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

Vincent Glode, Christian Opp, and Ruslan Sverchkov *

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Abstract

We study the decision to pool assets for a privately informed issuer attempting to sell securities to liquidity suppliers endowed with market power, as is often the case in over-the-counter markets. Contrary to what has been shown for competitive markets, issuing debt on a pool of assets becomes suboptimal in our environment when the potential gains from trade are large. In those cases, selling assets separately reduces the inefficient rationing that is typical in environments with market power. Our results can shed light on recently observed time-variation in the prevalence of pooling in financial markets.

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1 Introduction

Structured products are typically originated in over-the-counter (OTC) markets, where asymmetric information and market power have been shown to be prevalent frictions.[1] Their issuers may occasionally face prices that are not fully competitive as only a few financial institutions are well-positioned to acquire new securities; for example, as most institutions are subject to similar regulatory constraints, their holding costs might increase at the same time. Motivated by these observations, we study the security design problem of a privately informed issuer who possesses multiple assets and seeks liquidity from liquidity suppliers, or buyers, endowed with market power.

Our analysis reveals how the allocation of market power has relevant and robust implications for security design that contrast with the takeaways from models featuring competitive environments. In our setting, pooling all assets into one security is optimal for the issuer when facing competitive buyers, echoing the results of the existing literature (e.g., DeMarzo 2005). As diversification reduces an issuer's informational advantage, pooling assets helps alleviate adverse selection problems, which is in the interest of the issuer when prices are set competitively — in this case, the issuer fully internalizes the benefits of improving the efficiency of trade.

In contrast, when an issuer receives non-competitive offers for his securities, pooling assets still has the advantage of reducing adverse selection concerns, but it now comes at a cost, namely, a potential reduction in the issuer's information rents. Counter to conventional wisdom, an issuer may prefer not to pool assets, especially when the potential gains from trade are large relative to the information asymmetry between the issuer and prospec-

[1] For evidence that OTC trading often involves heterogeneously informed traders, see Green, Hollifield, and Schürhoff (2007), Jiang and Sun (2015), and Hollifield, Neklyudov, and Spatt (2017). For evidence that OTC trading tends to be concentrated among a small set of players, see Cetorelli et al. (2007), Atkeson, Eisfeldt, and Weill (2014), Begenau, Piazzesi, and Schneider (2015), Di Maggio, Kermani, and Song (2017), Hendershott et al. (2017), Li and Schürhoff (2019), and Siriwardane (2019).

tive buyers. In fact, any pooling decision that achieves perfect diversification is *never* optimal for an issuer facing market power on the demand side. We provide explicit, sufficient conditions under which the issuer's best option is to simply sell all assets separately. Under these conditions the issuer is strictly worse off when pooling assets, as diversification invites strategic buyers with market power to choose pricing strategies that lead to inefficient rationing and lower rents for the issuer. Pooling assets is then suboptimal for the issuer and for society. As pooling affects the *shape* of the distributions characterizing information asymmetries between issuers and buyers, it alters how elastically trade volume responds to prices, which is crucial in settings with market power. In particular, pooling generally worsens inefficient rationing when selling assets separately is already "fairly efficient."[2] Diversification makes the distribution characterizing the information asymmetry between agents have thinner tails, which, in turn, leads to less elastic trade volume in the right tail of the distribution and greater rationing in equilibrium.

Our results highlight how in recent years liquidity shortages among major institutions participating in OTC markets might have been an important driver of the dramatic declines in asset-backed security (ABS) issuances, which occurred concurrently with an increase in the volume of assets sold separately.[3] Our analysis shows that, when liquidity becomes scarce, the benefits of pooling assets highlighted in the literature can be swamped by an associated increase in the severity of market power problems. In periods of scarce liquidity, the benefits from unloading the assets are typically large for the issuer, but the few traders with excess liquidity gain market power. These two conditions, when combined, boost the relative benefits of the separate sale of assets versus the issuance of pooled securities — in

[2]Technically, this situation arises either if there is no exclusion of buyer types or if the exclusion only pertains to a relatively small subset of buyer types in the right tail of the distribution.

[3]In 2015, issuance volume of ABS in the U.S. was 60% lower than it was in 2006, while the issuance volume of CDO was 80% lower. In contrast, the total issuance volume in fixed income markets was 3% higher in 2015 than in 2006. For more data, see the Securities Industry and Financial Markets Association: http://www.sifma.org/research/statistics.aspx.

that sense, it is during periods when trade is most valuable (due to liquidity problems), yet difficult to implement (due to imperfect competition) that our novel insights become most relevant. Relatedly, our paper sheds light on the consequences of regulating the liquidity of financial institutions that are typically on the buy side of the structured securities market.

Early contributions by Subrahmanyam (1991), Boot and Thakor (1993), and Gorton and Pennacchi (1993) have emphasized the diversification benefits of pooling assets when securities are sold in competitive/centralized markets plagued by asymmetric information problems. Our paper focuses on the impact of market power on the decision to pool assets and derives novel insights that shed light on the securities issued in decentralized markets. The two papers closest to ours are DeMarzo (2005) and Biais and Mariotti (2005). Specifically, our focus on the decision to pool assets relates our analysis to DeMarzo (2005) who builds on the signaling-through-retention framework with price-taking buyers of DeMarzo and Duffie (1999) and shows that the pooling of assets dampens an issuer's ability to signal individual assets' quality through retention. However, when the number of assets is large and the issuer can sell debt on the pool of assets, this "information destruction effect" is dominated by the above-mentioned benefits of diversifying the risks associated with the issuer's private information about each asset's value. Issuing debt on a large pool of assets reduces residual risks and the information sensitivity of the security being issued.[4] In contrast to DeMarzo (2005) whose setup can be thought of as a centralized market where (price-taking) buyers compete for the asset, we consider the case of an issuer who faces a demand side endowed with market power, capturing a realistic feature of many over-the-counter markets.

Our focus on the role played by market power in an issuer's security design decision relates our analysis to Biais and Mariotti (2005) who analyze a model where the security

[4]See also Hartman-Glaser, Piskorski, and Tchistyi (2012) who model a moral hazard problem between a principal and a mortgage issuer and show that the optimal contract features pooling of mortgages with independent defaults, as it facilitates effort monitoring.

design stage is followed by a stage where either the issuer or the prospective buyer chooses a trading mechanism (i.e., a price-quantity menu) for selling the designed security. Their paper shows that in both cases issuers with bad assets participate in the market, whereas high-quality issuers might not (despite the presence of gains to trade). In particular, when the buyer can choose the trading mechanism, he effectively screens the issuer, trading off higher volume with lower issuer participation. In contrast, when the issuer can choose the mechanism, the setup becomes 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 avoid market exclusion.[5] However, unlike our paper, Biais and Mariotti (2005) only consider the case of an issuer wishing to sell one asset, thus their analysis is silent about the decision to pool multiple assets into one security.

Axelson (2007) studies an uninformed issuer's decision to design securities that are (centrally) traded in a uniform price auction with privately informed buyers. Axelson (2007) finds that pooling assets and issuing debt on these assets is always optimal when the number of assets is large, otherwise selling assets separately might be optimal if the signal distribution is discrete and competition is high enough. Since the issuer is uninformed and buyers compete for assets through an auction, Axelson's (2007) analysis is silent about how security design can be used to prevent being monopolistically screened by liquidity providers, which is the main focus of our paper.[6]

Palfrey (1983) analyzes a firm's decision to bundle products (or assets) sold in a second-

[5]Gorton and Pennacchi (1990), Dang, Gorton, and Holmstrom (2015), Farhi and Tirole (2015), and Yang (2019) also study the optimal information sensitivity of securities issued in markets with asymmetric information, These papers highlight the benefits of designing securities that split cash-flows into an information-sensitive part and a risk-less part. These papers are, however, silent about how pooling imperfectly correlated assets affects the issuer's ability to extract surplus when facing buyers with market power, which is the focus of our paper.

[6]See also DeMarzo, Kremer, and Skrzypacz (2005) and Inderst and Mueller (2006) who study optimal security design problems with informed buyers and only one asset.

price auction. In his model, customers have private information about their heterogenous valuations for the products. Selling the products separately is optimal when the sum of the expected second-highest valuation for each product is higher than the expected second-highest valuation for the bundle of all products. This comparison depends on the number of prospective customers and the distribution of their product-specific valuations. Instead, we vary the degree of competition among buyers who share the same valuation for the assets being sold and the cross-buyer heterogeneity in valuations that is central for Palfrey's (1983) results plays no role in our analysis.

In the next section, we describe the environment of our model and discuss an illustrative example where the issuer sells a pool of a continuum of assets. This example highlights that the presence of market power on the demand side greatly affects the issuer's benefits from pooling assets. Section 3 presents our main analysis of both a competitive market and one with market power. Section 4 discusses the robustness of our results to various alternative specifications of the environment. The last section concludes.

2 The Environment

Suppose an issuer has $n \geq 2$ fundamental assets to sell. These assets are indexed by i and the set of all these assets is denoted by $\Omega \equiv \{1, ..., n\}$. Each asset i produces a random payoff X_i at the end of the period. The assets' payoffs X_i are assumed to be identically and independently distributed according to the cumulative distribution function (CDF) $G(\cdot)$ with a probability density function (PDF) $g(\cdot)$ that is positive everywhere on its domain $\chi \equiv [0, \bar{x}]$.[7]

Market participants and their liquidity needs. As is common in the security design litera-

[7]The necessary condition for our results is that assets' payoffs are not perfectly correlated as the analysis can be generalized to the case where assets' payoffs exhibit some correlation.

ture, all agents are risk neutral and differential liquidity (or hedging) needs across traders are captured through different discount factors. In the analysis that follows, we will study and compare two (polar) market scenarios to highlight the importance of market power in the decision whether to pool assets.

In the first scenario, we assume that *several* deep-pocketed traders are better equipped to hold claims to future cash-flows than the issuer is (who needs liquidity today). Whereas the issuer applies a discount factor $\delta \in (0, 1)$ on future cash-flows, these prospective buyers apply a discount factor of 1. Thus, the ex ante private value of each fundamental asset is $\delta\, \mathbb{E}(X_i)$ for the issuer and $\mathbb{E}(X_i)$ for a buyer with good liquidity. As a result, there are gains from transferring the issuer's assets to such a buyer in exchange for cash now. Since there are multiple buyers who value assets more than the issuer in this scenario, these buyers bid competitively for the securities being sold by the issuer.

In the second scenario, we assume that only one buyer is better equipped to hold claims to future cash-flows than the issuer is; that is, only one buyer has a discount factor of 1. In this case, the one buyer with a superior liquidity position has market power; he is the only one bidding for the issuer's securities.[8] This scenario captures the idea that in some time periods when most potential counterparties in the market face similar regulatory constraints or liquidity needs as the issuer. For both scenarios, we will occasionally refer to the prospective buyers with a discount factor of 1 as "liquidity suppliers" (in line with the literature; see, e.g., Biais and Mariotti 2005).

Timing and information structure. We follow the existing literature (see, e.g., DeMarzo and Duffie 1999, Biais and Mariotti 2005) in the specification of the timing of the security design and trading game. First, the issuer designs the securities he plans to sell. Second, the issuer becomes informed about the realizations of each asset payoff X_i. Third, the

[8] Going forward, we will refer to this scenario as monopolistic demand or monopolistic liquidity supply. In this context, the buyer can also be referred to as a monopsonist.

buyer(s) make(s) take-it-or-leave offers to the issuer. Fourth, the issuer decides whether or not to accept any of these offer(s) in exchange for the securities; if multiple buyers offer an identical price that is accepted by the issuer, the security is randomly allocated among the highest bidders. Finally, all payoffs are realized.

Assuming that the issuer does not have private information at the initial security design stage increases the tractability of the analysis and shares similarities with the shelf registration process commonly used in practice (as also argued by DeMarzo and Duffie 1999, Biais and Mariotti 2005). In that process, issuers first specify and register with the SEC the securities they intend to issue. Then, potentially after several months, issuers bring these securities to the market. In the meantime, the issuer has typically obtained additional private information about future cash-flows, which allows for informed trading behavior. In Section 4, we discuss the robustness of our the main insights to changes in our timeline that would introduce signaling complications at the security design stage.

An illustrative example. Before proceeding with our main analysis, we present a simple, yet generic example that illustrates how the issuer's benefits from pooling assets crucially depend on the allocation of market power. Suppose the issuer owns a continuum of assets of measure one with i.i.d. payoffs X_i with finite mean and variance. The issuer considers pooling all assets and offering to sell this pool to the buyer(s).

First, we analyze the market scenario in which multiple prospective buyers have abundant liquidity (that is, they have a discount factor equal to one). In this case, buyers effectively compete in quotes à la Bertrand and offer a price that is equal to the expected security payoff conditional on the issuer accepting the offer. When the issuer tries to sell the assets as one pool, the law of large numbers applies, that is, perfect diversification implies that the pool's payoff is $\int_0^1 x_i di = \mathbb{E}[X_i]$ almost surely. As a result, adverse selection concerns are completely eliminated, and the competitive buyers offer a price $\hat{p} = \mathbb{E}[X_i]$ for this pool.

The maximum total surplus from trade, $\mathbb{E}[X_i] \cdot (1 - \delta)$, is attained and the issuer fully internalizes this surplus. That is, the issuer achieves the optimal expected payoff. The fact that pooling the continuum of assets eliminates information asymmetries is unambiguously beneficial when facing competitive buyers, as the issuer then fully internalizes the resultant improvements in trade efficiency (see also Theorem 5 in DeMarzo 2005).

In contrast, we now analyze the market scenario in which only one prospective buyer has liquidity to purchase the issuer's assets (i.e., only one buyer has a discount factor of 1). Acting as a de-facto monopolist, this buyer can choose the price that maximizes his expected payoff. In this case, this optimally chosen price is the issuer's reservation price for the pool of assets, that is, $p^* = \mathbb{E}[X_i]\delta$. As in the scenario with multiple prospective buyers, pooling the continuum of assets yields perfect diversification and eliminates adverse selection concerns. Yet, now that the demand side has market power, fully eliminating these information asymmetries has *no upside* for the issuer. Facing no informational disadvantage, the monopolistic liquidity supplier can extract all trade surplus, leaving the issuer indifferent between trading the security or not.

This generic result with a continuum of assets strikingly highlights the relevance of market power for the optimality of pooling assets from the perspective of the issuer. In the presence of such market power, the issuer's only source of surplus are information rents, which require retaining some private information. Thus, any pooling that leads to *perfect* diversification (as was the case in this example) is never optimal for an issuer when facing a prospective buyer with market power. Instead, the issuer prefers to retain some private information, which requires him to sell some assets separately. Being at an informational disadvantage, buyers with market power then strategically choose prices that jeopardize the realization of gains from trade. When deciding whether to pool assets, the issuer therefore faces the following trade-off: he can only extract rents when retaining some private information, but he still partially internalizes the inefficiencies emerging from adverse selection and the exercise of market power under asymmetric information. As a result, he may only choose to pool a subset of assets in order to achieve partial diversification (but not perfect diversification). Understanding these channels and how they affect the design of optimal securities is the focus of our main analysis below.

3 Main Analysis

We now formalize our paper's main insights. The issuer decides on the pooling of the n underlying assets and on the securities that specify payoffs as a function of the pools' payoffs. Formally, the issuer chooses a partition of the set Ω, that is, he groups the n assets into $m \leq n$ disjoint subsets denoted by Ω_j with $j \in \{1, ..., m\}$.[9] The corresponding m pools of assets then have the payoffs:

$$Y_j \equiv \sum_{i \in \Omega_j} X_i, \forall j. \tag{1}$$

The CDF G_j of Y_j then has positive and finite density g_j on the compact interval $\chi_j = [0, \bar{y}_j]$, where $\bar{y}_j \equiv \sum_{i \in \Omega_j} \bar{x}$. Going forward, we follow the convention of using capitalized letters for random variables and lower-case letters for their realizations. In line with the existing literature (see, e.g., Myerson 1981), we assume that these distributions satisfy a regularity condition that ensures that first-order conditions in the trading game with a monopolistic buyer are sufficient conditions for the optimal pricing decisions.

[9] Note that, whether the issuer pools the assets or not, he is still offering all assets to the buyer(s). Hence, even if we allowed for risk aversion, pooling assets would not by itself lead to better risk sharing among traders. The main impediment to risk sharing would then be the fact that the issuer's private information may result in socially inefficient trade breakdowns, which is already a force at play in our paper.

Assumption 1. *For any partition of Ω, the elasticity functions:*

$$e_j(y) \equiv \frac{g_j(y)}{G_j(y)} \cdot y, \;\; \forall j \tag{2}$$

are weakly decreasing on their respective supports χ_j.

Throughout our main analysis below, we will cover examples with distributions satisfying Assumption 1. When interpreting elasticity functions, it might help to remember that they represent the ratio of the local density $g_j(y_j)$ to the average density $G_j(y_j)/y_j$. These quantities will play an important role in understanding how a monopolistic buyer picks his pricing strategy. We also denote by $e(x_i) \equiv \frac{g(x_i)}{G(x_i)} \cdot x_i$ the elasticity function of each fundamental asset i.

The issuer chooses for each pooled payoff Y_j a security that is backed by that payoff. Specifically, the security payoff F_j is made contingent on the realized cash-flow Y_j according to the function $\varphi_j : \chi_j \to \mathbb{R}_+$ such that $F_j = \varphi_j(Y_j)$. We impose the standard limited liability condition:

(LL) $0 \leq \varphi_j \leq \mathrm{Id}_{\chi_j}$,

where Id_{χ_j} is the identity function on χ_j. In addition, as in Harris and Raviv (1989), Nachman and Noe (1994), and Biais and Mariotti (2005), we restrict the set of admissible securities by requiring that both the payoffs to the liquidity supplier and to the issuer be non-decreasing in the underlying cash-flow:

(M1) φ_j is non-decreasing on χ_j.

(M2) $\mathrm{Id}_{\chi_j} - \varphi_j$ is non-decreasing on χ_j.

The sets of admissible payoff functions for the securities is therefore given by $\{\varphi_j : \chi_j \to \mathbb{R}_+ |$ (LL), (M1), and (M2) hold$\}$.

3.1 Competitive Demand

In this subsection, we analyze the (benchmark) scenario in which the issuer faces multiple liquidity suppliers who use a discount factor of one. In this case, the issuer receives competitive ultimatum price quotes, a feature that is common in the literature (see, e.g., Boot and Thakor 1993, Nachman and Noe 1994, Friewald, Hennessy, and Jankowitsch 2015) and, importantly, delivers results that are consistent with DeMarzo's (2005) seminal analysis of an issuer's decision to pool assets.[10]

3.1.1 Optimality of Pooling Assets

Echoing the existing literature, our analysis of this scenario predicts that issuing debt on the whole pool of assets is optimal for the issuer.

Proposition 1. *If $\mathbb{E}[X_i] \geq \delta\bar{x}$, the issuer is indifferent between selling assets separately and selling them as a pool. If $\mathbb{E}[X_i] < \delta\bar{x}$, the issuer optimally pools all n assets and issues a debt security on this pool.*

To provide intuition for this result we will discuss the proof of Proposition 1 in the main text. At the trading stage, the issuer has perfect knowledge of the realizations x_i of future cash-flows X_i. Since the payoff of any security F_j is only contingent on $Y_j = \sum_{\Omega_j} X_i$, the issuer also perfectly knows the realization $f_j = \varphi_j(y_j)$ of F_j. Suppose the issuer uses a simple equity security (what DeMarzo and Duffie 1999, refer to as a "passthrough" security). If $\mathbb{E}[X_i] \geq \delta\bar{x}$, he can sell the assets separately (as equity), each at price $p = \mathbb{E}[X_i]$, since at this price even the highest issuer type $\bar{x}$ finds it optimal to accept the price. The

[10] DeMarzo (2005) considers a richer strategy space for the issuer through the posting of price-quantity menus, but our simpler structure allows us to illustrate the main intuition for the competitive case and more quickly reach the focus of our analysis, that is, the case with market power on the demand side. See Section 4 for a discussion of how retention would affect our results.

issuer obtains the same total payoff when pooling the assets and selling an equity security on the pool(s). Since the potential gains from trade are large enough (δ is sufficiently low), adverse selection does not impede the efficiency of trade even when assets are sold separately. The first-best level of total trade surplus is achieved, and the issuer fully internalizes this surplus.

In contrast, if $\mathbb{E}[X_i] < \delta\bar{x}$, the sale of an equity security on a single asset leads to adverse selection, since the highest issuer type $\bar{x}$ would not accept a price equal to $\mathbb{E}[X_i]$. Similarly, the sale of an equity security on a pool of $\tilde{n}$ assets leads to the exclusion of some issuer types, since the highest issuer type $\bar{y}_j = \tilde{n}\bar{x}$ would not accept a price equal to $\mathbb{E}[Y_j] = \tilde{n}E[X_i]$. In this case, it is useful to recall the following result from Biais and Mariotti's (2005) analysis of a setting with one underlying asset:

Lemma 1. *Given an underlying asset with random payoff Y and $\mathbb{E}[Y] < \delta\bar{y}$, the issuer optimally designs a debt security with the highest face value d such that a buyer just breaks even when purchasing this debt security at a price $p = \delta d$.*

Proof. See Proposition 4 in Biais and Mariotti (2005). □

Independent of his pooling choice that determines the underlying assets with payoffs Y_j, the issuer optimally uses a debt security when $\mathbb{E}[X_i] < \delta\bar{x}$ and equivalently, $\mathbb{E}[Y_j] < \delta\bar{y}_j$. To determine the issuer's optimal pooling decision, it is useful to first consider buyers' expected net profits. A buyer purchasing debt with face value d at a price $p = \delta d$ obtains the following expected net profit:

$$\int_0^d y g_j(y)dy + [1 - G_j(d)]d - \delta d = (1-\delta)d - \left(G_j(d)d - \int_0^d y g_j(y)dy \right), \quad (3)$$

$$= (1-\delta)d - \int_0^d G_j(y)dy, \quad (4)$$

where the last step follows from integration by parts. Next, we compare buyers' expected net-payoff from the sales of separate debt securities to that from the sale of a debt security on an underlying pool of assets. Consider first that the issuer sells $\tilde{n}$ individual debt securities with face value d. Further, suppose that each debt security is written on a separate underlying asset and the price in each transaction is δd. Then buyers' total expected net-profit (which may be negative) is:[11]

$$\tilde{n} \cdot \left((1-\delta)d - \int_0^d G(x)dx \right) = (1-\delta)\tilde{n}d - \int_0^{\tilde{n}d} G\left(\frac{y}{\tilde{n}}\right) dy, \tag{5}$$

where we used a change in variables, with $y = \tilde{n}x$. In contrast, consider now that the issuer pools the $\tilde{n}$ assets and issues one debt security with face value $d_j = \tilde{n}d$ and buyers purchase this debt at price δd_j. In this case, buyers' total expected net-profit (which again may be negative) is:

$$(1-\delta)\tilde{n}d - \int_0^{\tilde{n}d} G_j(y)dy. \tag{6}$$

The following lemma sheds light on the relative magnitude of the profits in (5) and (6).

Lemma 2. *The distribution of the pooled payoff $Y_j = \sum_{i=1}^{\tilde{n}} X_i$ second-order stochastically dominates the distribution of the payoff $\tilde{n}X_i$, that is,*

$$\int_0^s \left[G\left(\frac{y}{\tilde{n}}\right) - G_j(y) \right] dy \geq 0 \tag{7}$$

for any $s \in [0, \bar{y}_j]$.

Proof. See Appendix. □

[11] Note that the considered supposition does not impose that the buyers' participation constraint is satisfied. That is, the expected net-profit can be negative.

This lemma implies that buyers' total expected net-profit is *higher* in the scenario with pooling (i.e., (6) is greater than (5)). Next, recall that, according to Lemma (1), the *optimal* face value in each scenario would be set such that buyers break even, that is, the optimal face values would ensure that (5) and (6) are each equal to zero. The above result implies that if buyers break even at a face value d^* on separate sales (first scenario), then they make positive profits on the pooled sale if the face value is set equal to $\tilde{n}d^*$ (second scenario). It follows that the issuer can choose a face value $d_j^* \geq \tilde{n}d^*$ on the pool while still ensuring that the buyers can break even (as buyers' expected net-profit is a continuous function of d_j). Finally, observe that when issuing debt with break-even face values under each of the two scenarios, the issuer's total profits are $(1-\delta)\delta\tilde{n}d^*$ and $(1-\delta)\delta d_j^*$, respectively, and the issuer extracts the full gains from trade in the competitive market. Since $d_j^* \geq \tilde{n}d^*$, the issuer obtains a higher expected net-profit when pooling the $\tilde{n}$ assets and issuing debt with face value d_j^*.

In sum, the argument for the optimality of pooling is intuitive. In a market with competitive liquidity suppliers, the issuer extracts all the gains from trade. As a result, he fully internalizes any improvements in trade efficiency. Thus, when adverse selection concerns impede trade efficiency, the issuer seeks to minimize the information asymmetry between him and his prospective buyers by pooling assets. As pooling leads to diversification, it reduces the information asymmetry and its associated inefficiencies. In other words, the issuer does not face a trade-off when facing competitive buyers — reducing information asymmetry is always weakly beneficial. We will, however, show below that the unambiguous optimality of pooling ceases to hold when the supply of liquidity becomes imperfectly competitive.

3.2 Monopolistic Demand

In this subsection, we derive our paper's main results by considering the scenario in which the issuer faces an imperfectly competitive demand, a feature that is relevant for our understanding of actual OTC markets. In this setting, only one buyer has a discount factor of one, which imparts him the advantage of being a monopolistic liquidity supplier.[12]

We start by examining the optimal pricing decision of this buyer. Biais and Mariotti (2005) show that for a given security offered the optimal mechanism for the liquidity supplier with market power can be implemented via a take-it-or-leave-it offer (see also Riley and Zeckhauser 1983). In accordance, the buyer makes an ultimatum price offer p_j to maximize his ex-ante profit from purchasing a security with payoff F_j:

$$\Pr(\delta f_j \leq p_j)(\mathbb{E}[f_j|\delta f_j \leq p_j] - p_j) = \int_0^{p_j/\delta} (\varphi_j(y) - p_j) g_j(y) dy. \tag{8}$$

The optimal price p_j^m set by a monopolistic buyer identifies a marginal issuer type that is just willing to accept this price, $f_j^m = p_j^m/\delta$. Issuer types with security payoffs below the threshold value f_j^m participate in the trade, whereas issuer types with payoffs above f_j^m are excluded (i.e., they reject the offer).

3.2.1 Optimality of Separate Equity Sales

We now establish our first main result, which derives a sufficient condition for the strict optimality of selling assets separately. This result also provides the necessary and sufficient condition under which selling assets separately yields the first-best level of trade surplus.

[12]While we consider the case in which only one buyer has a discount factor of one, similar outcomes arise when there are multiple buyers with a discount factor of one, but these buyers face position limits. The central feature of our analysis is the presence of some degree of market power, that is, a buyer can strategically affect the prices of the securities being offered. Biais, Martimort, and Rochet (2000) show that this type of strategic pricing behavior also arises when multiple risk averse liquidity suppliers compete in mechanisms (see also Vives 2011).

Proposition 2. *Suppose that the following condition holds:*

$$e(\bar{x}) \geq \frac{\delta}{1-\delta}, \quad \text{or equivalently} \quad \delta \leq \bar{\delta}, \tag{9}$$

where $\bar{\delta} \equiv \frac{e(\bar{x})}{1+e(\bar{x})}$. *Then the following results obtain:*

(i) The issuer optimally sells each asset separately to a monopolistic buyer, that is,

$$\Omega_j = j \text{ and } \varphi_j(X_j) = X_j \text{ for } j = 1, ..., n. \tag{10}$$

The first-best level of total surplus from trade, $n(1-\delta)\mathbb{E}[X_i]$, *is then achieved and the issuer collects* $n\delta\bar{x}$, *obtaining a surplus of* $n\delta(\bar{x} - \mathbb{E}[X_i])$.

(ii) If the issuer pools any of the assets, the total surplus from trade is strictly below the first-best level $n(1-\delta)\mathbb{E}[X_i]$, *and the issuer's surplus is strictly below* $n\delta(\bar{x}-\mathbb{E}[X_i])$.

To provide intuition for these central results, we develop the proof here in the main text. First, consider part (i) of the proposition. Suppose that the issuer sells an equity claim on a pool j, such that, $\varphi_j(Y_j) = Y_j$. When designing the optimal security, the issuer anticipates the buyer's optimal pricing response. Using equation (8), we can write the buyer's marginal benefit of increasing the threshold type $f_j^m = y_j^m$ for $f_j^m \in [0, \bar{y}_j)$ as:

$$(1-\delta)f_j^m g_j(f_j^m) - \delta G_j(f_j^m). \tag{11}$$

This last equation highlights the generic trade-off that a buyer with market power faces when choosing the price he plans to offer. When marginally increasing the price to include marginal issuer types, the buyer benefits from extracting the full gains to trade $(1-\delta)f_j^m$ from these types, which have the local density $g_j(f_j^m)$. Yet, increasing the price also comes at the cost of paying more when trading with all infra-marginal types, which have measure $G_j(f_j^m)$. In net, the buyer benefits from increasing the marginal buyer type if expression (11) takes a strictly positive value (for any $f_j^m < \bar{y}_j$). This condition can be equivalently expressed as a condition applying to the above-defined elasticity function:

$$e_j(f_j^m) > \frac{\delta}{1-\delta}. \tag{12}$$

Now suppose the issuer simply sells all assets separately. Then the condition $e(\bar{x}) > \frac{\delta}{1-\delta}$ together with Assumption 1 ensures that the buyer's optimal price quote for each asset is $p_i = \delta\bar{x}$, allowing the issuer to collect $n\delta\bar{x}$. In this case, the marginal issuer type is the highest type on the support $[0, \bar{x}]$ and trade occurs with probability one, ensuring that the first-best level of surplus from trade is achieved.

Facing a monopolistic buyer, the issuer cannot collect more than $n\delta\bar{x}$ since the best possible payoff that all assets can deliver jointly is $n\bar{x}$ and a buyer with market power would never offer a price above $\delta n\bar{x}$, even if he believed that this maximum payoff on all assets was attained.

To address part (ii) of the proposition, we show that the issuer's surplus and the total surplus are strictly lower when assets are pooled. First, we introduce the following result:

Lemma 3. *For any set Ω_j that contains more than one element (that is, if there is pooling), the following condition is satisfied:*

$$e_j(\bar{y}_j) = 0 < \frac{\delta}{1-\delta}. \tag{13}$$

Proof. See Appendix. □

This lemma states that if the issuer pools assets and issues an equity security on the pool, the elasticity for this security at the upper bound of the support $\bar{y}_j$ is zero, implying the exclusion of a positive measure of types. The elasticity is zero at the upper bound $\bar{y}_j$ since the density for the outcome that two assets simultaneously achieve their highest possible value $\bar{x}$ is 0. The intuitive reason for this result is diversification: the more diversified pool of assets is less likely to generate an extreme outcome than each idiosyncratic asset separately. Figure 1 illustrates this result for the case where each separate asset follows a uniform distribution. The figure compares, after rescaling the domains (see caption details), the shapes of the PDFs of a single asset, a pool of two assets, and a pool of four assets. The graph illustrates the familiar notion that diversification leads to a more peaked distribution with thinner tails.

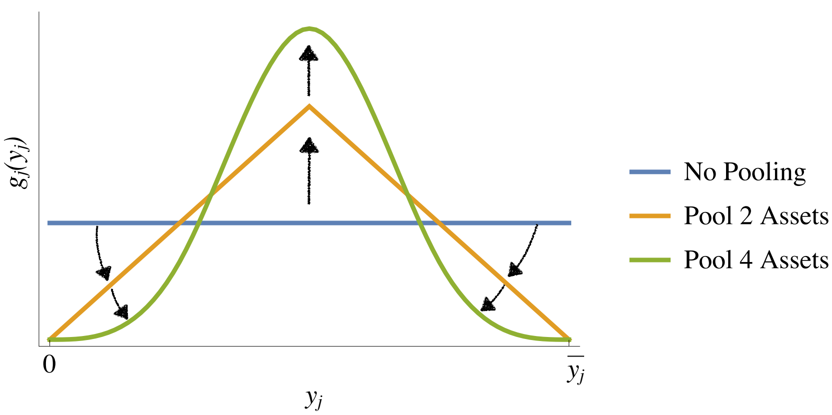

Figure 1: Effect of pooling on the shape of the probability density function. The graph considers a setting with four assets ($n = 4$), each of which has a payoff $X_i \sim$ Unif$[0, 1]$. The graph plots the PDF of a separate asset, a pool of 2 assets, and a pool of 4 assets. To compare the PDFs' shapes relative to their respective domains ($[0, 1]$, $[0, 2]$, and $[0, 4]$), the graph rescales the horizontal axis to represent the interval $\chi_j = [0, \bar{y}_j]$ for each PDF g_j.

These changes in the shapes of the PDFs map into corresponding changes in the elasticity functions $e_j(y_j)$, which govern the pricing behavior in the trading game (see equation (12)). Figure 2 confirms that as soon as two assets are pooled, the elasticity at the upper bound of the support $\bar{y}_j$ shrinks to zero. A thinner right tail of the PDF implies a lower elasticity in the right tail of the distribution (recall that the elasticity is the ratio of the local density $g_j(y_j)$ to the average density $G_j(y_j)/y_j$). Facing a less elastic response from the issuer in that part of the domain, a monopolistic buyer has stronger incentives to offer lower prices, which leads to the exclusion of high issuer types. If $\tilde{n} \geq 2$ assets are pooled in a set Ω_j, then the buyer optimally chooses a marginal issuer type strictly below $\bar{y}_j = \tilde{n}\bar{x}$, since $e_j(\bar{y}_j) = 0 < \frac{\delta}{1-\delta}$. Correspondingly, the price offered by the buyer is strictly below $\delta\tilde{n}\bar{x}$ for a pool of $\tilde{n}$ assets, and the issuer obtains an expected payoff from pooling that is strictly below $\delta\tilde{n}\bar{x}$.

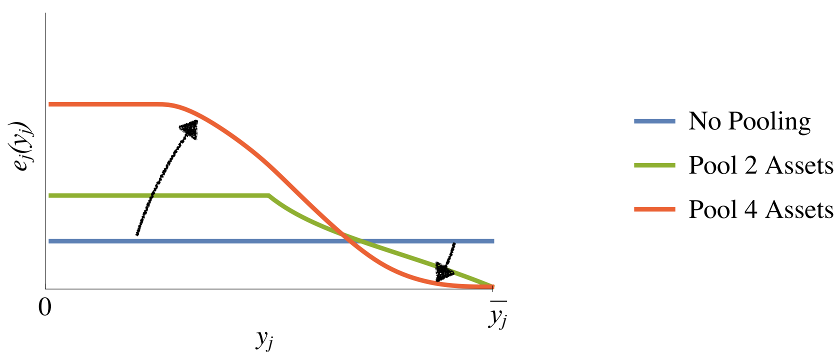

Figure 2: Effect of pooling on the shape of the elasticity function. The graph considers a setting with four assets ($n = 4$), each of which has a payoff $X_i \sim$ Unif$[0, 1]$. The graph plots the elasticity function of a separate asset, a pool of 2 assets, and a pool of 4 assets. To compare the elasticity functions' shapes relative to their respective domains ($[0, 1]$, $[0, 2]$, and $[0, 4]$), the graph rescales the horizontal axis to represent the interval $\chi_j = [0, \bar{y}_j]$ for each elasticity function e_j.

To conclude the proof of part (ii) of Proposition 2, we address whether the issuer, after pooling assets, could still obtain an equally beneficial payoff as under separate sales by designing an optimal security $F_j = \varphi_j(Y_j)$ on the pooled payoff Y_j. The following lemma characterizes the optimal security on a given underlying asset Y_j when an equity security leads to rationing.

Lemma 4. *When the trading of an equity security on a payoff Y_j leads to the exclusion of issuer types (i.e., if $e(\bar{y}_j) < \delta/(1-\delta)$) but sustains trade with positive probability (that is, if $e(0) > \delta/(1-\delta)$), the optimal security from the perspective of the issuer is a debt security with face value d_j^m, i.e., $\varphi = \min[Id_{\chi_j}, d_j^m]$, where d_j^m is the largest d such that:*

$$\underbrace{\int_0^d f_j g_j(f_j) df_j + [1 - G_j(d)]d - \delta d}_{\textit{Net-payoff from offering price } \delta d} - \underbrace{\int_0^{f_j^m} (f_j - \delta f_j^m) g_j(f_j) df_j}_{\textit{Net-payoff from offering price } \delta f_j^m < \delta d.} \geq 0, \tag{14}$$

and where f_j^m solves:

$$e_j(f_j^m) = \frac{\delta}{1-\delta}. \tag{15}$$

That is, the optimal debt contract specifies the highest face value such that the buyer weakly prefers offering a price for the debt that is always accepted by the issuer (δd) over offering a lower price that is only accepted by issuer types below the threshold type f_j^m.

Proof. As each of the pooled payoffs Y_j satisfy the regularity condition stated in Assumption 1, the results follow from Propositions 3, 4, and 5 in Biais and Mariotti (2005). □

Since any pooling of $\tilde{n} \geq 2$ assets in a set Ω_j leads to exclusion when an equity security is offered (as $e_j(\bar{y}_j) < \delta/(1-\delta)$), Lemma 4 implies that the best possible security written on that pool is a debt security with face value d_j^m. Yet, since $d_j^m < \bar{y}_j = \tilde{n}\bar{x}$, selling this debt security will also deliver a payoff to the issuer that is strictly below the one he obtains from selling the $\tilde{n}$ assets separately. Thus, the effects of diversification cannot be undone by designing a security that pays as a function of the pooled (diversified) cash-flow Y_j. This concludes our proof of Proposition 2.

In sum, when separate sales of assets are efficient, pooling assets leads to strictly worse outcomes, both for the issuer and for the overall efficiency of trade. This result emerges as pooling generically leads to a payoff distribution with thinner tails, and equivalently, a less elastic response to price quotes in the right tail of the payoff distribution (see Figure 2). A less elastic response causes a liquidity supplier with market power to optimally set prices that lead to inefficient rationing, harming both the issuer and the total trade efficiency. Thus, in contrast to the previously analyzed scenario with competitive liquidity suppliers (see Proposition 1), pooling assets may hurt the issuer when the demand side has market power.

3.2.2 Optimality of Separate Debt Sales

Proposition 2 provided the condition under which selling assets separately, as equity, is optimal for the issuer and attains the first-best level of trade surplus. We will now show that even when this condition is violated, it may be optimal for the issuer to sell assets separately. However, in those cases, the issuer will opt for separate debt securities rather than equity securities.

Proposition 3. *Suppose now that each elasticity function e_j is strictly decreasing on its respective support χ_j (recall that Assumption 1 only required them to be weakly decreasing). Then, for all $\delta \in \left(\bar{\delta}, \delta^*\right]$, where $\delta^* \in \left(\bar{\delta}, 1\right]$, it is optimal to issue a separate debt security for each asset payoff X_i.*

To prove this result it is useful to introduce additional notation. Let $\Pi(\delta)$ denote the issuer's profit, as a function of the parameter δ, from selling one underlying asset separately, and issuing an optimal security on that underlying asset. Further, let $\Pi_{\tilde{n}}(\delta)$ denote the issuer's profit, also as a function of δ, from pooling $\tilde{n}$ assets and issuing an optimal security on that underlying pool. The basic idea of the proof is to establish that these profits are continuous functions of δ, and then use the fact established in Proposition 2, which is that for $\delta = \bar{\delta}$ selling assets separately yields the issuer a strictly higher expected profit than from pooling assets:

$$\tilde{n}\Pi(\bar{\delta}) > \Pi_{\tilde{n}}(\bar{\delta}). \tag{16}$$

First, suppose the issuer issues equity securities. For all $\delta \in \left[\frac{e_j(\bar{x})}{1+e_j(\bar{x})}, \frac{e_j(0)}{1+e_j(0)}\right]$ the monopolistic buyer would target a marginal issuer type who is selling equity on a payoff Y_j as the interior type f_j^m satisfying:

$$e_j(f_j^m) = \frac{\delta}{1-\delta} \Leftrightarrow f_j^m(\delta) = e_j^{-1}\left(\frac{\delta}{1-\delta}\right), \tag{17}$$

where e_j is an invertible function, since it is assumed to be strictly decreasing on its support. Thus, for all $\delta \in \left[\frac{e_j(\bar{x})}{1+e_j(\bar{x})}, \frac{e_j(0)}{1+e_j(0)}\right]$, the marginal issuer type selling equity, f_j^m, is a continuous function of the discount factor δ. This result is useful, since as shown in Lemma 4, the optimal debt security, which will be issued for $\delta > \frac{e_j(\bar{x})}{1+e_j(\bar{x})}$, is implicitly characterized as a function of this marginal issuer type selling equity, f_j^m. Specifically, the optimal security from the perspective of the issuer is a debt security with face value d_j^m, $\varphi = \min[\mathrm{Id}_{\chi_j}, d_j^m]$ where d_j^m is the largest d such that:

$$\int_0^d f_j g_j(f_j) df_j + [1 - G_j(d)]d - \delta d \ - \int_0^{f_j^m} (f_j - \delta f_j^m) g_j(f_j) df_j \geq 0, \tag{18}$$

where $f_j^m = e_j^{-1}(\frac{\delta}{1-\delta})$. Note that this optimal face value d_j^m is then also a continuous function of δ. This continuity result holds for any set Ω_j, including the case where Ω_j includes only one asset.

Finally, note that if all the optimal face values d_j^m are continuous functions of δ, then the issuer's profit functions $\Pi(\delta)$ and $\Pi_{\tilde{n}}(\delta)$ are also continuous functions of δ, since:

$$\Pi(\delta) = \delta d^m(\delta) - \delta \int_0^{d^m(\delta)} fg(f)df - \delta[1 - G(d^m(\delta))]d^m(\delta) = \delta \int_0^{d^m(\delta)} G(f)df, \tag{19}$$

$$\Pi_{\tilde{n}}(\delta) = \delta d^m_{\tilde{n}}(\delta) - \delta \int_0^{d^m_{\tilde{n}}(\delta)} fg(f)df - \delta[1 - G(d^m_{\tilde{n}}(\delta))]d^m_{\tilde{n}}(\delta) = \delta \int_0^{d^m_{\tilde{n}}(\delta)} G_{\tilde{n}}(f)df, \tag{20}$$

where we use integration by parts to simplify the expressions.

Given equation (16) and the continuity of functions $\Pi(\delta)$ and $\Pi_{\tilde{n}}(\delta)$, we know that there is also a non-empty region $(\bar{\delta}, \delta^*)$ such that when δ lies in that region, we have:

$$\tilde{n}\Pi(\delta) > \Pi_{\tilde{n}}(\delta), \tag{21}$$

that is, selling $\tilde{n} \geq 2$ assets separately (with debt) is strictly better for the issuer than selling debt on a pool of $\tilde{n}$ assets. The upper bound of the region, δ^*, is implicitly defined by the lowest δ such that $\tilde{n}\Pi(\delta) = \Pi_{\tilde{n}}(\delta)$.

The main insight from Proposition 3 is that even when the potential gains to trade are smaller than required by the condition stated in Proposition 2, pooling assets may still be suboptimal for the issuer. The main difference relative to the result of Proposition 3 is that once separate equity securities do not trade fully efficiently, switching to separate debt securities is optimal. Yet, as the design of these debt securities is still intimately linked to the monopolistic liquidity supplier's incentives to inefficiently screen the issuer (the marginal issuer type from equity sales enters equation (18)), the elasticity of trading volume is still an important determinant of the issuer's net-profit. As pooling assets reduces this elasticity in the right tail of the payoff distribution (see Figure 2), it is undesirable to do so when the marginal issuer type from separate equity sales is sufficiently high, or equivalently, when the liquidity differences between the issuer and the buyer are sufficiently large (i.e., δ is sufficiently low).

3.2.3 Optimality of Pooling Assets when Adverse Selection is Severe

Unlike with competitive demand where it is always optimal to pool assets for the issuer, the predictions for the scenario with monopolistic demand are more nuanced and feature a trade-off between the benefits of diversification and the preservation of information rents. Propositions 2 and 3 have highlighted that the optimality of separate sales emerges when trade is particularly valuable, that is, when the buyer and the issuer differ more in terms of their liquidity. In contrast, when potential gains from trade are smaller, adverse selection concerns and the exercise of market power would lead to larger inefficiencies if assets were sold separately. Lower gains from trade (i.e., higher values of δ) cause the liquidity supplier to choose a more aggressive pricing strategy, which leads to the exclusion of a larger range of issuer types when equity securities are issued. In fact, whenever $\delta > \frac{e(0)}{1+e(0)}$ the trading of separate securities (whether it is equity or debt) fails completely as the elasticity function $e(x)$ then lies below $\delta/(1-\delta)$ everywhere on the support — all issuer types are excluded. Yet, as suggested by Figure 2, pooling assets increases the elasticity in the left tail of the distribution, and thus can allow sustaining trade when separate sales would lead to trade breakdowns. When adverse selection concerns are severe, relative to the magnitude of the potential gains from trade, we are back to the standard case where pooling assets helps reduce the perverse consequences of adverse selection.

Proposition 4. *Suppose that the issuer has $n > \frac{\delta}{1-\delta}$ assets. Then at least one of the subsets Ω_j will optimally consist of n^* assets, where $n^* > \frac{\delta}{1-\delta}$.*

Proposition 4 highlights that for sufficiently high values of the discount factor δ the issuer optimally pools multiple assets into a security. This result is directly linked to the previously mentioned fact that trade breaks down completely whenever the elasticity of an underlying asset at the lower bound of the support is already lower than $\delta/(1-\delta)$. Let $e_{\tilde{n}}(0)$ denote the elasticity function associated with a pool of $\tilde{n}$ assets. If $e_{\tilde{n}}(0) < \frac{\delta}{1-\delta}$, then trade will break down with probability 1 for any security written on this pool. Yet, as suggested by Figure 2, the elasticity at the lower bound increases when more assets are pooled, a fact that is established in the following lemma.

Lemma 5. *A pool of $\tilde{n}$ assets has the elasticity $e_{\tilde{n}}(0) = \tilde{n}$ at the lower bound of the support.*

Proof. See Appendix. □

Since trade breaks down completely whenever $e_{\tilde{n}}(0) < \frac{\delta}{1-\delta}$, the issuer can only attain a positive expected surplus when the elasticity of an underlying asset, evaluated at the lower bound, exceeds $\frac{\delta}{1-\delta}$. Since, as shown in Lemma 5, this elasticity for a pool of $\tilde{n}$ assets is exactly equal to $\tilde{n}$, the issuer will at least pool $n > \frac{\delta}{1-\delta}$ assets to ensure that he can attain an expected surplus greater than zero. At the same time, we know from our earlier analysis that pooling an infinite number of assets is also suboptimal for the issuer, as perfect diversification leads him to zero surplus. Thus, even when the issuer has a continuum of assets, he prefers to pool only a subset of the assets, or none at all.

Propositions 2, 3, and 4 have highlighted that the trade-offs faced when deciding whether to pool assets are intimately linked to the magnitude of the potential gains from trade. When they are sufficiently large (i.e., δ is sufficiently low) it is optimal to sell assets separately. In this case, the liquidity supplier is less worried about being adversely selected by the issuer and is more cautious in exercising his market power. Moreover, we have shown that when the issuer sells assets separately, the elasticity with which he responds to price changes is larger in the right tail of the distribution than when he is pooling assets. This elasticity in the right tail is relevant when the potential gains from trade are sufficiently large, causing the marginal issuer type to reside in that part of the distribution. Yet, when the potential gains from trade are sufficiently small, adverse selection concerns and the exercise of market power lead to complete market breakdowns when assets are sold separately. In this case, the issuer has to reduce the amount of asymmetric information to ensure that trade can occur. He thus pools assets. In particular, Lemma 5 reveals that the elasticity in the left tail of the support rises with the number of assets that are pooled, allowing trade to occur once sufficiently many assets have been pooled into the same security.

4 Discussion

In this section we discuss the robustness of our main insights to various changes in the environment.

Multiple constrained buyers. The main result of our paper, that is, pooling assets might be suboptimal when liquidity suppliers have market power, is derived in an environment in which only one buyer has a discount factor of one, but is deep-pocketed. Similar results obtain in the presence of multiple buyers, provided that these buyers face position limits, wealth constraints, or risk aversion. Consider a simple extension of our baseline model in which the aggregate position limit across all prospective buyers (measured in units of underlying assets) is marginally smaller than the total quantity of assets up for sale. In this case, each buyer's price setting strategy is identical to the one derived in our baseline model — as the total supply always exceeds the total demand, a buyer faces a residual supply curve that is unaffected by the others' pricing strategies.[13] As a result, the issuer still faces the trade-offs featured in our baseline model.

Signaling through retention. In the scenario with competing liquidity suppliers, allowing

[13]The result that capacity constraints can hamper competition is well known in the literature, see, for example, Green (2007).

the issuer to signal asset quality through partial retention, as in DeMarzo (2005), would yield results that are, unsurprisingly, consistent with DeMarzo (2005) — issuers with assets of higher quality would retain a higher fraction of the issue.[14] Signaling would then allow the high issuer types to separate themselves from the low types and would resolve the lemons problem for high values of δ. In contrast, when facing a liquidity supplier with market power, the issuer can be made worse off by signaling asset quality. 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 from implementing fully revealing retention policies is weakly lower than his profit without any signaling through retention (see also Glode, Opp, and Zhang 2018, for related arguments). Moreover, as mentioned earlier, Biais and Mariotti (2005) show that for a given security offered by the issuer the monopolistic buyer's optimal mechanism is to make a take-it-or-leave-it offer for the whole security, rather than using a menu of price-quantity offers that could result in the issuer using retention to signal asset quality.

Alternative interpretation. Our baseline 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, our model also allows an interesting 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 buyers about all future cash-flows. The question would then be 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

[14]See also Williams (2019) who studies the optimality and efficiency of security retention in the presence of search frictions.

from those occurring at later time periods (e.g., via zero coupon bonds). 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.

5 Conclusion

This paper studies the optimality of pooling assets when security issuers face a market in which 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 issuers, in particular when liquidity differences between the buy side and the sell side of the market are sufficiently large. While our results suggest that the dramatic decline of the ABS market post crisis may represent an efficient response by originators to drastic 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: Proofs Omitted from the Text

Proof of Lemma 2: We can express $\tilde{n}X_i$ as follows:

$$\tilde{n}X_1 = \sum_{i=1}^{\tilde{n}} X_i + \left[(\tilde{n}-1)X_1 - \sum_{k=2}^{\tilde{n}} X_k\right], \tag{A1}$$

where $\left[(\tilde{n}-1)X_1 - \sum_{k=2}^{\tilde{n}} X_k\right]$ has a conditional expected value of zero:

$$\mathbb{E}\left[(\tilde{n}-1)X_1 - \sum_{k=2}^{\tilde{n}} X_k \middle| \sum_{i=1}^{\tilde{n}} X_i\right] = (\tilde{n}-1)\,\mathbb{E}\left[X_1 \middle| \sum_{i=1}^{\tilde{n}} X_i\right] - \sum_{k=2}^{\tilde{n}} \mathbb{E}\left[X_k \middle| \sum_{i=1}^{\tilde{n}} X_i\right] \overset{a.s.}{=} 0. \tag{A2}$$

It directly follows that $\tilde{n}X_i$ is a mean-preserving spread of Y_j, and the distribution of Y_j thus second-order stochastically dominates the distribution of $\tilde{n}X_i$.

Proof of Lemma 3: Consider the convolution of $Y_{\tilde{n}} = \sum_{i=1}^{\tilde{n}} X_i$ and X_k where $k > \tilde{n}$, that is, $Y_{\tilde{n}+1} \equiv Y_{\tilde{n}} + X_k$, . Since these $Y_{\tilde{n}}$ and X_k are independent, we can write:

$$g_{\tilde{n}+1}(y_{\tilde{n}+1}) = \int_0^{\bar{x}} g_{\tilde{n}}(y_{\tilde{n}+1} - x) g(x) dx. \tag{A3}$$

Now evaluate $g_{\tilde{n}+1}$ at the upper bound of the support $\bar{y}_{\tilde{n}+1} = (\tilde{n}+1)\bar{x}$:

$$g_{\tilde{n}+1}((\tilde{n}+1)\bar{x}) = \int_0^{\bar{x}} g_{\tilde{n}}((\tilde{n}+1)\bar{x} - x) g(x) dx = 0, \tag{A4}$$

since the density $g_{\tilde{n}}$ is equal to zero for any outcome above $\tilde{n}\bar{x}$. As a result, the elasticity $e_{\tilde{n}+1}(\bar{y}_{\tilde{n}+1}) = g_{\tilde{n}+1}(\bar{y}_{\tilde{n}+1})\bar{y}_{\tilde{n}+1}/G(\bar{y}_{\tilde{n}+1})$ is also zero for all $\tilde{n} \geq 1$, that is, as soon as at least two assets are pooled, such that $\tilde{n}+1 \geq 2$, the elasticity of the pool will be zero at the upper bound $\bar{y}_{\tilde{n}+1}$.

Proof of Lemma 5: First, suppose that $g(0) > 0$ and $g'(0)$ is finite. By L'Hôpital's rule, the elasticity is:

$$\lim_{y \to 0} \frac{g(y)y}{G(y)} = \lim_{y \to 0} \frac{g'(y)y + g(y)}{g(y)} = \frac{g'(0)0 + g(0)}{g(0)} = 1. \tag{A5}$$

Next, suppose that $g(0) = 0$, $g'(0) > 0$, and $g''(0)$ is finite. Then the elasticity is:

$$\lim_{y \to 0} \frac{g(y)y}{G(y)} = \lim_{y \to 0} \frac{g'(y)y + g(y)}{g(y)} = \lim_{y \to 0} \frac{g''(y)y + 2g'(y)}{g'(y)} = 2. \tag{A6}$$

Then, suppose that $g(0) = 0$, $g'(0) = 0$, $g''(0) > 0$, and $g'''(0)$ is finite. The elasticity is:

$$\lim_{y \to 0} \frac{g(y)y}{G(y)} = \lim_{y \to 0} \frac{g'(y)y + g(y)}{g(y)} = \lim_{y \to 0} \frac{g''(y)y + 2g'(y)}{g'(y)} = \lim_{y \to 0} \frac{g'''(y)y + 3g''(y)}{g''(y)} = 3. \tag{A7}$$

More generally, if the n-th derivative of the density function g is the first derivative to be positive and finite, then the elasticity is $(n + 1)$.

It remains to be shown that if the density function of one underlying asset is positive at the lower bound (i.e., $g(0) > 0$), then if we construct a pool of $\tilde{n}$ assets, the first derivative of the density function of this pool that is positive (and non-zero) is the $(\tilde{n}-1)$-th derivative.

Consider the convolution of $Y_{\tilde{n}} = \sum_{i=1}^{\tilde{n}} X_i$ and X_k where $k > \tilde{n}$, that is, $Y_{\tilde{n}+1} \equiv Y_{\tilde{n}} + X_k$. Since these $Y_{\tilde{n}}$ and X_k are independent, we can write:

$$g_{\tilde{n}+1}(y_{\tilde{n}+1}) = \int_0^{\bar{x}} g_{\tilde{n}}(y_{\tilde{n}+1} - x)g(x)dx, \tag{A8}$$

and for $0 \leq y_{\tilde{n}+1} \leq \bar{x}$ we can write:

$$g_{\tilde{n}+1}(y_{\tilde{n}+1}) = \int_0^{y_{\tilde{n}+1}} g_{\tilde{n}}(y_{\tilde{n}+1} - x)g(x)dx. \tag{A9}$$

Thus, the derivatives become:

$$g'_{\tilde{n}+1}(y_2) = g_{\tilde{n}}(0)g(y_{\tilde{n}+1}) + \int_0^{y_{\tilde{n}+1}} g'_{\tilde{n}}(y_{\tilde{n}+1} - x)g(x)dx, \tag{A10}$$

$$g''_{\tilde{n}+1}(y_{\tilde{n}+1}) = g_{\tilde{n}}(0)g'(y_{\tilde{n}+1}) + g'_{\tilde{n}}(0)g(y_{\tilde{n}+1}) + \int_0^{y_{\tilde{n}+1}} g''_1(y_{\tilde{n}+1} - x)g(x)dx, \tag{A11}$$

$$g'''_{\tilde{n}+1}(y_{\tilde{n}+1}) = g_{\tilde{n}}(0)g''(y_{\tilde{n}+1}) + g'_{\tilde{n}}(0)g'(y_{\tilde{n}+1}) + g''_{\tilde{n}}(0)g(y_{\tilde{n}+1}) + \int_0^{y_{\tilde{n}+1}} g'''_{\tilde{n}}(y_{\tilde{n}+1} - x)g(x)dx. \tag{A12}$$

Hence, when evaluated at $y_{\tilde{n}+1} = 0$, we obtain the following derivatives:

$$g'_{\tilde{n}+1}(0) = g_{\tilde{n}}(0)g(0), \tag{A13}$$

$$g''_{\tilde{n}+1}(0) = g_{\tilde{n}}(0)g'(0) + g'_{\tilde{n}}(0)g(0), \tag{A14}$$

$$g'''_{\tilde{n}+1}(0) = g_{\tilde{n}}(0)g''(0) + g'_{\tilde{n}}(0)g'(0) + g''_{\tilde{n}}(0)g(0). \tag{A15}$$

Next consider the following iteration:

- Suppose we have $\tilde{n} = 1$. Then $g_1(0) = g(0) > 0$ and adding an asset yields $g_2(0) = 0$ (see above integral), and $g'_2(0) = g_1(0)g(0) = g(0)^2 > 0$.

- Suppose we have $\tilde{n} = 2$. Then, as just shown, $g_2(0) = 0$ and $g'_2(0) > 0$. Now if we add an asset, then it yields $g_3(0) = 0$ (integral equation), and $g'_3(0) = g_2(0)g(0) = 0$. Now consider $g''_3(0) = g_2(0)g'(0) + g'_2(0)g(0) = g'_2(0)g(0) > 0$.

- Suppose we have $\tilde{n} = 3$. Then, as just shown, $g_3(0) = 0$, $g'_3(0) = 0$, and $g''_3(0) > 0$. Now if we add an asset, then it yields $g_4(0) = 0$ (integral equation), $g'_4(0) =$

$g_3(0)g(0) = 0$, and $g_4''(0) = g_3(0)g'(0) + g_3'(0)g(0) = 0$. Now consider $g_4'''(0) = g_3(0)g''(0) + g_3'(0)g'(0) + g_3''(0)g(0) = g_3''(0)g(0) > 0$.

- ...

More generally, every time we add an asset to the pool, the next-higher derivative of the density function turns to zero, while leaving the derivatives thereafter positive.

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