D \in (1, 2]$	$D \in (0, 1]$
$\mathbb{E}[v_2^D \vert \delta v_2^D \leq p_2^D]$	$(1-q_1)(1-q_2)(D-1)\sigma + (1-q_1q_2)\sigma$	$(1-q_1q_2)D\sigma$

As in the case with assets being separately sold, issuing a debt security with a face value of $D \in (0, 1)$ is suboptimal. In contrast, issuing a debt security with a face value of σ is sustainable (i.e., even higher-valuation issuers are willing to sell the security at the equilibrium price) whenever $\delta \leq \delta_{20} \equiv 1 - q_1q_2$ which is higher than δ_{21}. In fact, setting $D = 1$ is optimal when $\delta = \delta_{20}$. Similarly, if $\delta \in [\delta_{22}, \delta_{20})$, the optimal $D \in (1, 2]$ decreases with δ and makes the highest participating issuer indifferent between collecting p_2^D and getting the reservation value:

$$(1-q_1)(1-q_2)(D-1)\sigma + (1-q_1q_2)\sigma = \delta D\sigma. \tag{6}$$

The optimal face value is then given by:

$$D = \frac{q_1 + q_2 - 2q_1q_2}{\delta - (1-q_1)(1-q_2)}. \tag{7}$$

Issuing the optimal debt security thus expands the region of δ where trade is possible and for some parameter values it makes the issuer, who extracts the full surplus from trade when facing competitive buyers, strictly better off.

Optimal security design. We have shown above that, when buyers are competitive, the region of δ that sustains efficient trade is expanded by pooling the two assets together whenever $q_1 \neq q_2$ (since $\min_i\{\delta_1^i\} < \delta_{22}$). Moreover, in cases where efficient trade is impossible to sustain, pooling the two assets and issuing debt on that pool is preferred by the issuer (and socially optimal) whenever $\delta \leq \delta_{20}$. When δ is greater than δ_{20} however, trade does not occur in equilibrium whether the issuer designs debt or equity securities. We will revisit these regions through a simple example once we have covered the case with a monopolistic buyer.

3.2 Buyer with market power

We now show how the issuer's optimal decision to pool assets changes when market power shifts to the demand side of the market. Suppose that only one buyer with a discount factor of 1 has enough capital to purchase the assets for sale. Since this buyer does not face competition, his price offer to the issuer corresponds to a take-it-or-leave-it offer, allowing him to screen the issuer based on his private information.

If the issuer is selling a security with future payoff v and the buyer offers p for the security, the buyer's ex-ante profit is equal to:

$$B(p) = \Pr(\delta v \leq p)(\mathbb{E}[v|\delta v \leq p] - p), \tag{8}$$

where $\{\delta v \leq p\}$ is the event that the offer is accepted. Unlike in the competitive case where buyers get zero profit, the buyer can now use his market power to maximize his expected profit. In equilibrium, he quotes a price that is lower than the security's expected payoff conditional on the event that the offer is accepted and he thus makes a positive profit. Similarly, the issuer's profit is:

$$S(p) = \Pr(\delta v \leq p)(p - \delta\, \mathbb{E}[v|\delta v \leq p]), \tag{9}$$

which accounts for the fact that if the issuer retains the security, its future payoff is discounted by δ to reflect his relative impatience. Finally, the total gains from trade are the sum of both agents' profits and are equal to $(1-\delta)\Pr(\delta v \leq p)\,\mathbb{E}[v|\delta v \leq p]$. Even though the buy side has the full market power, the total surplus is split between the buyer and the issuer, since the issuer collects rents associated with his private information.

Selling asset separately. If the issuer sells the two assets separately, the buyer chooses between offering the lowest quotes that result in different levels of issuer type participation: $p_1^i \in \{0, \delta\sigma\}$. Using the derivations above we can calculate the probability that trade is accepted and the ex-ante expected profits for both agents from trading each asset i:

	$p_1^i = \delta\sigma$	$p_1^i = 0$
$\Pr(\delta v_1^i \leq p_1^i)$	1	q_i
$B(p_1^i)$	$(1-q_i)\sigma - \delta\sigma$	0
$S(p_1^i)$	$\delta q_i \sigma$	0

We use the same notation for thresholds on δ as above, but use a macron to indicate the case where the buyer has market power. The buyer prefers to quote the high price $p_1^i = \delta\sigma$ whenever:

$$(1-q_i)\sigma - \delta\sigma \geq 0 \Leftrightarrow \delta \leq \bar{\delta}_1^i \equiv 1 - q_i. \tag{10}$$

Intuitively, screening the issuer by offering him a low price is suboptimal when the gains from trade are large and when losing a fraction of the market is costly. When designing a security, the issuer would like to avoid being screened, as his profit increases with the price, i.e., $S(\delta\sigma) > S(0)$. Note that for the separate sale of each asset the thresholds with competitive buyers (see condition (2)) and with a monopolistic buyer (see condition (10)) are identical. Finally, for the same reasons as above, issuing a debt security rather than an equity security on a pool of one asset with binomial payoffs is suboptimal for the issuer.

Selling a pool of two assets. When the issuer sells equity on a pool of two assets, the pooled security's payoff v_2 has three possible realizations and the buyer chooses among quoting three possible prices: $p_2 \in \{0, \delta\sigma, 2\delta\sigma\}$. The probability that trade is accepted and the ex-ante expected profits for both agents are summarized in the following table:

	$p_2 = 2\delta\sigma$	$p_2 = \delta\sigma$	$p_2 = 0$
$\Pr(\delta v_2 \leq p_2)$	1	$1-(1-q_1)(1-q_2)$	$q_1 q_2$
$B(p_2)$	$(2-q_1-q_2)\sigma - 2\delta\sigma$	$(q_1+q_2-2q_1q_2)\sigma - (q_1+q_2-q_1q_2)\delta\sigma$	0
$S(p_2)$	$(q_1+q_2)\delta\sigma$	$q_1 q_2 \delta\sigma$	0

The buyer offers to pay the high price $p_2 = 2\delta\sigma$ whenever:

$$(2-q_1-q_2)\sigma-2\delta\sigma \geq (q_1+q_2-2q_1q_2)\sigma-(q_1+q_2-q_1q_2)\delta\sigma \Leftrightarrow \delta \leq \bar{\delta}_{22} \equiv \frac{2(1-q_1-q_2+q_1q_2)}{2-q_1-q_2+q_1q_2}. \quad (11)$$

Otherwise, he offers to pay the intermediate price $p_2 = \delta\sigma$ whenever:

$$(q_1+q_2-2q_1q_2)\sigma-(q_1+q_2-q_1q_2)\delta\sigma \geq 0 \Leftrightarrow \delta \leq \bar{\delta}_{21} \equiv \frac{q_1+q_2-2q_1q_2}{q_1+q_2-q_1q_2}. \quad (12)$$

Finally, if both of these conditions are violated, the buyer finds it optimal to offer a price of zero.

The intuition for the inequalities follows the same logic as before. Screening the issuer is suboptimla when the gains from trade are high. Higher gains to trade represented by a lower discount factor for the issuer are thus needed to sustain trade at a higher price. As a result, the second threshold $\bar{\delta}_{21}$ is higher than the first $\bar{\delta}_{22}$. Again, the issuer prefers to avoid being screened as his profits are increasing in the offered price: $S(2\delta\sigma) > S(\delta\sigma) > S(0)$.

Unlike when assets are sold separately, the first threshold $\bar{\delta}_{22}$ (see condition (11)) with a monopolistic buyer differs from the first threshold δ_{22} (see condition (3)) with competitive buyers. In particular, $\bar{\delta}_{22}$ is lower than δ_{22}, and when $q_1 = q_2 = q$ the threshold $\bar{\delta}_{22}$ is lower than the threshold $\bar{\delta}_1$ for the sale of one asset in (see condition (10)). These inequalities imply that there is a region of δ where the separate sale of assets is more profitable than the sale of an equity claim on the pool.

We now allow the issuer to offer a debt security on the pool of two assets with a face value of $D\sigma$. Since debt is equivalent to equity whenever v_2 is below $D\sigma$, we focus on situations where issuing a debt security differs from issuing an equity stake. Thus, we look for cases where the buyer finds it optimal to quote a price $p_2^D = \delta D\sigma$. The issuer's and buyer's ex-ante expected profits when $p_2^D = \delta D\sigma$ are summarized in the following table:

	$D \in (1,2]$ & $p_2^D = \delta D\sigma$	$D \in (0,1]$ & $p_2^D = \delta D\sigma$
$B(p_2^D)$	$(1-q_1)(1-q_2)(D-1)\sigma + (1-q_1q_2)\sigma - \delta D\sigma$	$(1-q_1q_2)D\sigma - \delta D\sigma$
$S(p_2^D)$	$q_1q_2\delta\sigma + (1-(1-q_1)(1-q_2))\delta(D-1)\sigma$	$q_1q_2\delta D\sigma$

For the same reason as in the case with separate asset sales, the debt security with a face value of $D \in (0,1)$ is never optimal. Issuing debt with a face value of σ is, however, sustainable whenever $\delta \leq \bar{\delta}_{20} \equiv 1-q_1q_2$, just like with competitive buyers. In fact, setting $D = 1$ is again optimal when $\delta = \bar{\delta}_{20}$. Similarly, if $\delta \in [\bar{\delta}_{21}, \bar{\delta}_{20})$, the optimal D makes the buyer indifferent between collecting

$B(D\sigma)$ and $B(0)$. The optimal face value must thus be equal to:

$$D = \frac{q_1 + q_2 - 2q_1q_2}{\delta - (1-q_1)(1-q_2)}. \tag{13}$$

Analogously, if $\delta \in [\bar{\delta}_{22}, \bar{\delta}_{21})$, the optimal d makes the buyer indifferent between collecting $B(D\sigma)$ and $B(\sigma)$ and must therefore satisfy:

$$D = \frac{1 - (1-q_1)(1-q_2)\delta}{\delta - (1-q_1)(1-q_2)}. \tag{14}$$

As with competitive buyers, the debt security allows to improve the issuer's profits from issuing a security on the pool of assets.

Optimal security design. The main difference with the earlier analysis of the competitive buyer case is that pooling might not be optimal in a market where buyers have market power to screen the issuer. This result is associated with the presence of a region $\delta \in [\bar{\delta}_{22}, \min\{\bar{\delta}_1^1, \bar{\delta}_1^2\}]$ where the separate sale of assets leads to efficient trade whereas selling equity on a pool of assets leads to the issuer being screened by the buyer. To further illustrate this result we provide the following numerical example.

3.3 Simple numerical example

Suppose the issuer has two assets of the same quality $q_1 = q_2 = \frac{1}{2}$. With competitive buyers, we obtain $\delta_1 = \delta_{22} = \frac{1}{2}$, $\delta_{21} = \frac{2}{3}$, and $\delta_{20} = \frac{3}{4}$. These quantities imply that if the issuer sells the two assets separately his total ex-ante profit from both sales is:

$$2S = \begin{cases} (1-\delta)\sigma, & \text{if} \quad \delta \in (-\infty, \frac{1}{2}] \\ 0, & \text{if} \quad \delta \in (\frac{1}{2}, +\infty). \end{cases} \tag{15}$$

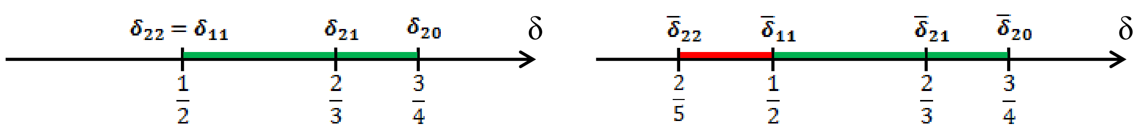
If instead he chooses to sell an equity claim on a pool of two assets his profit is:

$$S = \begin{cases} (1-\delta)\sigma, & \text{if} \quad \delta \in (-\infty, \frac{1}{2}] \\ \frac{1}{2}(1-\delta)\sigma, & \text{if} \quad \delta \in (\frac{1}{2}, \frac{2}{3}] \\ 0, & \text{if} \quad \delta \in (\frac{2}{3}, +\infty). \end{cases} \tag{16}$$

The issuer is therefore indifferent between the two types of security when $\delta \in (-\infty, \frac{1}{2}]$ or $\delta \in (\frac{2}{3}, +\infty)$ if he's facing competitive buyers. However, he strictly prefers pooling when $\delta \in (\frac{1}{2}, \frac{2}{3}]$. Moreover, by designing an optimal debt security on the pool of two assets his profit becomes:

$$S = \begin{cases} (1-\delta)\sigma, & \text{if} \quad \delta \in (-\infty, \frac{1}{2}] \\ (\frac{3}{4} + \frac{1}{4}\frac{3-4\delta}{4\delta-1})(1-\delta)\sigma, & \text{if} \quad \delta \in (\frac{1}{2}, \frac{3}{4}] \\ 0, & \text{if} \quad \delta \in (\frac{3}{4}, +\infty). \end{cases} \tag{17}$$

For any δ the issuer's profit with the optimal debt security on the pool dominates his profit from selling assets separately, or from issuing an equity claim on the pool. Panel (a) in Figure 1 identifies the region of δ where issuing debt on the pool is strictly more profitable than the separate sale of the two assets with competitive buyers.



(a) Competitive buyers

(b) Monopolistic buyer

Figure 1: For the parameter region highlighted in green issuing a debt claim on the pool of assets is optimal. The region highlighted in red indicates parameterizations where the separate sale of assets is optimal. In the other regions the issuer is indifferent between the two options.

With a monopolistic buyer, we obtain $\bar{\delta}_1 = \frac{1}{2}$, $\bar{\delta}_{22} = \frac{2}{5}$, $\bar{\delta}_{21} = \frac{2}{3}$, and $\bar{\delta}_{20} = \frac{3}{4}$. If the issuer tries to sell the two assets separately, his total ex-ante profit is:

$$2S = \begin{cases} \delta\sigma, & \text{if} \quad \delta \in (-\infty, \frac{1}{2}] \\ 0, & \text{if} \quad \delta \in (\frac{1}{2}, +\infty). \end{cases} \tag{18}$$

If, instead, he tries to sell an equity claim on a pool of two assets, his ex-ante profit becomes:

$$S = \begin{cases} \delta\sigma, & \text{if} \quad \delta \in (-\infty, \frac{2}{5}] \\ \frac{1}{4}\delta\sigma, & \text{if} \quad \delta \in (\frac{2}{5}, \frac{2}{3}] \\ 0, & \text{if} \quad \delta \in (\frac{2}{3}, +\infty). \end{cases} \tag{19}$$

Finally, if he issues an optimal debt security on the pool of two assets, his profit becomes:

$$S = \begin{cases} \delta\sigma, & \text{if} \quad \delta \in (-\infty, \frac{2}{5}] \\ (\frac{1}{4} + \frac{3}{4}\frac{1-\delta}{4\delta-1})\delta\sigma, & \text{if} \quad \delta \in (\frac{2}{5}, \frac{2}{3}] \\ (\frac{1}{4} + \frac{3}{4}\frac{3-4\delta}{4\delta-1})\delta\sigma, & \text{if} \quad \delta \in (\frac{2}{3}, \frac{3}{4}] \\ 0, & \text{if} \quad \delta \in (\frac{3}{4}, +\infty). \end{cases} \tag{20}$$

The issuer's profit can increase by issuing the optimal debt security on the pool of assets rather than issuing equity. However, unlike with competitive buyers, there is now a region $\delta \in (\frac{2}{5}, \frac{1}{2}]$ where the issuer is strictly better off by sidestepping pooling and instead selling assets separately. When the buyer has market power, the threshold for the unscreened sale of a pool of two assets (i.e., $\bar{\delta}_{22}$) is lower than the thresholds for the unscreened sale of individual assets (i.e., $\bar{\delta}_1^i$). Even though the debt security dominates the equity security when pooling the assets, the issuer is unable to unload all his exposure to the assets and has to retain some in the form of a call option. Panel (b) in Figure 1 identifies the region of δ where selling assets separately is more profitable than issuing debt on the pool of assets.

The intuition behind these results can be explained by analyzing how pooling affects the distribution of a security's payoff (which we further discuss in the next section). Suppose the issuer tries to sell the two assets separately. Since assets are independent and have the same quality, the quoted prices and outcomes in the two trades are the same. For the buyers this situation is effectively the same as if the issuer offered only one asset with twice the payoff: $2v_1$. The distribution of potential payoffs on such asset is given by:

	$2v_1 = 0$	$2v_1 = \sigma$	$2v_1 = 2\sigma$
Pr	1/2	0	1/2.

The shape of the distribution is identical to the one corresponding to the individual asset. However, the shape of the distribution changes when assets are pooled. The distribution of the pool is given by:

	$v_2 = 0$	$v_2 = \sigma$	$v_2 = 2\sigma$
Pr	1/4	1/2	1/4

Although the means of the two distributions are the same, the right tail of the second distribution is thinner. When buyers are competitive and deep-pocketed the efficiency of trade solely depends on the mean of distribution and thus pooling does not affect the optimal decision of the issuer. Yet, when buyers have market power, there is a trade off between prices and expected volume. The thickness of the right tail affects the cost of market exclusion. As a result, pooling assets incentivizes the buyer to screen out the high issuer types and is thus detrimental to the issuer.

4 Two assets with continuously distributed payoffs

In this section, we show that the main insights presented above do not change when assets' payoffs are continuously distributed. Moreover, the case with continuously distributed payoffs allows to further emphasize the role played by the shape of the distribution in the optimal screening behavior by a buyer endowed with market power and how the issuer can preempt this screening through optimal security design.

We first examine the optimal pricing decisions by a monopolistic buyer who is offered an equity or a debt security with arbitrary payoffs. Next, we establish some properties of the payoff distribution for a pool of two assets. Finally, we compare the issuer's profits from designing debt and equity securities on separate assets and on a pool of assets.

4.1 Buyer's optimal pricing of arbitrary securities

Suppose first that the seller issues an equity security producing a future random payoff v, with a cumulative distribution function $F(v)$ and a positive density $f(v)$ everywhere on its domain $v \in [0, \bar{v}]$. We assume that the distribution is well-behaved, in line with the literature, and satisfies the following assumption:

Assumption 1. *The function*

$$h(v) \equiv v \frac{f(v)}{F(v)} \tag{21}$$

is monotonically decreasing on the support of the distribution $[0, \bar{v}]$.

As in the discrete case, if the buyer offers a price p in exchange for the equity stake on that asset, the buyer's profit is given by:

$$B(p) = \Pr(\delta v \leq p)(\mathbb{E}[v|\delta v \leq p] - p). \tag{22}$$

Specifically, any issuer who knows that the security will pay out at most p/δ accepts the offer while any issuer who knows that the asset will pay out more than p/δ rejects the offer (i.e., gets screened out). We can rewrite the buyer's profit function as:

$$B(p) = \int_0^{p/\delta} (v - p) f(v) dv. \tag{23}$$

Under the regularity condition assumed above, we can solve the buyer's profit maximization problem using its first-order condition. The optimal pricing threshold, or marginal issuer type, v^* is then characterized by:

$$(1 - \delta) v^* f(v^*) - \delta F(v^*) = 0. \tag{24}$$

When choosing v^*, the buyer tradeoffs the benefits of convincing more buyer types to participate in the trade and the losses associated with reducing the price collected by the participating issuer types. The seller's profit at the optimal screening price $p = \delta v^*$ is equal to:

$$\begin{aligned} S(\delta v^*) &= \Pr(v \leq v^*)(\delta v^* - \delta\, \mathbb{E}[v | v \leq v^*]) \\ &= \delta v^* F(v^*) - \delta \int_0^{v^*} v f(v) dv \\ &= \delta \int_0^{v^*} (v^* - v) f(v) dv \end{aligned} \tag{25}$$

which is increasing in v^*.

Now, suppose instead that the seller issues a debt security with a face value D. The payoff of the security is now given by $v^D = \min\{v, D\}$. Thus, an issuer can at most give the buyer a payoff of D and thereby accepts with probability one any price weakly higher than δD. The buyer's pricing decision is thus equivalent to what he would face if the issuer with $v \in [D, \bar{v}]$ were replaced by a positive mass of size $\Pr(v \geq D)$ whose valuation is equal to δD. If the buyer were to find it optimal to offer a price below δD, this positive mass of high issuer type would reject the offer and we would be back to a situation consistent with the issuance of equity. In other words, trading debt is equivalent to trading equity whenever the buyer quotes a price $p < \delta D$.

Moreover, it is never optimal for the issuer to pick $D < v^*$, since it would imply that the issuer collects a lower payoff from selling the debt security than from selling an equity security. When trying to buy a debt security with face value $D > v^*$, the buyer is now comparing the strategy of offering the high price δD to the strategy of offering the optimal equity price δv^*. In the former case where $p = \delta D$, the buyer's profit is:

$$\begin{aligned} B^D(\delta D) &= \Pr(v^D \leq D)(\mathbb{E}[v^D | v^D \leq D] - \delta D) \\ &= \int_0^D (v - \delta D) f(v) dv + (1 - F(D))(1 - \delta) D. \end{aligned} \tag{26}$$

Consider now the issuer's choice of a face value D. If the buyer offers the high price δD the issuer earns no profit whenever $v \geq D$. However, whenever $D > v^*$ an issuer who learns that $v \in (v^*, D)$ collects a positive profit, in contrast with the zero profit associated with an equity security over that region of v. As a result, the issuer collects a higher expected profit from issuing a debt security that is not screened by the buyer than from issuing an equity security. Formally, the issuer's profit when offered a price $p = \delta D$ is:

$$\begin{aligned} S^D(\delta D) &= \Pr(v^D \leq D)(\delta D - \delta\, \mathbb{E}[v^D | v^D \leq D]) \\ &= \delta D F(D) - \delta \int_0^D v f(v) dv \\ &= \delta \int_0^D (D - v) f(v) dv \\ &= S(\delta D), \end{aligned} \tag{27}$$

which is increasing in D.

Given that the buyer is more likely to screen for higher values of D, it is optimal for the issuer to choose the highest D for which the buyer offers a price δD. This condition implies that at the optimal D the buyer is indifferent between quoting $p = \delta D$ and $p = \delta v^*$:

$$B^D(\delta D) = B(\delta v^*). \tag{28}$$

By continuity of $B^D(p)$, it is straightforward to show that the optimal D is strictly greater than v^*. The issuer is thus strictly better off by issuing the optimal debt security than by issuing an equity security (i.e., $S(\delta D) > S(\delta v^*)$ since $S'(\cdot) > 0$ and $D > v^*$).

4.2 Issuer's decision to pool assets

Using the derivations above for arbitrary payoff distributions, we can now compare the issuer's profit functions when he pools the two assets and when he does not. But first, we must state a few properties of the payoff distributions that will simplify the analysis.

When considering the separate sale of two assets, it is useful to establish the following result:

Lemma 1. *The sale of two separate securities, each issued on an asset producing a random payoff X_i distributed according to a c.d.f. $F(x)$ that satisfies Assumption 1, is equivalent from all traders' perspective to the sale of the same type of security issued on an asset producing a random payoff $2X_i$ with c.d.f. $F_2(x) = F(\frac{x}{2})$.*

While selling two different securities, one issued on asset 1 and the other issued on asset 2, is equivalent to selling one security issued on two times asset 1, when X_1 and X_2 are i.i.d., selling a security issued on both securities leads to different incentives to screen for the buyer. Thus, the issuer's decision to pool or not the two assets is identical to the decision of selling securities associated with payoffs of $X_1 + X_2$ or $2X_i$, respectively. This comparison is convenient since both $2X_i$ and $X_1 + X_2$ are distributed on the same interval $x \in [0, 2\bar{x}]$ and the difference in the optimal trading decisions of the issuer and the buyer will come from the difference in the shapes of the two distributions.

The following results will be useful in this comparison:

Lemma 2. *The distribution of payoff $X_1 + X_2$, where X_1 and X_2 are i.i.d. random variables with c.d.f. $F(x)$, second-order stochastically dominates the distribution of $2X_i$ and has thinner tails.*

These distributional properties foreshadow that the incentives to screen the issuer of a security on a pool of two assets will be stronger than if the issuer were instead selling the two assets separately. As we will show, it is sometimes the case that separate securities can be sold in a socially efficient manner while a pool of the same assets is sold at a screening, less efficient price.

Useful to our analysis below is the fact that the second-order stochastic dominance can characterized by the following inequality:

$$\int_0^x [F_2(y) - F_p(y)]dy \geq 0 \tag{29}$$

for any x in the support $[0, 2\bar{x}]$. The maximum of this difference is reached at some point $x = x'$ where $F_2(x') = F_p(x')$, meaning that $F_2(x) > F_p(x)$ for $x \in (0, x')$ while $F_2(x) < F_p(x)$ for $x \in (x', 2\bar{x})$. Furthermore, if both random variables X_i are symmetrically distributed around $\bar{x}$, then it must be that $x' = \bar{x}$.

4.3 Comparing payoffs from equity securities

Although we showed above that when trading with a monopolistic buyer the issuer is strictly better off designing a debt security on an asset than an equity security, we start by comparing the issuer's profits from issuing separate equity securities for each asset and from issuing one equity security on a pool of assets. This exercise will highlight the intuition that pooling assets increase the buyer's incentives to screen the issuer and can thereby be detrimental to an issuer facing a buyer with market power. Once that intuition is covered, we will introduce the design of the optimal debt security and show that our intuition also holds there.

Recall that an optimal pricing threshold $x^* = \frac{p}{\delta}$ is characterized by the first-order condition of the buyer's profit maximization problem, which can be written using equations (21) and (24) as:

$$\frac{1}{h(x^*)} = \frac{(1-\delta)}{\delta}, \tag{30}$$

and define a function $k(x) \equiv \frac{1}{h(x)}$. The regularity condition in Assumption 1 states that this function monotonically increases on the support $[0, 2\bar{x}]$. Since the function $k(x)$ measures the buyer's incentives to screen the issuer by offering a lower price, it is useful to examine its properties for the distributions $2X_i$ and $X_1 + X_2$. While all the main results we derive below are analytical, we use plot in Figure 2 a numerical example for the functions $k_p(x)$ and $k_2(x)$, which respectively capture the buyer's incentives to lower the price below $p = \delta x$ when the security is issued on a pool of two assets or when separate securities are issued for each asset.

From Lemma 2, we know that the payoff distribution for the pooled security has thinner tails, which also means that $F_p(x) > F_2(x)$ and $f_p(x) < f_2(x)$ as $x \to 2\bar{x}$. This in turn implies that $k_p(x) > k_2(x)$ as $x \to 2\bar{x}$ and the buyer has stronger incentives to screen the issuer by offering a price lower than $p = 2\delta\bar{x}$.[8] More generally, if the monotonically increasing functions $k_p(x)$ and $k_2(x)$ intersect only once at some $x = x'$ and the random variables X_i both follow an identical symmetric distribution, then $x' > \bar{x}$ as $k_p(\bar{x}) < k_2(\bar{x})$. We denote by δ' the unique value of δ such that $k_p(x') = k_2(x') = \frac{1-\delta'}{\delta'}$.

For low values of the discount factor, $\delta < \delta'$, the optimal marginal issuer the buyer targets has a lower valuation x^* when trying to purchase a pool with payoff $X_1 + X_2$ than when trying to purchase the two assets separately: $x_p^* < x_2^*$. However, for high values of the discount factor, $\delta \in (\delta', \frac{1}{1+k_2(0)})$, the order of the screening thresholds is reversed: $x_p^* > x_2^*$. Lastly, if $\delta \in [\frac{1}{1+k_2(0)}, \frac{1}{1+k_p(0)})$ the assets

[8] Throughout the section, the subscripts p and 2 correspond to the distributions $F_p(x)$ and $F_2(x)$ respectively.

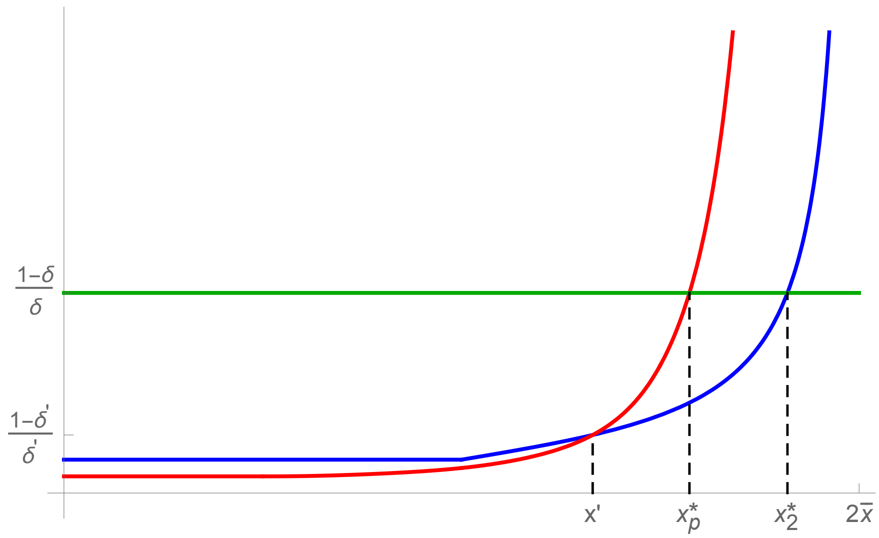


Figure 2: This figure plots the functions $k_p(x)$ for a pool of assets (red), $k_2(x)$ for separate sales (blue), and a level $\frac{1-\delta}{\delta}$ (green). The parameterization assumes that X_i for $i = 1, 2$ are independent, uniform random variables on $[0, 1]$, $\delta' = 0.53$, and $\bar{x} = 2$.

cannot be sold separately, as the issuer is completely screened out by the buyer, but pooled security is only partially screened and some gains from trade are realized.

Finally, having established the inequalities in screening thresholds x^* for an equity security with a payoff $2X_i$ and for an equity security with a payoff $X_1 + X_2$, we can now compare the issuer's expected profits in the two cases.

Integrating by parts, the issuer's profit from being offered a price δx can be simplified to:

$$S(\delta x) = \delta \int_0^x (x - y) f(y) dy = \delta (x - y) F(y)|_0^x + \delta \int_0^x F(y) dy = \delta \int_0^x F(y) dy. \tag{31}$$

Since $X_1 + X_2$ second-order stochastically dominates $2X_i$ for any $x \in [0, 2\bar{x}]$, we know that:

$$S_2(\delta x) - S_p(\delta x) = \delta \int_0^x [F_2(y) - F_p(y)] dy \geq 0, \tag{32}$$

which means, if the buyer were to offer the same price $p = \delta x$ regardless of the security, the issuer would have strictly higher profits by selling separately the two assets than by selling them as part of a pool. However, as we know, the buyer optimally offers different prices in the two cases. We however know that whenever the discount factor is small enough, i.e., $\delta \in (0, \delta')$, the buyer tries to screen the issuer more aggressively if he is selling a pool of assets than two separate assets: $x_2^* > x_p^*$. Given that the issuer's profit is an increasing function of the offered price, the following inequality must hold: $S_2(\delta x_2^*) > S_2(\delta x_p^*)$. Therefore, for $\delta \in (0, \delta')$ the issuer is better off selling a different equity security for each asset than selling one equity security on the pool of assets.

4.4 Comparing payoffs from debt securities

As shown in subsection 4.1, an issuer is always able to design a debt security that generates a higher expected profit than a comparable equity security. In this subsection, we will show that when δ is sufficiently low and the payoff distribution $F(x)$ is symmetric, the issuer is better off selling separate debt securities on each asset than selling a debt security on the pool of assets. In other words, when the buyer is endowed with market power, pooling assets may be suboptimal, even if debt securities are allowed. We focus on the case where $\delta \in (0, \delta')$ and the buyer's screening behavior was more aggressive for pooled securities than non-pooled securities in the scenario with equity securities only.

It has already been established that the issuer's profit from selling a debt security is given by the same function as in the equity case:

$$S(\delta D) = \delta \int_0^D (D - v) f(v) dv. \tag{33}$$

Therefore, if we can show that the optimal face value of debt when the payoff is $2X_i$ is higher than the optimal face value of debt when the payoff is $X_1 + X_2$, i.e., $D_2 > D_p$, then the same argument as in the equity case above can be carried out when debt securities are allowed.

The analysis will prove that $D_2 > D_p$ for δ close to zero — the issuer thereby being better off issuing separate debt securities for each asset than one debt security on the pool of assets. Recall that the issuer chooses the optimal D such that the buyer's profit from buying the debt security without screening, at a price δD, is the same as his optimal profit from buying an equity security. Using our earlier notation, the optimal face values D_2 and D_p are determined by $B_2^D(\delta D_2) = B_2(\delta x_2^*)$ and $B_p^D(\delta D_p) = B_p(\delta x_p^*)$. While again our main results are derived analytically below, we plot in Figure 3 the relevant payoff functions associated with a simple numerical example.

To compare the relative positions of D_2 and D_p, we must first study the relative positions of the functions $B_2^D(\delta D)$ and $B_p^D(\delta D)$ and the levels $B_2(\delta x_2^*)$ and $B_p(\delta x_p^*)$. We can establish that $B_2(\delta x_2^*) < B_p(\delta x_p^*)$. Integrating by parts, the buyers's profit from buying an equity security at a

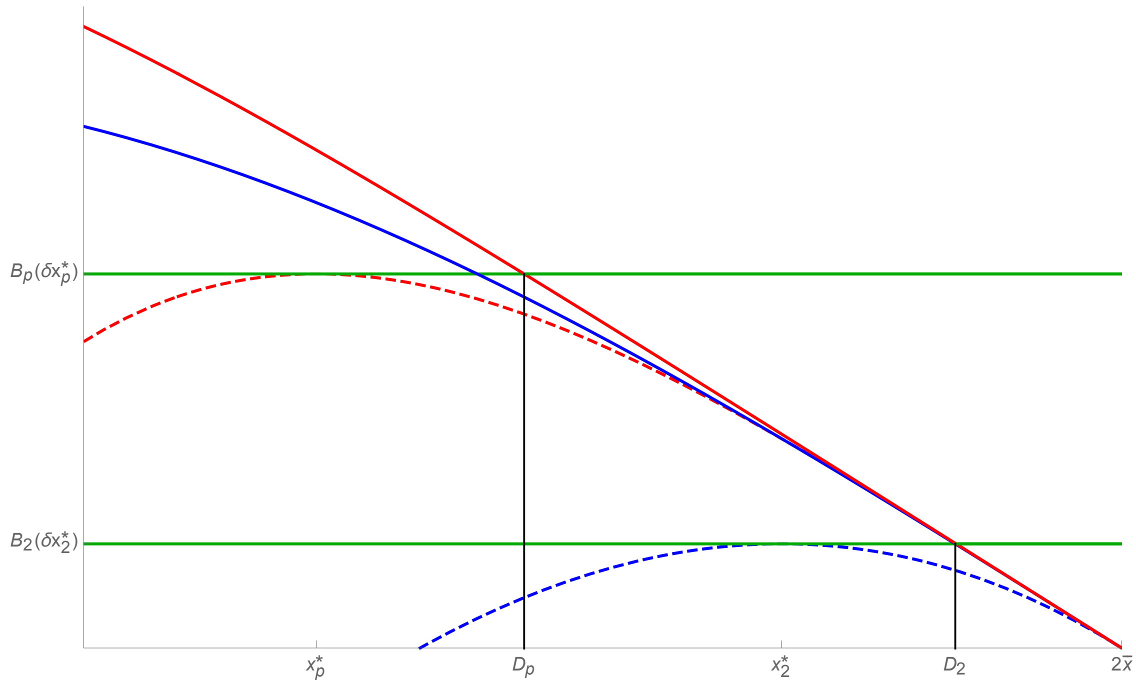


Figure 3: This figure plots the buyer's profit functions for an equity security $B(\delta x)$ (dashed) and for a debt security $B^D(\delta D)$ (solid), each drawn for the two cases: selling a pool of assets (red) and separately selling the two assets (blue). It also plots the buyer's maximum profit levels $B_2(\delta x_2^*)$ and $B_p(\delta x_p^*)$ for equity (green), and the optimal values for D_p and D_2 (black). The parameterization assumes that X_i for $i = 1, 2$ are independent, uniform random variables on $[0, 1]$, $\delta = 0.25$, and $\bar{x} = 2$.

price δx can be simplified to:

$$\begin{aligned} B(\delta x) &= \int_0^x (y - \delta x) f(y) dy \\ &= (y - \delta x) F(y)|_0^x - \int_0^x F(y) dy \\ &= (1 - \delta) x F(x) - \int_0^x F(y) dy. \end{aligned} \tag{34}$$

Therefore, for $x > \bar{x}$ the second-order stochastic dominance of $F_p(x)$ implies that $F_p(x) \geq F_2(x)$ and that:

$$B_p(\delta x) - B_2(\delta x) = (1 - \delta) x (F_p(x) - F_2(x)) + \int_0^x [F_2(y) - F_p(y)] dy \geq 0. \tag{35}$$

Geometrically, the function $B_p(\delta x)$ lies above the function $B_2(\delta x)$ for any $x > \bar{x}$ and the maximum of the former function must therefore be higher than the maximum of the latter function. The buyer's profit at the optimal equity screening threshold of $X_1 + X_2$ is strictly higher than the buyer's profit at the optimal equity screening threshold of $2X_i$:

$$B_p(\delta x_p^*) > B_2(\delta x_2^*). \tag{36}$$

We can similarly establish that the function $B_p^D(\delta D)$ lies above the function $B_2^D(\delta D)$. Indeed, the buyer's profit from buying debt with the face value D at a price δD is:

$$B^D(\delta D) = B(\delta D) + (1-\delta)(1-F(d))d = (1-\delta)d - \int_0^x F(y)dy. \tag{37}$$

Using the second-order stochastic dominance of $F_p(\cdot)$, we know that the function $B_p^D(\delta D)$ lies above the function $B_2^D(\delta D)$ for any $D \in (0, 2\bar{x})$. Additionally, at the right tail of the distribution (as $x = 2\bar{x}$), all the four profit functions have the same value:

$$B_p(\delta 2\bar{x}) = B_2(\delta 2\bar{x}) = B_p^D(\delta 2\bar{x}) = B_2^D(\delta 2\bar{x}) = 2\,\mathbb{E}[X_i] - \delta 2\bar{x} = \bar{x}(1-2\delta). \tag{38}$$

Having determined the relative positions of the functions $B_2^D(\delta D)$ and $B_p^D(\delta D)$ and the levels $B_2(\delta x_2^*)$ and $B_p(\delta x_p^*)$, we now identify the relative positions of D_2 and D_p. Since the function $B_p^D(\delta D)$ lies above the function $B_2^D(\delta D)$ for any D, the former must cross both levels $B_2(\delta x_2^*)$ and $B_p(\delta x_p^*)$ closer to the right boundary $2\bar{x}$ than the latter. However, the main question is whether it crosses the higher level $B_p(\delta x_p^*)$, the point D_p, further from $2\bar{x}$ than $B_2^D(\delta D)$ crosses the lower level $B_2(\delta x_2^*)$, the point D_2.

Going back to our last numerical example, Figure 4 zooms in on the region of interest. It can be seen that the profit functions $B_2^D(\delta D)$ and $B_p^D(\delta D)$ as well as their slopes are close near the right tail, $2\bar{x}$. The derivative of the buyer's profit function which determines the slope is:

$$[B^D(\delta D)]' = 1 - \delta - F(D). \tag{39}$$

Hence, the slopes of functions B_2^D and B_p^D are indeed the same at the right tail $2\bar{x}$ where both $F_2(2\bar{x}) = F_p(2\bar{x}) = 1$.

Denote as D' the face value of debt for which $B_p^D(\delta D') = B_2(\delta x_2^*)$. By the properties of the profit functions established above, $D' > D_2$ and $D' > D_p$. Thus, to match up D_2 and D_p we can compare $D' - D_2$ and $D' - D_p$.

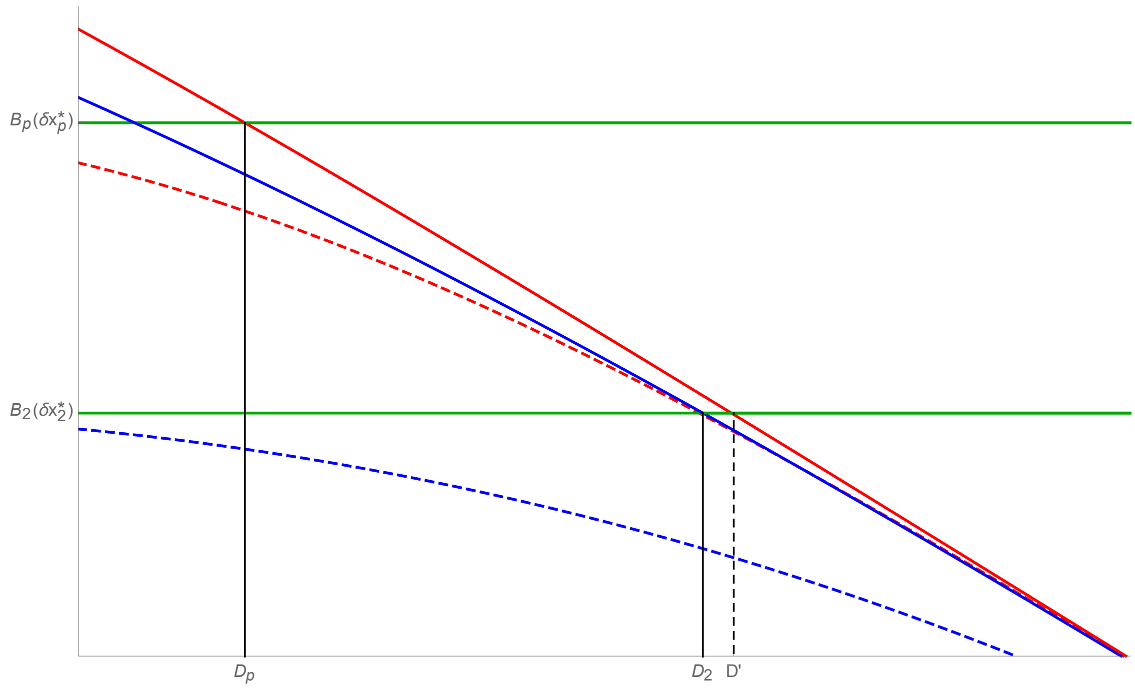


Figure 4: This figure plots the buyer's profit functions for an equity security $B(\delta x)$ (dashed) and for a debt security $B^D(\delta D)$ (solid), each drawn for the two cases: selling a pool of assets (red) and separately selling the two assets (blue). It also plots the buyer's maximum profit levels $B_2(\delta x_2^*)$ and $B_p(\delta x_p^*)$ for equity (green), and the optimal values for D_p and D_2 (black). The parameterization assumes that X_i for $i = 1, 2$ are independent, uniform random variables on $[0, 1]$, $\delta = 0.25$, and $\bar{x} = 2$.

Up to a linear approximation, these differences are each given by:

$$D' - D_p \approx \frac{B_p(\delta x_p^*) - B_2(\delta x_2^*)}{-[B_p^D(\delta D')]'}. \tag{40}$$

$$D' - D_2 \approx (2\bar{x} - D_2) - (2\bar{x} - D') = \frac{B_2(\delta x_2^*) - B_2(\delta 2\bar{x})}{-[B_2^D(\delta D_2)]'} - \frac{B_2(\delta x_2^*) - B_2(\delta 2\bar{x})}{-[B_p^D(\delta D')]'}. \tag{41}$$

Finally, $D_p < D_2$ whenever $D' - D_p > D' - D_2$ which, substituting the formulas from the above, is expanded to:

$$\frac{B_p(\delta x_p^*) - B_2(\delta x_2^*)}{-[B_p^D(\delta D')]'} > \frac{B_2(\delta x_2^*) - B_2(\delta 2\bar{x})}{-[B_p^D(\delta D_2)]'} - \frac{B_2(\delta x_2^*) - B_2(\delta 2\bar{x})}{-[B_p^D(\delta D')]'}, \tag{42}$$

which is equivalent to:

$$\frac{B_p(\delta x_p^*) - B_2(\delta x_2^*)}{B_2(\delta x_2^*) - B_2(\delta 2\bar{x})} > \frac{-[B_p^D(\delta D')]'}{-[B_2^D(\delta D_2)]'} - 1 = \frac{\delta - 1 + F_p(D_2)}{\delta - 1 + F_2(D')} - 1 = \frac{F_p(D') - F_2(D_2)}{\delta - 1 + F_2(D_2)}. \tag{43}$$

This shows that $D_p < D_2$ whenever either $B_p(\delta x_p^*) - B_2(\delta x_2^*)$ is high, $B_2(\delta x_2^*) - B_2(\delta 2\bar{x})$ is low, or

$F_p(D') - F_2(D_2)$ is low.

Lastly we show that condition (43) is satisfied for δ close to zero. For low values of the discount factor $\delta \to 0$ the buyer almost does not screen and $x_2^* \to 2\bar{x}$ and $x_p^* \to 2\bar{x}$. Therefore, both differences $B_2(\delta x_2^*) - B_2(\delta 2\bar{x}) \to 0$ and $B_p(\delta x_p^*) - B_2(\delta x_2^*) \to 0$. However, because of the thinner tails of X_1+X_2, x_p^* approaches the right tail $2\bar{x}$ at a slower rate than x_2^*. Hence, $B_p(\delta x_p^*) - B_2(\delta x_2^*) > B_2(\delta x_2^*) - B_2(\delta 2\bar{x}) \approx 0$. At the same time, $D_2 \to 2\bar{x}$ and $D' \to 2\bar{x}$ when $\delta \to 0$ and an application of the L′Hôpital's rule to the right-hand side of condition (43) yields:

$$\left.\frac{F_p(D') - F_2(D_2)}{\delta - 1 + F_2(D_2)}\right|_{\delta \to 0} \approx \frac{f_p(2\bar{x}) - f_2(2\bar{x})}{1 + f_2(2\bar{x})} = 0. \tag{44}$$

Summing up the above analysis, the condition is satisfied for $\delta \to 0$ and therefore by monotonicity in some interval around zero, i.e. for $\delta \in (0, \bar{\delta})$ with $\bar{\delta} > 0$.

Thus, in this interval where δ is small, the optimal face value of debt for an asset with payoff $2X_i$ is higher than the optimal face value of debt for an asset with payoff $X_1 + X_2$. Therefore, employing the argument from the beginning of this section, the optimal debt security issued on a pool of two assets yields a lower profit compared to the profit obtained from selling two optimal debt securities issued on each asset. Equivalently, the issuer is strictly better off selling debt on separate assets than on the pool of assets. Given the analysis from subsection 4.1, the former option also dominates selling equity on any of these portfolios.

5 Discussion

In this section we argue that the main result holds under various alternative scenarios. First, we separately consider scenarios where there are more than 2 assets, where the scarcity of liquidity is modeled differently with multiple constrained buyers instead of one monopolistic buyer, and where the issuer could signal asset quality. Finally, we highlight the possibility of adding a time dimension to the setup.

More than two assets. Throughout the paper, we have analyzed the decision of an issuer to pool two assets and issue a security on this pool. Our main result that pooling assets can be suboptimal when facing a buyer with market power, however, extends to cases with more than two assets. The limiting case with $n \to +\infty$ assets provides a clear intuition for why that is. Suppose the issuer has access to an infinite number of assets indexed by i. Each asset i produces a payoff that is independently distributed. If the issuer faces a group of competitive buyers, pooling all these assets into one security guaranteed, by the law of large numbers, to always deliver its expected payoff, say μ, is optimal, as all buyers offer a price μ and the issuer extracts the full surplus $(1-\delta)\mu$. Now if the issuer instead faces a monopolistic buyer and were to pool all the assets into one security guaranteed to deliver a payoff μ, the monopolistic buyer would find it optimal to offer a price $\delta\mu$, which would leave the issuer with no surplus. Pooling an infinite number of assets leads to non-existent tails in the distribution of payoffs (i.e., payoff realizations always equal their expectation) and leaves the issuer with no information rents. The issuer can therefore do better by separately selling a subset of these assets such that he is not fully screened out and is able to extract some rents, consistent with the above analysis for $n = 2$ assets. (See Appendix B for a formal extension of our model to the case with $n > 2$ assets producing identically distributed payoffs that follow a binomial distribution.)

Constrained buyers. The main result of the paper that the pooling might be suboptimal compared to separate sales is derived in the model with one deep-pocketed buyer endowed with full market power. The characteristics of a market with liquidity shortages are, however, consistent with this setup. Specifically, we show in Appendix B that the main result holds in an extended model containing several buyers who have position limits which might be due to scarce market liquidity. Buyers with position limits cannot compete aggressively and thereby quote prices similar to the monopolist buyer prices. Because of this the issuer prefers the same securities as in the baseline model and might find pooling suboptimal.

In particular, we consider two extensions of the model with different types of constraints. In the first extension, deep-pocketed buyers are limited by the number of risk units they can take in their inventory. We show that when the total number of risk units demanded is lower than the number of supplied units the constrained buyers quote the same prices as a monopolist buyer would. In the second extension, buyers have limited wealth to post quotes and acquire assets. We show that under this scenario, if the buyers' wealth is sufficiently constrained, the sale of a security on a pool might be inefficient and separate sales are preferred by the issuer.

Signaling through retention. In the case of competing buyers, allowing the issuer to signal the quality of the assets through partial retention would yield results consistent with DeMarzo (2005) — issuers with assets of higher quality would retain a higher fraction of the issue. Signaling would allow the high type issuers to separate themselves from the low types and would resolve the lemons problem for high values of δ. In contrast, when facing a buyer with market power, the issuer can be made worse off by signaling the quality of his assets. Since the buyer has all bargaining power once he knows the issuer type he is able to extract all the surplus from trade and leave the issuer with zero profit. In this case the issuer's profit with fully revealing retention policies is weakly worse than his profit without any signaling through retention. (See Glode, Opp, and Zhang (2018) for related arguments.)

Alternative interpretation. The model assumes that the cash flows of different assets occur at the same time and we study whether pooling such assets is optimal for the issuer. However, the model allows an alternative interpretation where a time dimension is added to the assets' payoffs. Suppose the issuer has an asset that pays cash flows in different time periods. To map this situation to our model each particular cash flow can be viewed as an asset from our setup, while the asset itself can be considered as a pool of such cash flows. For such a mapping, we would also need to assume that the issuer is better informed than the buyers about all future cash flows. The question would be then whether it is optimal for the issuer to sell the asset as it is, pooling all cash flows across time, or to separate them and sell, for example, cash flows occurring earlier separately from those occurring at later time periods. The prediction of the model is that when the demand side has market power we should see more separation across the time dimension of cash flows.

6 Conclusion

This paper studies the optimality of pooling and tranching under asymmetric information when security originators face a market where liquidity is scarce and buyers endowed with such liquidity may have market power. Contrary to the standard result that pooling and tranching are optimal practices, we find that selling assets separately may be preferred by originators to avoid being inefficiently screened by buyers. While our results suggest that the dramatic decline of the ABS market post crisis may represent an efficient response by originators to changes in liquidity and market power in OTC markets, it also highlights the potential welfare implications of liquidity constraints imposed on financial institutions in the new market environment.

Appendix A Proofs of Lemmas

Proof of Lemma 1: Recall that if $F(x)$ and $f(x)$ are the c.d.f. and the p.d.f. of a random variable X then a random variable $2X$ has a c.d.f. $F_2(x) = F(\frac{x}{2})$ and a p.d.f. $f_2(x) = \frac{f(\frac{x}{2})}{2}$.

Using this property we analyze a sale of equity issued on an asset paying $2X$. Since the regularity condition in Assumption 1 is also satisfied by the distribution $F_2(x)$, the optimal screening threshold x_2^* is given by the FOC of the buyer's profit maximization problem:

$$(1-\delta)x_2^* f_2(x_2^*) = \delta F_2(x_2^*). \tag{A1}$$

Substituting in the above the p.d.f. and the c.d.f. of the random variable X we obtain:

$$(1-\delta)x_2^* f(x_2^*/2)/2 = \delta F(x_2^*/2). \tag{A2}$$

This is the FOC of the buyer's optimization problem if the underlying asset is X, (24), with $x^* = x_2^*/2$. Therefore, the optimal equity screening threshold for an asset $2X$ is twice as large as the optimal equity screening threshold for an asset X, $x_2^* = 2x^*$.

Analogous steps can be taken in the case of a debt issued on an asset $2X$ to find that the optimal debt level D_2 is twice as large as the optimal debt level for a debt issued on an asset X, $D_2 = 2D$.

Furthermore, given the established properties, the issuer's profit from selling a security issued on an asset $2X$ is twice as large as that from a sale of the same security issued on an asset X:

$$\begin{aligned} S(\delta 2y) = \delta \int_0^{2y} (2y - x) f_2(x) dx = \int_0^{y} (2y - 2x) f_2(2x) d(2x) = \\ = 2\delta \int_0^{y} (y - x) f_1(x) dx = 2S(\delta y). \end{aligned} \tag{A3}$$

Similarly, the buyer's profit is twice as large as that from buying a security issued on an asset with payoff X.

Therefore, from the issuer's and the buyer's perspectives two separate sales of an asset with random payoff X is the same as a sale of one asset with random payoff $2X$.

Proof of Lemma 2: Denote as $F_p(x)$ and $f_p(x)$ the c.d.f. and a p.d.f. of a random variable $X_1 + X_2$. Since X_1 and X_2 are independent and both have a density function $f(x)$ the function

$f_p(x)$ is, by definition, the convolution of the two functions $f(x)$ and $f(x)$ and is given by:

$$f_p(x) = \int_{-\infty}^{+\infty} f(x-y)f(y)dy = \int_0^{\bar{x}} f(x-y)f(y)dy. \tag{A4}$$

This can be further reduced, since $f(x) \geq 0$ on $x \in [0, \bar{x}]$, to obtain

$$f_p(x) = \begin{cases} \int_0^x f(x-y)f(y)dy, & \text{if } \; 0 \leq x \leq \bar{x} \\ \int_{x-\bar{x}}^{\bar{x}} f(x-y)f(y)dy, & \text{if } \; \bar{x} < x \leq 2\bar{x}. \end{cases} \tag{A5}$$

To see that the distribution of $X_1 + X_2$ has substantially thinner tails than the distribution $2X$ consider the shape of its density function $f_p(x)$ close to zero, its left tail. From equation (A5) $f_p(0) = 0$ even if $f_2(0) = \frac{f(0)}{2}$ might not be equal to zero.

Turning back to the left tail of the distribution $X_1 + X_2$, the first two derivatives of its density $f_p(x)$ are

$$f_p'(x) = f(0)f(x) + \int_0^x f'(x-y)f(y)dy, \tag{A6}$$

$$f_p''(x) = f(0)f'(x) + f'(0)f(x) + \int_0^x f''(x-y)f(y)dy. \tag{A7}$$

Hence, their values at the left boundary are $f_p'(0) = f^2(0)$ and $f_p''(0) = 2f(0)f'(0)$. Thus, it is possible that $f_p'(0) = f_p''(0) = 0$ when $f_2(0) = \frac{f(0)}{2} = 0$ even if $f_2'(0) = \frac{f'(0)}{4}$ and $f_2''(0) = \frac{f''(0)}{8}$ might not be equal to zero. Since the same results can be obtained for the right tail it follows that the distribution of $X_1 + X_2$ has smoother, thinner tails than the distribution of $2X_i$.

Another way to see this fact is to notice that $2X_i$ is a mean preserving spread of $X_1 + X_2$. Indeed, the former can be written as the sum of the latter and $X_1 - X_2$:

$$2X_1 = X_1 + X_2 + (X_1 - X_2), \tag{A8}$$

and $X_1 - X_2$ has conditional expected value of zero

$$\mathbb{E}[X_1 - X_2 | X_1 + X_2] = \mathbb{E}[X_1 | X_1 + X_2] - \mathbb{E}[X_2 | X_1 + X_2] \stackrel{a.s.}{=} 0. \tag{A9}$$

Therefore, the distribution of $X_1 + X_2$ second-order stochastically dominates the distribution of $2X_i$.

Appendix B Extensions to the baseline model

B.1 The case with $n > 2$ assets and binomially distributed payoffs

This section generalizes our results to pools of $k \leq n$ assets.

B.1.1 Competitive (deep-pocketed) buyers

In this subsection, we consider a market with competitive buyers. Suppose first that the issuer offers an equity claim on a pool of k assets and there are several competitive unconstrained buyers. Again, any buyer quotes the price $p_k = \mathbb{E}[v_k | v_k \leq m\sigma]$ when it is higher than the reservation value of the highest participating issuer: $m\delta\sigma$. Writing out the conditional expectation, this is equivalent to requiring that:

$$\frac{\sum_{i=0}^{m} \Pr(v_k = i\sigma)(i\sigma)}{\sum_{i=0}^{m} \Pr(v_k = i\sigma)} \geq m\delta\sigma. \tag{B1}$$

As before, these inequalities allow us to characterize the thresholds for the discount factor δ at which trade at prices $E(v_k|v_k \leq m\sigma)$ is possible:

$$\delta_{km} \equiv \frac{\sum_{i=0}^{m} \Pr(v_k = i\sigma)i}{m\sum_{i=0}^{m} \Pr(v_k = i\sigma)}. \tag{B2}$$

Whenever δ is higher than the threshold δ_{km}, it means that the gains to trade are too low to sustain trade at a price $\mathbb{E}[v_k|v_k \leq m\sigma]$. Specifically, the upper bound on δ, which corresponds to the lowest gains from trade where trade is efficient can be written as:

$$\delta_{kk} \equiv \delta_k \equiv \frac{\mathbb{E}[v_k]}{k}. \tag{B3}$$

Later, we will obtain analogous thresholds for a market with a monopolistic buyer and show how they differ in the two cases and how they can be used to find the solution to the issuer's problem.

As before, the issuer can improve his profits by issuing debt instead of equity on a pool of k assets. If the face value is $D\sigma$ with $D \in (m-1, m]$ then the offered price which is equal to the expected security payoff, assuming that all issuer types participate in the trade, is:

$$p_k = \mathbb{E}[v_k^D | v_k \leq D\sigma] = \sum_{i=0}^{m-1} \Pr(v_k = i\sigma)(i\sigma) + \sum_{i=m}^{k} \Pr(v_k = i\sigma)D\sigma. \tag{B4}$$

Setting $D \in (0,1)$ is however never optimal. An optimal level of $D = 1$ can be sustained when δ

reaches its highest bound where any trade is possible in equilibrium:

$$\delta_{k0} \equiv \sum_{i=1}^{k} \Pr(v_k = i\sigma) = 1 - \Pr(v_k = 0). \tag{B5}$$

As δ decreases within the interval $[\delta_k, \delta_{k0})$ the optimal level of face value $D\sigma$ rises and the issuer's profit increases. In that region, the issuer's profit is higher than the proceeds from selling an equity stake on the pool. Unlike with an equity stake, there is no exclusion with the optimal debt security and all issuer types participate in the trade, although the higher types have to retain some exposure to the payoff in the form of a call option.

The analysis of the optimal decision to pool is analytically involved if we consider it for general levels of δ. Instead we focus below on the region of δ where efficient trade is possible and pooling is optimal (i.e., below the highest bound δ_k). Any asset or pool of assets can be characterized by this bound. The higher δ_k the larger the region where there is efficient trade. Note also that with competitive buyers δ_k depends only on the mean of distribution of v_k but not on the shape of its density. To see what implications this property has on the decision to pool we consider adding one asset to an already existing pool.

Adding an asset to the pool. Suppose the issuer hesitates between selling a pool of $k-1$ assets and selling a pool of k assets. The bounds allowing for efficient trade with the two candidate securities are related as follows:

$$\delta_k = \frac{\mathbb{E}[v_k]}{k} = \frac{k-1}{k}\delta_{k-1} + \frac{1}{k}\delta_1^k. \tag{B6}$$

The bound on the larger pool is the weighted average of the bounds for efficient trade of the existing pool δ_{k-1} and the additional asset δ_1^k. If the issuer adds an asset with the same mean payoff as the existing pool, the bound for the efficient trade of the pool does not change, as $\delta_k = \delta_{k-1}$. In particular, if the issuer pools assets with the same mean payoff, which might be less than perfectly correlated, δ_k is constant for all k. This means that pooling such assets when buyers are competitive does not harm trade efficiency, in a sense that the region of δ where trade is efficient does not change as k increases. If $\delta \leq \delta_1$ the decision to pool is optimal and remains so as long as the issuer adds assets to the pool without changing the mean payoff. This is in sharp contrast to the case with a monopolistic buyer, as we will see later.

If the additional asset added to the existing pool of assets has higher mean payoff than the average payoff of the assets already in the pool the bound increases. This means that the region of efficient trade and optimal pooling expands. To be more precise, if $\delta_1 > \delta_{k-1}$ then $\delta_k \in (\delta_{k-1}, \delta_1)$. If $\delta \in (\delta_{k-1}, \delta_k)$ the decision to add this asset to the existing pool is optimal since otherwise the trade would involve the sale of the optimal debt security on the existing pool, as $\delta > \delta_{k-1}$, and the efficient sale of the additional asset, as $\delta < \delta_1$. Pooling the additional asset increases the issuer's profit because he is able to sell all assets and does not require to use a debt security (which would result in the issuer retaining a call option).

The opposite is, however, true if the asset being added has a lower mean than the average asset payoff of the existing pool. If $\delta_1 < \delta_{k-1}$ then $\delta_k \in (\delta_1, \delta_{k-1})$. The benefit of pooling in this case is that it allows to sell the additional asset, which could not be sold separately. If $\delta \in (\delta_1, \delta_k)$ it is the only change in the issuer's payoff and it leads to an increase in the issuer's profit. However, if $\delta \in (\delta_k, \delta_{k-1})$, the impact of pooling on the issuer's profit is ambiguous, since in this region the issuer has to use the optimal debt security and retains some cash flows in the form of a call option.

B.1.2 Buyer with market power

Turning to the market where one buyer has market power, we derive analogous thresholds for the discount factor δ and determine how they change if some assets are added to the existing pool. Suppose first that the issuer offers an equity claim on the pool of k assets for sale and the buyer quotes $p_k = m\delta\sigma$, for $0 \leq m \leq k$. According to condition (8), the buyer's ex-ante profit can be written as:

$$\begin{aligned} B(m\delta\sigma) &= \Pr(v_k \leq m\sigma)(\mathbb{E}[v_k | v_k \leq m\sigma] - m\delta\sigma) \\ &= \sum_{i=0}^{m} \Pr(v_k = i\sigma)(i\sigma - m\delta\sigma). \end{aligned} \tag{B7}$$

Similarly, employing (9), the ex-ante profit to the issuer is:

$$\begin{aligned} S(m\delta\sigma) &= \Pr(v_k \leq m\sigma)(m\delta\sigma - \delta\,\mathbb{E}[v_k | v_k \leq m\sigma]) \\ &= \sum_{i=0}^{m} \Pr(v_k = i\sigma)(m\delta\sigma - i\delta\sigma). \end{aligned} \tag{B8}$$

Again, the issuer's profit increases with m, meaning that the issuer prefers to avoid being screened and to receive the highest possible offer: $p_k = k\delta\sigma$.

The buyer prefers a quote of $m\delta\sigma$ to a quote of $(m-1)\delta\sigma$ whenever $B(m\delta\sigma) - B((m-1)\delta\sigma) \geq 0$.

From equation (B7), this condition is equivalent to:

$$\begin{aligned}
0 &\leq \sum_{i=0}^{m} \Pr(v_k = i\sigma)(i\sigma - m\delta\sigma) - \sum_{i=0}^{m-1} \Pr(v_k = i\sigma)(i\sigma - (m-1)\delta\sigma) \\
&= \Pr(v_k = m\sigma)(m\sigma - m\delta\sigma) - \sum_{i=0}^{m-1} \Pr(v_k = i\sigma)\delta\sigma \\
&= \Pr(v_k = m\sigma)m(1-\delta)\sigma - \Pr(v_k \leq (m-1)\sigma)\delta\sigma. \qquad \text{(B9)}
\end{aligned}$$

Again, the above inequality can be written as a threshold on the discount factor:

$$\delta \leq \bar{\delta}_{km} \equiv \frac{m \Pr(v_k = m\sigma)}{\Pr(v_k \leq (m-1)\sigma) + m \Pr(v_k = m\sigma)}. \qquad \text{(B10)}$$

The buyer prefers to quote the highest quote $p_k = k\delta\sigma$ whenever $B(m\delta\sigma) - B((m-1)\delta\sigma) \geq 0$ for $\forall m \in \{1, \ldots, k\}$. For tractability, we restrict our attention to distributions for which $\frac{m \Pr(v_k = m\sigma)}{\Pr(v_k \leq (m-1)\sigma)}$ monotonically declines with m, resulting into decreasing $\bar{\delta}_{km}$.[9]

Therefore, the m inequalities reduce to one condition $B(k\sigma) - B((k-1)\sigma) \geq 0$ which, according to equation (9), can be written as:

$$\delta \leq \bar{\delta}_{kk} \equiv \bar{\delta}_k \equiv \frac{k \Pr(v_k = k\sigma)}{1 + (k-1)\Pr(v_k = k\sigma)}. \qquad \text{(B11)}$$

This is the highest value of δ for which screening is not profitable and trade can thus be efficient. Before conducting an analysis on how the thresholds change with the size of the pool, we consider issuing debt on the pool. Debt can improve the issuer's ex-ante profits whenever an equity claim on the same pool would end up being screened by the issuer. For a face value of debt $D\sigma$, the whole issue is sold when the buyer offers $p_k^D = D\delta\sigma$ as every issuer type values the issue at most at $D\delta\sigma$. If the buyer instead makes a lower offer, the outcome becomes equivalent to the screened sale of equity with higher issuer types refusing to trade. If $D \in (m-1, m]$ for $0 \leq m \leq k$ and the buyer offers $D\delta\sigma$ then his ex-ante profit is:

$$\begin{aligned}
B(D\delta\sigma) &= \Pr(v_k^D \leq D\sigma)(\mathbb{E}[v_k^D | v_k^D \leq D\sigma] - D\delta\sigma) \\
&= \sum_{i=0}^{m-1} \Pr(v_k = i\sigma)(i\sigma) + \sum_{i=m}^{k} \Pr(v_k = i\sigma)(D\sigma) - D\delta\sigma, \qquad \text{(B12)}
\end{aligned}$$

[9] This restriction is satisfied, for example, if $q_i = 1/2$ for all assets but can be violated for some different q_i.

while the issuer's profit is:

$$\begin{aligned} S(D\delta\sigma) &= \Pr(v_k^D \leq D\sigma)(D\delta\sigma - \delta\,\mathbb{E}[v_k^D | v_k^D \leq D\sigma]) \\ &= \delta \sum_{i=0}^{m-1} \Pr(v_k = i\sigma)(D\sigma - i\sigma). \end{aligned} \tag{B13}$$

Note that the issuer prefers to sell debt with higher face value d. As before, a debt security with $D \in (0,1)$ is suboptimal. Moreover, the boundary above which no trade occurs (i.e., $\bar{\delta}_{k0}$) is the same as with competitive buyers.

For any other $\delta \in [\bar{\delta}_k, \bar{\delta}_{k0})$ the optimal level of the face value of debt $D \in (1,k]$ increases as δ decreases. In particular, if $\delta \in (\bar{\delta}_{k(m+1)}, \bar{\delta}_{km}]$ the optimal value of d makes the buyer indifferent between the two options: (i) not screening, paying $\delta D\sigma$ for the debt security, and receiving a profit of $B(D\delta\sigma)$, and (ii) optimally screening, offering a price of $\delta m\sigma$, and receiving a profit of $B(m\delta\sigma)$. It can be shown that the optimal face value $d > m$ and the condition $B(D\delta\sigma) = B(m\delta\sigma)$ pins down its level. Moreover if $m = k-1$, i.e. $\delta \in (\bar{\delta}_{kk}, \bar{\delta}_{k(k-1)}]$, the optimal $D \in (k-1,k) = (m, m+1)$. However, if $m < k-1$ it might be the case that $d > m+1$.

As with competitive buyers, we will now focus on the region of δ where efficient trade is possible and pooling is optimal (i.e., below the highest bound $\bar{\delta}_k$). Any asset or pool of assets can be characterized by this bound. The higher $\bar{\delta}_k$ the more likely it is that there is trade without screening. Note also that unlike with competitive buyers, $\bar{\delta}_k$ depends on the shape of the distribution of v_k, in particular, on its density in the tail. To see how this property changes the optimal decision to pool relative to a market with competitive buyers we consider the same application as in the previous section, namely the addition of one asset to an existing pool.

Adding an asset to the pool. Suppose the issuer hesitates between selling a pool of $k-1$ assets and selling a pool of k assets. The first pool is characterized by a threshold $\bar{\delta}_{k-1}$ and the larger pool is characterized by $\bar{\delta}_k$. Using definition in (B11), we can identify conditions when $\bar{\delta}_{k-1} < \bar{\delta}_k$ in the following way:

$$\frac{(k-1)\Pr(v_{k-1} = (k-1)\sigma)}{1 + (k-2)Pr(v_{k-1} = (k-1)\sigma)} < \frac{kPr(v_k = k\sigma)}{1 + (k-1)\Pr(v_k = k\sigma)} \tag{B14}$$

$$\Leftrightarrow (k-1)\Pr(v_{k-1} = (k-1)\sigma) + \Pr(v_k = k\sigma)\Pr(v_{k-1} = (k-1)\sigma) < k\Pr(v_k = k\sigma).$$

Since $\Pr(v_{k-1} = (k-1)\sigma) = \Pr(v_k = k\sigma) + \Pr(v_{k-1} = (k-1)\sigma, \varphi_k = 0)$, the above becomes:

$$(k-1)\Pr(v_{k-1} = (k-1)\sigma, \varphi_k = 0) < \Pr(v_k = k\sigma)(1 - \Pr(v_{k-1} = (k-1)\sigma)) \tag{B15}$$

$$\Leftrightarrow (k-1)\frac{\Pr(v_{k-1} = (k-1)\sigma, \varphi_k = 0)}{\Pr(v_k = k\sigma)(1 - \Pr(v_{k-1} = (k-1)\sigma))} < 1. \tag{B16}$$

If this condition is satisfied, we know that the threshold for the pool with the additional asset to be traded efficiently (i.e., $\bar{\delta}_k$) is higher than the threshold for the existing pool to be traded efficiently (i.e., $\bar{\delta}_{k-1}$). Intuitively, adding one more asset to the existing pool of assets is beneficial, in terms of reducing the region with screening, whenever assets in the current pool are relatively bad, $1 - \Pr(v_{k-1} = (k-1)\sigma)$ is high, or the additional asset $\sigma\varphi_k$ is relatively good, $\frac{\Pr(v_{k-1}=(k-1)\sigma, \varphi_k=0)}{\Pr(v_k=k\sigma)}$ is low.

B.1.3 Simple parametric example

We illustrate our general result with the following example where assets have the same quality ex ante: $\varphi_i \sim Ber(1-q)$. Then condition (B16) simplifies to:

$$(k-1)\frac{q(1-q)^{k-1}}{(1-q)^k(1-(1-q)^{k-1})} < 1. \tag{B17}$$

Using a Taylor series expansion this expression reduces to:

$$(k-1)\frac{q}{(1-q)} < 1 - (1 - (k-1)q) \tag{B18}$$

$$\Leftrightarrow \frac{1}{1-q} < 1. \tag{B19}$$

This inequality never holds and adding one more asset to the pool reduces the region of efficient trade, as the corresponding threshold decreases, $\bar{\delta}_k < \bar{\delta}_{k-1}$. This is in sharp contrast with the case of competitive buyers where even pooling assets with the same mean is harmless in terms of efficiency. Since with a monopolistic buyer the threshold $\bar{\delta}_k$ decreases with k the issuer might prefer to avoid creating one large pool of assets and might instead want to create several smaller pools to sell them separately. For example, if $\delta \in (\bar{\delta}_k, \bar{\delta}_{k/2}]$ the issuer can increase his ex-ante profits by selling two same-size parts of one large pool separately. Since the large pool is screened by the buyer, the issuer has to use the optimal debt security and has to retain some exposure. In contrast, the separate sales of each part are not screened and using equity securities on the smaller pools allows the issuer to sell all assets. Figure 5 illustrates this situation.

Figure 5: In the parameter region highlighted in red the separate sale of the two halves of the pool is strictly more profitable than the sale of the debt on the pool.

Moreover, the threshold for the resulting pool may be lower not only in the special case with independent identical assets. Suppose the issuer has two assets which can be sold separately. If sold separately, these assets are characterized then by $\bar{\delta}_1^1$ and $\bar{\delta}_1^2$ but as a pool they are characterized by $\bar{\delta}_2$. If $\bar{\delta}_1^1 < \bar{\delta}_2$ there is a region of gains from trade where a sale of individual asset is screened while a sale of a pool is not. According to (B11), $\bar{\delta}_1^1 < \bar{\delta}_2$ implies:

$$\frac{\Pr(v_1 = \sigma)}{1 + (1-1)\Pr(v_1 = \sigma)} < \frac{2\Pr(v_2 = 2\sigma)}{1 + (2-1)\Pr(v_2 = 2\sigma)}, \tag{B20}$$

or equivalently,

$$\Pr(v_1 = \sigma) - 2\Pr(v_2 = 2\sigma) + \Pr(v_2 = 2\sigma)\Pr(v_1 = \sigma) < 0. \tag{B21}$$

The above condition holds for the general case and allows for arbitrary correlations between the two assets. However, to illustrate the point, we can assume that assets φ_i are independent. Then (B21) reduces to $1 - 2(1-q_2) + (1-q_1)(1-q_2) < 0$ or

$$\frac{q_2}{1-q_2} < q_1. \tag{B22}$$

The threshold for the resulting pool $\bar{\delta}_2$ is higher than the threshold for the first asset $\bar{\delta}_1^1 = 1 - q_1$ when q_1 is sufficiently high, while q_2 is relatively low which means that the first asset should be "bad" while the second added asset should be "good." Note that in a market with a monopolistic buyer the required quality of a "good" asset should be higher than in a market with competitive buyers where the condition was that the first asset's mean is lower than that of the second asset $q_2 < q_1$. With the monopolistic buyer, it is not enough to add an asset that is simply better, this asset needs to be sufficiently better. As a result, if the two added assets are similar in quality, that is, they do not differ much in the means, the threshold for the pool is lower than both thresholds for the individual assets and consequently there is a region $\delta \in [\bar{\delta}_2, \min\{\bar{\delta}_1^1, \bar{\delta}_1^2\}]$ where pooling is not optimal and the separate sale of the assets strictly dominates the sale of equity or debt on the pool.

B.2 Buyers with constraint on risk units

We consider an extension of the model with a finite number of buyers who are constrained by their position limits. In this section, the position limit is a constraint on the number of risk units a buyer can take where a risk unit is defined as any security with a maximum cash flow of 1. We suppose that the total position limit across all buyers is less than or equal to the total supply offered by the issuer. We show that in this case the issuer's optimal decision to pool assets is similar to the case of one buyer.

Instead of one monopolistic buyer, we now assume that there are two deep-pocketed buyers, each with a discount factor of 1, who have position limits of one risk unit each. Therefore, the two buyers cannot buy more than two risk units in total. The seller, as before, has two assets with binomial cash flows. This implies that two risk units can be sold by either selling two assets separately or by selling two identical halves — shares of a pool of the two assets. We also assume that buyers submit quotes for both risk units and the seller picks up the best quotes. If the two buyers submit the same quote for a unit the seller allocates it to one of them randomly with equal probabilities.

If the assets are ex-ante identical the seller must choose between offering each asset separately or two halves of a pool containing both assets. In this case each unit is sold separately as if to a monopolistic buyer since it is not optimal for one buyer to undercut the other buyer. Offering slightly higher price than monopolistic for any unit would only result in a trade of this unit, one of the two identical units that could have been obtained by quoting monopolistic price. Formally, there are several equilibria with the buyers quoting monopolistic price for one or both units which differ only in outcomes of buyer-unit matches.

If the seller has more than two assets there are more than two risk units. Thus, some of them are retained while the pricing of the two sold units is the same as above. Therefore, when the total number of risk units demanded is lower than the supplied one the constrained buyers quote the same prices as the monopolist buyer would. Thus, the optimal pooling decision of the issuer does not change compared to the case of one buyer with full market power.

Assets of different quality. If the assets are ex-ante different a new situation arises when the issuer decides to sell assets separately. Now, the risk units are different and the asset with a better quality (i.e., higher expected cash flow) is not priced as in the monopolistic buyer case. Assume the contrary, then by offering slightly higher price than the monopolistic price, a buyer can get the better asset which results into higher profits than the purchase of the lower quality asset for the monopolist price. The last result is due to the fact that the monopolist buyer profits are higher for the the higher quality asset. The buyers keep increasing bids for the higher quality asset until the profit obtained from its purchase is equal to the monopolist buyer's profit from the purchase of the lower quality asset. Therefore, the separate sale of assets of different quality to constrained buyers increases the issuer's profits compared to the monopolist buyer case. Consequently, if the separate sale is preferred by the issuer facing a monopolist buyer it is also preferred when facing buyers with position limits.

Formally, suppose as before that asset payoffs are $v_1^i = \varphi_i \sigma$ where $\varphi_i \sim Ber(1-q_i)$ for $i = 1, 2$. Then in the monopolist buyer case an asset i is traded if $\delta \leq 1 - q_i$ and the profits of the seller and the buyer are

$$S_i(p_i) = q_i p_i = q_i \delta \sigma \tag{B23}$$

$$B_i(p_i) = (1-q_i)\sigma - p_i = (1-q_i)\sigma - \delta\sigma \tag{B24}$$

where $p_i = \delta\sigma$ is the efficient price. Assume that $q_1 < q_2$ and both assets can be traded efficiently, i.e. $\delta < 1 - q_2$, then $B_1(p_1) > B_2(p_2)$. If the seller allocates the better quality asset first without considering the quotes for another asset any equilibrium must satisfy the following two properties. First, the profit obtained from the lower quality asset is equal to the monopolist case profit as it can be guaranteed by quoting monopolist price for this asset and zero for the first asset. Second, the buyers' profits obtained from the two assets are equal since otherwise a buyer would either withdraw from competition for the first asset or slightly undercut the competitor. Therefore, the competition for the high quality asset in the case of the two constrained buyers increases the price $\tilde{p}_1$ offered for this asset until $B_1(\tilde{p}_1) = B_2(p_2)$ or

$$(1-q_1)\sigma - \tilde{p}_1 = (1-q_2)\sigma - p_2. \tag{B25}$$

Consequently, the price offered for this asset is $\tilde{p}_1 = \delta\sigma + (q_2 - q_1)\sigma$ while the total profit of the seller is

$$S = \delta(q_1 + q_2)\sigma + (q_2 - q_1)\sigma. \tag{B26}$$

The last term is the increase in the issuer's profits compared to the monopolistic buyer case.

If only the high quality asset can be traded, i.e., $1 - q_2 < \delta < 1 - q_1$, the situation becomes equivalent to the case of competitive buyers and one asset. Therefore, the quoted price is $p_1 = (1 - q_1)\sigma$, the buyers' profits are $B = 0$ while the seller's profit is $S = (1 - \delta)(1 - q_1)\sigma$. Finally, if $1 - q_1 < \delta$ no asset is traded.

The analysis illustrates another reason why the separate sale of assets might be beneficial to the issuer in the presence of several buyers with position limits on risk units. If assets are of different quality buyers compete for the assets of higher quality to fill their limits and that increases the issuer's profits compared to the monopolistic buyer case. In contrast, when the issuer sells homogeneous shares on the pool of the assets buyers with position limits do not compete and quote the monopolist buyer prices. Therefore, the region where the separate sale is preferred by the issuer is larger in the case of several constrained buyers compared to the case of a single buyer with full market power. In the former case this region is $\delta \in [0, \min\{\bar{\delta}_1^1, \bar{\delta}_1^2\}]$ while in the later case it is $\delta \in [\bar{\delta}_{22}, \min\{\bar{\delta}_1^1, \bar{\delta}_1^2\}]$.

B.3 Buyers with constraint on wealth

In this section, we consider the same extension of the model with two constrained buyers except that now the constraint is in terms of a buyer's wealth w. This constraint limits a buyer's quotes as we assume that their sum cannot be greater than his wealth w.[10] Suppose the seller has two identical assets characterized by the parameter q and creates two risk units as before, by either selling them separately or selling two identical shares issued on the pool of the two assets. We focus on the interval for the discount factor δ where in the monopolistic buyer case the assets can be traded efficiently separately but the efficient trade breaks down when they are sold in a pool, $\Delta = [\bar{\delta}_{22}, \bar{\delta}_1^1]$.

Selling separately. First, we analyze the case where the assets are sold separately. In region Δ, the monopolist buyer quotes the efficient price $\delta\sigma$ for each asset. Offering any price below this price results in a negative profit since such offer is rejected by the seller with positive cash flows. Therefore, if a buyer's wealth is constrained as: $\delta\sigma \leq w < 2\delta\sigma$, each buyer quotes $\delta\sigma$ for one of the assets and the outcome is the same as in the case of the risk unit constrained buyers. If a

[10]The constraint can be motivated by a requirement to post a collateral for a quote. Such constraint might also result from a model with a large punishment imposed on a buyer who cannot fulfill his quotes.

buyer's wealth is higher, $2\delta\sigma \leq w \leq 2(1-q)\sigma$, they compete for the assets and bid half of their wealth, $\frac{w}{2}$, for each asset while the profits are non-negative. There is no profitable deviation since undercutting on one asset results in a surrender of the other asset. The expected profit from each asset is then given by $B_i = \frac{1}{2}((1-q)\sigma - \frac{w}{2})$. Thus, when assets are sold separately and a buyer's wealth is in the region $\delta\sigma \leq w < 2\delta\sigma$ the quoted price is the same as in the monopolist buyer case and assets are sold efficiently.

Pooling. Now we consider the case when assets are pooled. From the baseline model we know that in the monopolist buyer case the profit from quoting a price $p \geq 2\delta\sigma$ is $B_2(p) = 2(1-q)\sigma - p$, the profit from quoting a price $\delta\sigma \leq p < 2\delta\sigma$ is $B_1(p) = 2(q-q^2)\sigma - (2q-q^2)p$ and the profit from quoting any price below $\delta\sigma$ is negative since it is rejected by any seller with a positive cashflow. Consequently, in Δ the monopolist buyer quotes the inefficient, low price $\delta\sigma$ for the pool since the profit from quoting the efficient price $2\delta\sigma$ is lower, $B_1(\delta\sigma) > B_2(2\delta\sigma)$. It can also be noted that if the monopolist buyer is offered one of the two identical halves of the pool he simply quotes half of his optimal price for the whole pool.

Therefore in Δ, if $\frac{1}{2}\delta\sigma \leq w < \delta\sigma$ the two buyers quote $\frac{1}{2}\delta\sigma$ for different units and the outcome is the same as in the case of the monopolistic buyer. If $w \geq \delta\sigma$ instead the buyers must compete for the units. If the buyers' wealth w is slightly higher than $\delta\sigma$ they bid half of their wealth, $\frac{w}{2}$, for each unit. This is the equilibrium for $\delta\sigma \leq w \leq p_0$ where p_0 is given by $B_1(p_0) = B_2(2\delta\sigma)$, the inefficient low price that yields to the monopolist buyer the same profit as the efficient price. The expected profit from each unit is then equal to $B_i = \frac{1}{2}((q-q^2)\sigma - (2q-q^2)\frac{w}{2})$. As above, there is no profitable deviation since undercutting on one asset results in a surrender of the other asset.

Due to the discrete nature of the assets' cash flows there is no equilibrium for the values of wealth in the region $p_0 < w < \frac{p_0}{2} + \delta\sigma$ as a buyer has always an option to quote the price $\delta\sigma$. If $\frac{p_0}{2} + \delta\sigma \leq w < 2\delta\sigma$ the buyers quote a high price $\delta\sigma$ for one unit, each buyer for different unit, and a low price $w - \delta\sigma$ for another. Compared to the previous region, there is enough wealth to both win one unit by quoting the price $\delta\sigma$ and to deter deviations by the other buyer. In the equilibrium both units are sold efficiently. Finally, if $2\delta\sigma \leq w \leq 2(1-q)\sigma$ the buyers quote half of their wealth, $\frac{w}{2}$, for each unit while the profits are non-negative. The expected profit from each unit is then given by $B_i = \frac{1}{2}((1-q)\sigma - \frac{w}{2})$.

Overall, comparing the outcomes in the cases of the separate sales and the pooling, when $\delta \in \Delta$ and $\delta\sigma \leq w < 2\delta\sigma$, we can see that separate sales yield efficient outcomes while the sale in the pooling case is inefficient when $\delta\sigma \leq w < \frac{p_0}{2} + \delta\sigma$. Therefore, the main conclusion that the pooling might be inefficient compared to the separate sales holds if the buyers' wealth is sufficiently constrained.

References

Atkeson, Andrew G, Andrea L Eisfeldt, and Pierre-Olivier Weill. 2012. "The Market for OTC Credit Derivatives." UCLA Working Paper.

Axelson, Ulf. 2007. "Security Design with Investor Private Information." *The Journal of Finance* 62 (6), 2587-2632.

Begenau, Juliane, Monika Piazzesi, and Martin Schneider. 2015. "Banks' Risk Exposures." NBER Working Paper.

Biais, Bruno and Thomas Mariotti. 2005. "Strategic Liquidity Supply and Security Design." *The Review of Economic Studies* 72 (3), 615-649.

Cetorelli, Nicola, Beverly Hirtle, Donald P Morgan, Stavros Peristiani, and Joao AC Santos. 2007. "Trends in Financial Market Concentration and their Implications for Market Stability." *Economic Policy Review* 13 (1).

Dang, Tri Vi, Gary Gorton, and Bengt Holmstrom. 2015. "The Information Sensitivity of a Security." NBER Working Paper.

DeMarzo, Peter and Darrell Duffie. 1999. "A Liquidity-Based Model of Security Design." *Econometrica* 67 (1), 65-99.

DeMarzo, Peter M. 2005. "The Pooling and Tranching of Securities: A Model of Informed Intermediation." *Review of Financial Studies* 18 (1), 1-35.

Di Maggio, Marco, Amir Kermani, and Zhaogang Song. 2017. "The Value of Trading Relations in Turbulent Times." *Journal of Financial Economics* 124 (2), 266-284.

Farhi, Emmanuel and Jean Tirole. 2015. "Liquid Bundles." *Journal of Economic Theory* 158, 634-655.

Glode, Vincent, Christian C. Opp, and Xingtan Zhang. 2018. "Voluntary Disclosure in Bilateral Transactions." *Journal of Economic Theory,* forthcoming.

Hartman-Glaser, Barney. 2017. "Reputation and Signaling in Asset Sales." *Journal of Financial Economics* 125, 245-265.

Hendershott, Terrence, Dan Li, Dmitry Livdan, and Norman Schürhoff. 2015. "Relationship Trading in OTC Markets." Working Paper, Swiss Finance Institute.

Leland, Hayne E and David H Pyle. 1977. "Informational Asymmetries, Financial Structure, and Financial Intermediation." *The Journal of Finance* 32 (2), 371-387.

Li, Dan, and Norman Schürhoff. 2014. "Dealer Networks." Working Paper, Swiss Finance Institute.

Siriwardane, Emil. 2017. "Limited Investment Capital and Credit Spreads." *Journal of Finance*, forthcoming.

Williams, Basil. 2016. "Search, Liquidity, and Retention: Signaling Multidimensional Private Information." Working Paper, New York University.