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Adverse Selection and Intermediation Chains

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Abstract

We propose a parsimonious model of over-the-counter trading with asymmetric information to rationalize the existence of intermediation chains that stand between the buyers and sellers of assets. Trading an asset through multiple intermediaries can preserve the efficiency of trade by spreading an adverse selection problem over many sequential transactions. An intermediation chain that involves heterogeneously informed agents helps ensure that the information asymmetries counterparties face in each transaction are small enough to result in socially efficient trading strategies by all parties involved. Our model makes novel predictions about rent extraction and socially optimal network formation when adverse selection problems impede the efficiency of trade.

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Adverse Selection and Intermediation Chains *

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Keywords: Intermediation Chains, OTC Trading Networks, Asymmetric Information, Information Percolation, Payments for Order Flow
JEL Codes: G20, D82, D85

1 Introduction

Transactions in decentralized markets often feature the successive participation of several intermediaries. For example, Viswanathan and Wang (2004, p.1) note that in foreign exchange markets "much of the inter-dealer trading via direct negotiation is sequential (an outside customer trades with dealer 1 who trades with dealer 2 who trades with dealer 3 and so on) and involves very quick interactions". Adrian and Shin (2010) argue that, more broadly, the U.S. financial system shifted in recent decades from a traditional (i.e., centralized) model of financial intermediation to a market-based model characterized by "the long chain of financial intermediaries involved in channeling funds" [p.604]. In this paper, we propose a parsimonious model of over-the-counter (OTC) trading with asymmetric information to shed light on the existence of these *intermediation chains*.

By layering an adverse selection problem over multiple sequential transactions heterogeneously informed traders can fulfill an important economic role in intermediating trade. Our model considers two asymmetrically informed agents wishing to trade an asset through bilateral bargaining in order to realize exogenous gains to trade (say, for liquidity reasons). One agent is assumed to be an expert who is well informed about the value of the asset, whereas the other agent is uninformed. A standard result in models like ours is that trade breaks down between agents when the potential gains to trade are small relative to the degree of information asymmetry about the asset's value. When this is the case, we show that involving a moderately informed agent — whose information quality ranks between that of the buyer and that of the seller — to intermediate trade can improve trade efficiency.

In contrast to other intermediation theories where one intermediary suffices to eliminate inefficient behavior, our simple mechanism can be extended to explain why trading often goes through several intermediaries rather than through simpler trading networks centered around one dominant broker. We show that trade efficiency can be further improved by reallocating the adverse selection problem over multiple sequential transactions as long as the difference in information quality is small between the two counterparties involved for each transaction. It is therefore crucial to have intermediaries located within the trading network such that each trader's information set is similar, although not identical, to that of nearby traders (i.e., his counterparties). Thus, for large adverse selection problems a high number of intermediaries may be needed to sufficiently reduce the informational asymmetries that each agent faces when it is his turn to trade the asset. Greater information asymmetries require longer intermediation chains and, overall, more trading across agents, which contrasts with the conventional wisdom that asymmetric information should be associated with low trading volume (as is the case in the seminal model of Akerlof 1970). Our model shows that the original adverse selection problem between a buyer and a seller is reallocated in a non-linear fashion when several heterogeneously informed intermediaries are involved. Each pair of sequential traders bargains based on conditional distributions for the value of the asset that are different than the distribution that characterizes the original information asymmetry without intermediaries. Splitting an information asymmetry over a sequence of several transactions among heterogeneously informed agents can be socially optimal as it sustains efficient trade.

Each trader involved in a network, however, needs to be privately incentivized to sustain trade and preserve the surplus. The conditional distributions for the value of the asset that each heterogeneously informed trader and his counterparty face determine their incentives to trade efficiently. Our model thus speaks to how trading networks impact the ability of all involved parties to extract rents and their willingness to sustain socially efficient trade in equilibrium. In some cases, the intermediary sector extracts more rents through informed trading than the additional surplus it creates for society. In those cases, intermediaries are, however, willing to offer cash payments, or subsidized services, to the other traders involved in order to secure a place in the trading network. Deal-flow is valuable to an intermediary involved in a chain and we derive the existence of a system of budget-balanced ex ante transfers that guarantees that every agent involved benefits from the implementation of a socially efficient network. We also show how the intuition developed in our baseline model can be extended to situations in which information percolates through trade as in Duffie, Malamud, and Manso (2009, 2013).

Intermediation is known to facilitate trade, either by minimizing transaction costs (Townsend 1978), by concentrating monitoring incentives (Diamond 1984), or by alleviating search frictions (Rubinstein and Wolinsky 1987, Yavaş 1994, Duffie, Gârleanu, and Pedersen 2005, Neklyudov 2013). Our paper specifically speaks to how intermediaries can solve asymmetric information problems. We already know from Myerson and Satterthwaite (1983) that an uninformed third party who subsidizes transactions can help to eliminate these problems in bilateral trade. Trade efficiency can also be improved by the involvement of fully informed middlemen who care about their reputation

(Biglaiser 1993) or who worry that informed buyers could force them to hold on to low-quality goods (Li 1998). Contrary to these models, our model considers the possibility that an intermediary's information set differs from that of the agents originally involved in the transaction. In our static model without subsidies, warranties, or reputational concerns, the involvement of an intermediary who is either fully informed or totally uninformed does not improve trade efficiency. Thus, the idea that moderately informed intermediaries can reduce trade inefficiencies simply by layering adverse selection over many sequential transactions fundamentally differentiates our paper from these earlier papers.

Reputational concerns are also central in Babus (2012) who models OTC markets where agents meet sporadically and have incomplete information about other traders' past behaviors. In equilibrium, a central intermediary who heavily penalizes anyone defaulting on his prior obligations becomes involved in all trades. Our model shows that, when asymmetric information relates to the asset being traded rather than to traders' past actions, multiple intermediaries may be needed to sustain the social efficiency of trade. Thus, rationalizing intermediation chains, which are often observed in financial markets, distinguishes our paper from the papers cited above and from many market microstructure models with heterogeneously informed traders but where trading among intermediaries plays no role. Examples of those models include Kyle (1985) and Glosten and Milgrom (1985), where competitive market makers learn from order flow data and intermediate trade between liquidity traders and informed traders, and Jovanovic and Menkveld (2012), where high frequency traders learn quickly about the arrival of news and intermediate trade between early traders who post a limit order and late traders who react to the limit order using information that became available since its posting.

Gofman (2011) studies the inefficiencies in resource allocation that arise when traders face (non-informational) bargaining frictions in a sparse OTC network. In his model, an allocation is more likely to be efficient when the network is sufficiently dense (although the relationship is not necessarily monotonic). We study the optimality of trading networks, taking as given the existence of an adverse selection problem, and find that a trading network needs to be sparse enough to sustain efficient trade in our model. Otherwise, uninformed traders might be tempted to contact socially inefficient counterparties, in an attempt to reduce the number of strategic, informed intermediaries trying to extract surplus away from them. (We discuss the role that payments for order flow might play in alleviating this problem.)

Our paper also relates to Malamud and Rostek (2013) who study the concurrent existence of several exchanges in decentralized markets. In their paper, creating a new private exchange may improve the liquidity in all other exchanges as it reduces the price impact that strategic traders impart when simultaneously trading the same asset at different prices on multiple exchanges. In our paper, this particular mechanism plays no role as trading is bilateral, occurs sequentially among intermediaries, and entails a fixed transaction size. Instead, adding moderately informed traders to an intermediation chain may improve liquidity as it reduces the information asymmetry that each trader faces when it is his turn to bargain with a better informed counterparty.

Although our model could also apply in many non-financial situations, the empirical literature on financial markets documents many facts that help to contextualize our theory of trade intermediation. Many papers document that transactions among intermediaries, a key prediction of our model, account for a substantial fraction of trading both in centralized and in decentralized financial markets.[1] For example, Lyons (1996) estimates that "inter-dealer trading" accounts for up to 85% of transaction volume in foreign exchange markets. According to a 2013 report by the Bank of International Settlements, inter-dealer transaction volume in those markets averages $2.1 trillion per day. Weller (2013) also shows that a median number of 2 intermediaries are involved between the initial seller and the final buyer of gold, silver, and copper futures contract and up to 10% of round-trip transactions require the involvement of at least 5 intermediaries.

Empirical papers such as Hansch, Naik, and Viswanathan (1998) find that inventory management can explain part of the inter-dealer trading observed in financial markets, but key features of inter-dealer trading still remain unexplained. In particular, inventory risk sharing does not provide an economic rationale for intermediation chains — risk sharing would in fact be optimized if all traders were directly connected. Further, Manaster and Mann (1996) find that the positive relationship between trader inventories and transaction prices they observe in futures trading data violates the predictions of inventory control models such as Ho and Stoll (1983). Manaster and

[1] See, e.g., Gould and Kleidon (1994) for Nasdaq stocks, Reiss and Werner (1998) and Hansch, Naik, and Viswanathan (1998) for London Stock Exchange stocks, Lyons (1996) for foreign exchange instruments, Hollifield, Neklyudov, and Spatt (2012) for securitized products, Li and Schüroff (2012) for municipal bonds, and Weller (2013) for metals futures.

Mann (1996, p.973) conclude that the intermediaries they study are "active profit-seeking individuals with heterogeneous levels of information and/or trading skill," elements that are usually absent from inventory control theories.[2] Our model simultaneously features asymmetric information and inventory management motives.[3] The intermediaries in our model are effectively averse to holding inventories (i.e., non-zero positions) since they are not the efficient holders of the asset, that is, those who realize the gains to trade. Yet, information asymmetries may prevent them from offloading the asset to potential buyers and creating a surplus.

In the model by Viswanathan and Wang (2004), the issuer of a security sometimes prefer to have a given set of dealers, heterogeneous only in their inventory levels, sequentially trading the security over having the same dealers participating in a centralized auction where the supply of the security is split among them. The argument they highlight is based on differences in how strategic dealers can behave when trading bilaterally versus participating in a centralized auction — sequential bilateral trading allows a dealer who just bought the security to act as a monopolist who controls the price and inventory of securities to be traded in later stages. Our paper instead proposes an information-based explanation for transaction chains.

Recent empirical evidence on the OTC trading of securitized products appears to lend support to the mechanism we highlight in our paper. In particular, Hollifield, Neklyudov, and Spatt (2012) show that instruments that can be traded both by unsophisticated and sophisticated investors (i.e., "registered" instruments) are usually associated with higher spreads paid to dealers (often viewed as a measure of adverse selection), more inter-dealer trading, and a higher number of dealers involved in their trading than instruments that can be traded only by sophisticated investors (i.e., "rule 144a" instruments). They also show that the spread paid to dealers is positively correlated in the cross-section of round-trip transactions with the length of the transaction chain and with the proportion of inter-dealer trades. These findings are all consistent with our model's main predictions that larger information asymmetries require longer intermediation chains, more inter-dealer trade, and are associated with larger rents going to intermediaries.

[2] See also Glosten and Harris (1988), Stoll (1989), Foster and Viswanathan (1993), Hasbrouck and Sofianos (1993), Madhavan and Smidt (1993), and Keim and Madhavan (1996) for early evidence that informational asymmetries impact intermediated transactions in financial markets.

[3] Madhavan and Smidt (1993) also combine asymmetric information and inventory management motives, but their model remains silent about the empirical phenomenon of intermediation chains. Their model features centralized trading, rather than OTC trading, and does not allow for multiple intermediaries.

In the next section, we model a simple adverse selection problem between two asymmetrically informed traders. We show in Section 3 how adding moderately informed intermediaries can eliminate trading inefficiencies that arise in such a setup. We discuss how our results relate to payments for order flow and information percolation in Section 4. The last section concludes.

2 The Adverse Selection Problem

Our model assumes two risk-neutral agents who consider trading an asset over the counter: the current owner who values the asset at v and a potential buyer who values it at $v + \Delta$. A potential interpretation for this interaction is that of a firm wishing to offload a risk exposure (e.g., to interest rates, foreign exchange rates, or commodity prices) that meets an expert able to hold the risk exposure more efficiently (e.g., by means of pooling or diversification). The firm, also referred to as the seller, tries to sell a risky asset to the expert, also referred to as the buyer, because the expert values the asset more than the firm does. Trade is thus labeled as efficient only if the gains to trade Δ are always realized and the asset ends up in the hands of the expert with probability 1.

The gains to trade Δ are constant and known to all agents, but the common value v is uncertain and takes the form:

$$v = \sum_{n=1}^{N} \phi_n \sigma,$$

where the N factors $\phi_n \in \{0, 1\}$ are drawn independently from a Bernoulli distribution with $\Pr[\phi_n = 1] = 1/2$. The common value is thus binomial distributed with $v \sim B\left(N, \frac{1}{2}\right)$ and we denote by Φ the full set of factor realizations $\{\phi_1, \phi_2, ..., \phi_N\}$.[4]

Although the role that intermediation will play in our model is relatively simple, multi-layered bargaining problems with asymmetric information are usually complex to study given the potential for multiple equilibria arising from the various types of off-equilibrium beliefs. We therefore make a few stylized assumptions that will allow us to keep the model sufficiently tractable to analyze, in Section 3, multiple sequential transactions taking place among a large number of heterogeneously informed traders.

First, we assume that, in any transaction, the current holder of the asset makes an ultimatum

[4]Shin (2003) also assumes a Binomial distribution, albeit a multiplicative one, to model uncertain asset values. His paper's focus, however, significantly differs from ours and pertains to the optimal disclosure of information by a manager and its effects on asset prices.

offer (i.e., quotes a asking price) to his counterparty. Focusing on ultimatum offers simplifies the analysis of equilibrium bidding strategies and is consistent with the characterization of sequential inter-dealer trading by Viswanathan and Wang (2004, p.1) as "very quick interactions." Assuming that a seller quotes a price rather than assuming that a buyer makes an offer will simplify the interpretation of our results and could be interpreted, for example, as a consequence of the scarcity of the asset being traded (which endows its holder with some bargaining power).

Second, we assume that prior to trading the seller is uninformed about the realizations of ϕ_n that determine the common value v, whereas the expert observes the full set Φ of factor realizations. We want to highlight here that in the context of many financial products endowing a "buyer" with the information advantage rather than the "seller" is a relatively arbitrary distinction; for example, a firm could be viewed as the buyer of an insurance policy, or, alternatively, as the seller of a risk exposure.

Third, agents know how well informed their counterparties are since we assume that the set of factors that each agent observes is common knowledge.[5] Although traders in our setting are asymmetrically informed about the common value component v, all traders know the quality of the information available to their counterparties. Seppi (1990) lends support to this assumption arguing that agents knowing the identity of their trading counterparties is an important distinction between OTC trading and centralized/exchange trading.

Together, these three assumptions eliminate signaling concerns from our model and guarantee the uniqueness of our equilibrium without the need for equilibrium refinements. We are, thus, able to derive closed-form solutions for many objects of interest that would otherwise be hard to uniquely pin down. For example, the lemma that follows characterizes a limited set of price quotes the seller chooses from when trading directly with the expert buyer.

Lemma 1 (Price candidates under direct trade) *If the seller and the expert buyer trade directly, the seller optimally chooses to quote one of $(N+1)$ price candidates p_i, where p_i is defined as*

$$p_i = i\sigma + \Delta, \quad i \in \{0, ..., N\}.$$

[5] Morris and Shin (2012) relax the common-knowledge assumption in a bilateral trading setup similar to the one modeled in this section and show how the resulting coordination problems can magnify the effect of adverse selection on trade efficiency.

The unconditional probability with which the expert buyer accepts a price quote p_i is given by:

$$\pi_i = \sum_{k=0}^{N-i} \begin{pmatrix} N \\ k \end{pmatrix} \left(\frac{1}{2}\right)^N .$$

Proof. The expert buyer optimally accepts to pay a given price $\tilde{p}$ if and only if $\tilde{p} \leq v + \Delta$. Given the Binomial distribution for v, the price candidates $p_i = i\sigma + \Delta$ for $i \in \{0, ..., N\}$ represent the maximum prices the seller can charge conditional on ensuring any given feasible acceptance probability. Further, the seller strictly prefers quoting p_N relative to non-participation, since doing so increases his average payoff by $\frac{\Delta}{2^N}$. ∎

For trade to be efficient and occur with probability one, the seller must find it optimal to quote p_0 in equilibrium rather than any other price candidate p_i, where $i \in \{1, ..., N\}$. The following proposition provides a necessary and sufficient condition for the fundamentals of the asset (σ, Δ, N) to ensure efficient trade when seller and expert buyer interact directly.

Proposition 1 (Efficient direct trade) *Direct trade between the seller and the expert buyer is efficient if and only if the following condition is satisfied:*

$$\frac{\sigma}{\Delta} \leq \frac{1}{2^N - 1}. \tag{1}$$

Proof. Lemma 2, which we present and derive in Appendix A, shows that the incentive to increase the price quote from p_i to p_{i+1} is strongest at $i = 0$ and the condition for the seller to prefer to quote a price p_0 rather than p_1 also implies that he prefers p_0 over any p_i where $i \in \{1, ..., N\}$. A seller who decides to quote p_1 rather than p_0 receives a higher price $(p_1 - p_0 = \sigma)$ with probability $1 - \left(\frac{1}{2}\right)^N$, but forgoes extracting the gains to trade Δ with probability $\left(\frac{1}{2}\right)^N$. The seller thus chooses to quote p_0 among all prices if and only if doing so generates a weakly higher expected payoff than quoting p_1:

$$\begin{aligned} \pi_0 p_0 &\geq \pi_1 p_1 + (1 - \pi_1) \cdot 0 \\ \Leftrightarrow \Delta &\geq \left(1 - \left(\frac{1}{2}\right)^N\right)(\sigma + \Delta) . \end{aligned}$$

The result in Proposition 1 follows directly from the last inequality. ■

Efficient trade thus requires a small value for $\frac{\sigma}{\Delta}$, which quantifies the price concession made by the seller when quoting the lowest price p_0 relative to the gains to trade he extracts from sustaining trade. When $\frac{\sigma}{\Delta}$ is high and there is too much adverse selection relative to the surplus created by trade, trade breaks down with probability $\left(\frac{1}{2}\right)^N$ or greater and at least $\frac{\Delta}{2^N}$ in surplus from trade is destroyed.[6]

Next, we will show how a trading network that splits the information asymmetry over a sequence of transactions can induce fully efficient behavior on the part of heterogeneously informed traders. Although other mechanisms have been proposed to solve adverse selection problems (see, for example, the literature on optimal security design which includes: DeMarzo 2005, Chakraborty and Yilmaz 2011, Yang 2013), the idea that intermediation chains can by themselves eliminate these problems is novel and may help us to understand their prevalence in decentralized markets.

3 Intermediation Chains

In this section, we consider the involvement of M intermediaries who observe different *subsets* of Φ, the full set of factor realizations ϕ_n. Like the seller, these intermediaries privately value the asset at v, thus, trading the asset to them is not sufficient to realize gains to trade. Moreover, these intermediaries do not bring new information to the table, as their information is nested by the information available to the expert buyer. However, as we show below, intermediation chains involving traders with different levels of expertise can improve the efficiency of trade by reallocating an adverse selection problem over several sequential transactions.

Consider a simple "linear" trading network in which the uninformed firm offers to sell the asset to intermediary 1. If trade occurs, intermediary 1 then offers to sell the asset to the next trader in the network, intermediary 2. Conditional on trade occurring, these bilateral interactions are repeated up until we reach the end of the chain, where intermediary M offers to sell the asset to the expert buyer. (To simplify the notation, we label the firm/seller as trader 0 and the expert

[6] Asymmetric information could also affect the gains to trade Δ rather than only affecting the common value v as is the case in our model. For example, gains to trade could be influenced by private information about a dealer's order flow. We know, however, from Myerson and Satterthwaite (1983) that asymmetric information leading to inefficient trading is a common result in bilateral bargaining, and we simplify the analysis by focusing on only one type of information asymmetry.

buyer as trader $M+1$.) Traders are not allowed to deviate from the trading network by bypassing the trader who is next in line in the intermediation chain (we discuss this assumption later in the section). Further, consistent with how we modeled trading without an intermediary, we assume that whoever owns the asset and tries to sell it quotes an ultimatum price to his counterparty.

The M intermediaries are assumed to be heterogeneously informed, as it is often the case in OTC markets. In fact, the main mechanism that makes intermediation valuable in our model can be highlighted best by assuming that the subset of factor realizations that intermediary m observes before trading is nested by the subset of factor realizations that intermediary $m+1$ observes before trading: $\Phi_m \subseteq \Phi_{m+1} \subseteq \Phi$, for $m \in \{0, 1, ..., M\}$. Trader 1 is thus assumed to be the intermediary with the least expertise, as he only observes realizations from N_1 factors, say $\{\phi_1, \phi_2, ..., \phi_{N_1}\}$, which can be interpreted as information that is relatively cheap to acquire and easy to interpret. Trader 2 observe the same N_1 factors $\{\phi_1, \phi_2, ..., \phi_{N_1}\}$ as well as $(N_2 - N_1)$ extra factors that are a little bit harder or more expensive to gather. And so on until we reach the expert (i.e., trader $M+1$) who observes all factors included in Φ. This linear network with increasingly informed traders implies that the information set of the proposer of a price quote is always weakly dominated by the responder's information set. Figure 1 shows an example of information sets in a trading network with two intermediaries.

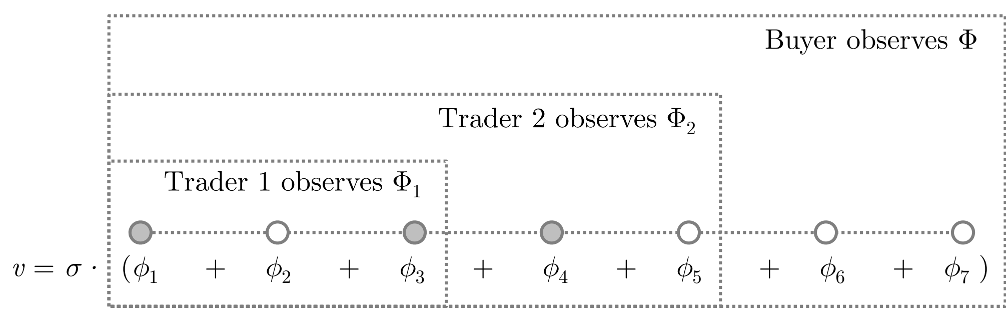

Figure 1: **Example of information sets in trading network.** The figure illustrates our informational structure when two intermediaries are involved ($M = 2$) in trading an asset whose common value v depends on seven factors ϕ_i ($N = 7$). The dotted rectangles indicate the set of factor realizations that are observable to the two intermediaries and to the expert buyer (remember: the firm/seller observes none of these factors). Factor realizations $\phi_i \in \{0, 1\}$ are indicated by the circles that are either unfilled (for $\phi_i = 0$) or filled (for $\phi_i = 1$). The seller is uninformed and thus does not observe any of the factor realizations.

Nesting traders' information sets eliminates signaling concerns and ensures the uniqueness of our equilibrium despite the fact that we consider $(M+1)$ bargaining problems among $(M+2)$ heterogeneously informed agents. Moreover, the recursive nature of our model yields a clean and transparent analytical proof of our main result: an intermediation chain can preserve the efficiency of trade in situations where some surplus would be destroyed if trade were to occur through fewer intermediaries. As will become clear soon, what ultimately contributes to sustaining efficient trade is that the chain reduces the distance in counterparties' information sets, although information sets do not necessarily have to be nested for our mechanism to work. For example, we show in Section 4 that if information sets are non-nested initially but information percolates through trade as in Duffie, Malamud, and Manso (2009, 2013), a similar idea will apply as the asset will be held by increasingly better informed agents through the chain. The proposition below formalizes our main result and is followed by the analysis of two special cases that help illustrate the intuition.

Proposition 2 (Efficient trade in an intermediation chain) *Trade is efficient throughout the trading network if and only if:*

$$\frac{\sigma}{\Delta} \leq \min_{m\in\{0,1,\ldots,M\}} \frac{1}{2^{(N_{m+1}-N_m)} + \frac{N-N_{m+1}}{2} - 1}. \tag{2}$$

Under efficient trade, the expected surplus from trade is split between the original seller who obtains $\Delta - \frac{N}{2}\sigma$ *and each trader* $m \in \{1, ..., M+1\}$ *who obtains* $\left(\frac{N_m - N_{m-1}}{2}\right)\sigma$.

Proof. Consider a situation in which trader m currently holds the asset and tries to sell it to trader $m+1$. Trader m knows that G_m of the N_m factor realizations he observes have a value of 1. Similarly, trader $m+1$ knows that G_{m+1} of the N_{m+1} factor realizations he observes have a value of 1. The condition that information sets satisfy $\Phi_m \subseteq \Phi_{m+1} \subseteq \Phi$ implies that $0 \leq N_m \leq N_{m+1} \leq N$ and $0 \leq G_m \leq G_{m+1} \leq N$. Assume for now that whenever trader $m+1$ acquires the asset, subsequent trading is efficient, which requires that subsequent traders $k \in \{m+1, m+2, ..., M\}$ each charge a price:

$$p_0^k = G_k\sigma + \Delta,$$

and maximize subsequent trade probability. Trader m then chooses to quote one of $(N_{m+1} - N_m + 1)$

price candidates defined as:

$$p_i^m = (G_m + i)\,\sigma + \Delta, \quad i \in \{0, ..., N_{m+1} - N_m\}.$$

The weakly better informed trader $m+1$ only accepts to pay a price p_i^m if it is weakly lower than the price he plans to quote to trader $m+2$, that is, $p_0^{m+1} = G_{m+1}\sigma + \Delta$. For trade to be efficient between traders m and $m+1$, trader m must find it optimal to quote p_0^m in equilibrium rather than any other price candidate p_i^m. Lemma 2 in Appendix A shows that trader m finds optimal to quote p_0^m rather than any other p_i^m if and only if quoting p_0^m makes him wealthier in expectation than quoting p_1^m:

$$\begin{aligned} G_m\sigma + \Delta &\geq \left(1 - \left(\frac{1}{2}\right)^{(N_{m+1}-N_m)}\right)\left[(G_m + 1)\,\sigma + \Delta\right] + \left(\frac{1}{2}\right)^{(N_{m+1}-N_m)}\left(G_m + \frac{N - N_{m+1}}{2}\right)\sigma \\ \Leftrightarrow \frac{\sigma}{\Delta} &\leq \frac{1}{2^{(N_{m+1}-N_m)} + \left(\frac{N-N_{m+1}}{2}\right) - 1}. \end{aligned}$$

Recursively applying this condition to each trading stage yields the following condition for efficient trade throughout the trading network:

$$\frac{\sigma}{\Delta} \leq \min_{m \in \{0,1,...,M\}} \frac{1}{2^{(N_{m+1}-N_m)} + \left(\frac{N-N_{m+1}}{2}\right) - 1}.$$

Under efficient trade, each trader $m \in \{1, ..., M\}$ collects an expected surplus of:

$$\begin{aligned} E\left[p_0^m | \Phi_{m-1}\right] - p_0^{m-1} &= G_{m-1}\sigma + \left(\frac{N_m - N_{m-1}}{2}\right)\sigma + \Delta - \left[G_{m-1}\sigma + \Delta\right] \\ &= \left(\frac{N_m - N_{m-1}}{2}\right)\sigma, \end{aligned}$$

the final buyer (trader $M+1$) collects an expected surplus of:

$$\begin{aligned} E\left[v | \Phi_M\right] + \Delta - p_0^M &= G_M\sigma + \left(\frac{N - N_M}{2}\right)\sigma + \Delta - \left[G_M\sigma + \Delta\right] \\ &= \left(\frac{N - N_M}{2}\right)\sigma, \end{aligned}$$

and the initial seller (trader 0) collects a surplus of:

$$\Delta - E\left[v\right] = \Delta - \frac{N}{2}\sigma.$$

■

The proposition formalizes the intuition that an asset characterized by the triplet (σ, Δ, N) is more likely to be traded efficiently within a network if the differences in expertise between sequential trading partners $(N_{m+1} - N_m)$ are small. By focusing on traders' behavior along the efficient trading path, we are able to exploit the recursivity of the sequence of transactions and show in a tractable way how intermediation chains can help resolve an adverse selection problem. Formally, the condition in eqn. (2) for efficient trade is weakly less restrictive than the corresponding condition in eqn. (1) for the case without intermediaries. (In fact, due to the recursive nature of our model, eqn. (2) corresponds to eqn. (1) when we set $M = 0$.)

The holder of an asset faces the following trade-off when choosing the price he quotes to his counterparty. If the conditions for efficient trade are satisfied for all subsequent transactions in the chain, the prospective seller recognizes that subsequent trading will preserve the whole gains to trade Δ. Hence, he compares the benefit of extracting the full Δ with the cost of sustaining efficient trade with a counterparty who possesses an information advantage of $(N_{m+1} - N_m)$ factors. When a trader faces a counterparty who is significantly better informed than him, he might find optimal to quote a high price, in case the informed counterparty receives good signals and accepts to pay the high price. However, this strategy also comes at a cost since the quoted price sometimes exceeds the counterparty's valuation of the asset. Although such trading strategies may be privately optimal for less informed traders, they are socially inefficient since gains to trade are destroyed with positive probability. Transactions between more homogenously informed agents give asset holders lower incentives to quote inefficiently high prices, relative to the gains to trade Δ, as marginally better informed counterparties are less likely to accept such high offers. Intermediation chains can thus preserve efficient trade in situations where trade would otherwise break down with positive probability.

Moreover, as the ratio $\frac{\sigma}{\Delta}$ increases and the adverse selection problem worsens, a higher number of intermediaries M may be needed to sufficiently bound the information asymmetries that each trading counterparty faces. Specifically, it is easy to show that adding intermediaries helps to relax the restriction on $\frac{\sigma}{\Delta}$ derived in Proposition 2. Suppose an intermediary m' is added between traders m and $m+1$. If the expertise of intermediary m' differs from that of those already involved in the chain, in particular if $N_m < N_{m'} < N_{m+1}$, the terms on the right-hand side of eqn. (2) should weakly increase for all layers of transactions. First, all terms on the right-hand side of (2) that do not involve trader m' remain the same as before. Second, both of the terms that involve trader m' are strictly greater than the old term they replace:

$$\frac{1}{2^{(N_{m+1}-N_{m'})}+\frac{N-N_{m+1}}{2}-1} > \frac{1}{2^{(N_{m+1}-N_m)}+\frac{N-N_{m+1}}{2}-1},$$

and

$$\frac{1}{2^{(N_{m'}-N_m)}+\frac{N-N_{m'}}{2}-1} > \frac{1}{2^{(N_{m+1}-N_m)}+\frac{N-N_{m+1}}{2}-1}.$$

The socially optimal response to greater information asymmetries is thus longer intermediation chains and more trading among all agents involved.

The proposition also shows that, given equal informational distances between bilateral counterparties, $(N_{m+1}-N_m)$ for all m, efficient trade is hardest to sustain at the beginning of the chain where less is known about the overall value of the asset. Earlier in the chain, the expected value of the asset linked to the factors that are unknown to trading counterparties is greater, which makes the possibility of charging a high price and being stuck with the asset less costly than it is later in the chain.

Conditional on efficient trade throughout the network, each informed trader collects rents that increase with the uncertainty in asset value, σ, as well as with his informational advantage over the trader that sells him the asset, $(N_m - N_{m-1})$. These rents come from the optimality for trader $m-1$ to charge a low price to trader m in order to ensure his full participation in the trade and preserve the whole gains to trade Δ. Trader m only pays $G_{m-1}\sigma + \Delta$ and expects to collect $G_m\sigma + \Delta$. The intermediary sector as a whole is therefore able to extract rents of $\frac{N_M}{2}\sigma$ in total. Among the networks that sustain efficient trade, networks with fewer, more distanced, intermediaries increase the rents that accrue to the expert as well as the average rent a moderately informed intermediary extracts. Our model thus makes predictions about how surplus from trade should be distributed among heterogeneously informed OTC market participants and contributes to the literature on rent-extraction in finance (Murphy, Shleifer, and Vishny 1991, Philippon 2010, Bolton, Santos, and Scheinkman 2012, Glode, Green, and Lowery 2012, Biais and Landier 2013, Glode and Lowery 2013).

To further illustrate how moderately informed intermediaries can help solve an adverse selection problem between two asymmetrically informed traders, we now analyze two special cases of our model (in which $N = 2$ and $N = 3$, respectively).

Two-Factor Case: Suppose an asset is worth $v = \phi_1\sigma + \phi_2\sigma$ to the seller and $v + \Delta$ to the buyer. Without an intermediary, the seller chooses to quote one of three price candidates: (i) Δ, which is accepted by the buyer with probability 1; (ii) $\sigma + \Delta$, which is accepted with probability 3/4; (iii) $2\sigma + \Delta$, which is accepted with probability 1/4.

The first price candidate Δ splits the surplus from trade such that the seller collects $\Delta - \sigma$ and the buyer collects σ. The second price candidate $\sigma + \Delta$ produces an expected surplus of $\frac{3}{4}\Delta - \frac{1}{4}\sigma$ for the seller and $\frac{1}{4}\sigma$ for the buyer. The third price candidate produces an expected surplus of $\frac{1}{4}\Delta$ for the seller and no surplus for the buyer. Quoting the low price Δ is thus optimal for the seller, making trade efficient, if and only if $\frac{\sigma}{\Delta} \leq 1/3$.

However, when an agent observes ϕ_1 and intermediates trade between the seller and the buyer, trade can be efficient even though $\frac{\sigma}{\Delta} > 1/3$. Specifically, when holding the asset the intermediary is in expectation wealthier from quoting $\phi_1\sigma + \Delta$ rather than $\phi_1\sigma + \sigma + \Delta$ if and only if:

$$\phi_1\sigma + \Delta \geq \frac{1}{2}(\phi_1\sigma + \sigma + \Delta) + \frac{1}{2}\phi_1\sigma,$$

which simplifies to $\frac{\sigma}{\Delta} \leq 1$. Given that, the seller chooses between a price candidate Δ, which is accepted by the intermediary with probability 1, and a price candidate $\sigma + \Delta$, which is accepted by the intermediary with probability 1/2. The seller is in expectation wealthier when quoting Δ rather than $\sigma + \Delta$ if and only if:

$$\Delta \geq \frac{1}{2}(\sigma + \Delta) + \frac{1}{2}\left(\frac{\sigma}{2}\right),$$

which simplifies to $\frac{\sigma}{\Delta} \leq 2/3$.

Hence, in the region where $1/3 < \frac{\sigma}{\Delta} \leq 2/3$, trade is efficient if an intermediary who observes only one of the two factors is involved, but inefficient without an intermediary. The total surplus generated by trade in equilibrium increases from $\frac{3}{4}\Delta$ without an intermediary to Δ with an intermediary. The buyer extracts $\sigma/2$ with an intermediary, which is twice as much as what he would get without an intermediary. Because trade occurs at a low price between the seller and the intermediary, the intermediary is also able to extract a surplus $\sigma/2$. The seller extracts $\Delta - \sigma$, which is however less than what he would extract without an intermediary (i.e., $\frac{3}{4}\Delta - \frac{1}{4}\sigma$) when $\frac{\sigma}{\Delta} > 1/3$.

When an intermediary is involved, the difference in information quality between counterparties is small enough in both transactions to allow for efficient trade throughout the network. However, this comes at the cost of adding a strategic agent, the intermediary, who captures a share of the surplus and makes the uninformed seller worse off. When trading directly with the expert, the seller has the (socially inefficient) option of selling the asset at a price $\sigma + \Delta$, which the expert accepts to pay with probability 3/4. With the intermediary, the seller can still sell the asset at a price $\sigma + \Delta$, this time to the intermediary, but the intermediary only accepts to pay this price with probability 1/2. By making the socially inefficient price quote $\sigma + \Delta$ less attractive to the seller, the intermediary makes him worse off in the region where $1/3 < \frac{\sigma}{\Delta} \leq 2/3$, thus he makes trade more efficient. As a consequence, if allowed the seller would prefer to bypass the intermediary and make an ultimatum offer to the buyer. This deviation would lead to a lower social surplus than if trade goes through the intermediary. The socially efficient trading network therefore centers around a moderately informed intermediary, and it is also *sparse*, in the sense that the seller cannot contact the buyer himself. Alternatively, the expert buyer could commit to ignore any offer coming directly from the uninformed seller, since the buyer is better off when trade goes through a moderately informed intermediary; the expert buyer collects a surplus of $\sigma/2$ when trade goes through the intermediary and is efficient compared to $\sigma/4$ when trade breaks down because no intermediary is involved. The fact that, in practice, it is nearly impossible for retail investors and unsophisticated firms to contact the most sophisticated trading desks directly and bypass the usual middlemen suggests that sparse intermediated networks, or equivalent commitments by sophisticated trading desks, are sensible outcomes of our theory. We also discuss in Section 4 the role that ex ante transfers such as payments for order flow can play in ensuring that the socially efficient trading network is Pareto dominant.

Note also that in the region where $1/3 < \frac{\sigma}{\Delta} \leq 2/3$ the surplus the moderately informed agent collects from intermediating trade is greater than the surplus he could collect if he stayed outside the trading network and (credibly) offered to sell his signal to the uninformed agent, in the spirit of Admati and Pfleiderer (1988, 1990). The reason for this result is that a moderately informed intermediary is rewarded for improving trade efficiency, but he also extracts rents from the uninformed agent.

Moreover, replacing the intermediary with a different one who instead observes zero or two factors would eliminate any benefit of intermediation here. Hence, if offered the opportunity to choose his own information set, a potential intermediary should opt for acquiring more information than the least informed trader and less information than the most informed trader, as it is the only way for the intermediary to play a valuable role in our model.

Finally, note that if trade breaks down despite the involvement of an intermediary, the total surplus that is generated from trade is weakly greater without an intermediary than with one. The intermediary's strategic behavior aimed at appropriating a share of the surplus then becomes an impediment to trade that overpowers the benefits of his involvement that we highlighted so far. This result might help to formalize the role that intermediation chains have played in the recent crisis (i.e., times of high uncertainty), as discussed by Adrian and Shin (2010)

The next special case we consider will help to illustrate that, as the adverse selection problem between the ultimate buyer and seller worsens, more intermediaries may be needed to preserve efficient trade.

Three-Factor Case: Suppose that the asset is worth $v = \phi_1\sigma + \phi_2\sigma + \phi_3\sigma$ to the seller and $v + \Delta$ to the buyer. Without the involvement of intermediaries, we know from eqn. (2) that the seller chooses to quote the efficient price Δ if and only if $\frac{\sigma}{\Delta} \leq \frac{1}{7}$. Proposition 2 also implies that an intermediary who observes the realization of one of the three factors allows for efficient trade if and only if:

$$\frac{\sigma}{\Delta} \leq \min \left\{ \frac{1}{2^2 - 1}, \frac{1}{2 + \binom{2}{2} - 1} \right\} = 1/3,$$

whereas an intermediary who observes the realizations of two of the three factors allows for efficient trade if and only if:

$$\frac{\sigma}{\Delta} \leq \min \quad \left\{ \frac{1}{2-1}, \frac{1}{2^2 + \left(\frac{1}{2}\right) - 1} \right\} = 2/7.$$

Thus, as in the two-factor case, adding a second layer of transactions to reduce the distance between counterparties' information sets can eliminate entirely the trading inefficiencies that adverse selection imposes. Overall, in the region where $1/7 < \frac{\sigma}{\Delta} \leq 1/3$, trade is efficient if a moderately informed intermediary is involved, but is inefficient without him.

Involving two intermediaries further extends the region of efficient trade. An intermediation chain in which the seller trades with a first intermediary who observes one factor before trading with a second intermediary who observes two factors (including the one the first intermediary observes) before trading with the expert buyer allows for efficient trade if and only if:

$$\frac{\sigma}{\Delta} \leq \min \quad \left\{ \frac{1}{2-1}, \frac{1}{2 + \left(\frac{1}{2}\right) - 1}, \frac{1}{2 + \left(\frac{2}{2}\right) - 1} \right\} = 1/2.$$

In the region where $1/3 < \frac{\sigma}{\Delta} \leq 1/2$, trade is thus efficient if two heterogeneously informed intermediaries are involved, but is inefficient with zero or one intermediary.

An important implication of our analysis is that intermediaries should be located within the trading network such that each trader's information set is similar, but not identical, to that of nearby traders. It is socially optimal to have, for example, the least sophisticated intermediaries trading directly with the least informed end-traders, in this case the firm, and the most sophisticated intermediaries trading directly with the most informed end-traders, in this case the expert.

Our paper also highlights that the optimality of specific trading networks greatly depends on the trading frictions that are most relevant in a given context. In Babus (2012), agents meet sporadically and have incomplete information about other traders' past behaviors. The optimal trading network is then centered around a single intermediary who is involved in all trades and who can heavily penalize anyone defaulting on his prior obligations. If the information asymmetry relates to the asset being traded rather than to traders' past actions, our model shows that multiple heterogeneously informed intermediaries may be needed to sustain the social efficiency of trade. In Gofman (2011), traders face non-informational bargaining frictions that imply that socially efficient outcomes are easier to achieve when the network is sufficiently dense (although the relationship is not always monotonic). On the other hand, in our model a trading network needs to be sufficiently sparse to sustain efficient trade. Otherwise, uninformed parties might trade with much better informed traders, thereby reducing trade efficiency. (We also discuss in the next section the role that payments for order flow might play in alleviating this problem.) Given that various trading frictions are more relevant in some situations than others, our results and those derived in the related papers above can help us understand which type of network should arise in different contexts.

4 Discussion

In this section, we discuss how ex ante transfers such as payments for order flow allow socially efficient networks to Pareto dominate socially inefficient ones and how information percolation allow the intuition developed in our baseline model to survive when traders' information sets are non-nested.

4.1 Reallocating Rents

So far, we have shown that if a social planner wants to maximize the social surplus from trade between an uninformed seller and an expert buyer, he will have trade occurring through a chain where the uninformed seller trades the asset to a slightly better informed intermediary, who then trades it to another slightly better informed intermediary, and so on until the asset reaches the expert buyer. This intermediation chain will allow trade to occur efficiently, preserving all gains to trade, in situations where direct trading between the buyer and the seller would be inefficient.

We, however, also know that when an intermediation chain helps preserve more social surplus than direct trade, the seller is better off without the intermediation chain. When $\frac{\sigma}{\Delta} > \frac{1}{2^N - 1}$, the uninformed seller extracts a higher surplus in direct trade by quoting the expert buyer an inefficient price than the surplus he extracts from trading through a socially optimal intermediation chain (i.e., $\Delta - E[v]$). Thus, because of the informational rents that informed intermediaries and the expert are able to extract, the seller finds it too expensive to trade through the socially optimal network and would prefer the withdrawal of intermediaries. In that sense, implementing an intermediation chain to solve an adverse selection problem maximizes the social surplus from trade, but it is not a Pareto improvement over direct trading between the buyer and seller. Moreover, we can show that in the two-factor case the intermediary sector adds social value, in the form of greater gains to trade being preserved, but it sometimes extract more value than it adds in total.

Two-Factor Case, revisited: In the region where $1/3 < \frac{\sigma}{\Delta} \leq 2/3$, the seller quotes a price $\sigma + \Delta$ when there is no intermediary, yielding an expected surplus of $\frac{3}{4}\Delta - \frac{1}{4}\sigma$ for the seller and $\sigma/4$ for the buyer. With an intermediary who observes one factor realization, the seller only extracts $\Delta - \sigma$ in expectation, while the buyer and intermediary each extract $\sigma/2$. The seller is made worse off by the involvement of the intermediary whereas the buyer is better off. Overall, the intermediary creates $\Delta/4$ of social surplus, but extracts $\sigma/2$. Thus, within that region the intermediary sector creates more value than it extracts if and only if $\frac{\sigma}{\Delta} < 1/2$.

It is, however, simple to construct a system of ex ante transfers that makes all parties better off when trade occurs efficiently through an intermediation chain rather than inefficiently through direct trade. Since intermediaries do not extract rents when they are not part of the trading network, ex ante transfers that take place before agents observe factor realizations and begin trading can ensure that the initial seller and the ultimate buyer of the asset both benefit from the implementation of a socially efficient trading network. In financial markets, these transfers from the intermediary sector to the ultimate buyers and sellers of securities may come in the form of cash payment for order flow, profitable IPO allocations, soft dollars, or subsidies on various other services that intermediaries perform. In fact, there is ample empirical evidence that such "perks" are commonly used by financial intermediaries to compensate traders for their business (see, e.g., Blume 1993, Chordia and Subrahmanyam 1995, Reuter 2006, Nimalendran, Ritter, and Zhang 2007).[7] The proposition below shows the existence of transfers that allow the socially efficient network to Pareto dominate socially inefficient networks.

Proposition 3 (Ex ante transfers) *Let θ denote the difference between the surplus that an efficient intermediation chain preserves and the surplus that direct trade preserves when inefficient.*

[7] Arrangements that involve payments for order flow in equity and option markets are required to be disclosed in advance in Rule 606 reports. Thus, just like in our model, transfers of this type do not vary based on transaction-specific information (i.e., a particular realization of v), although they vary based on the expertise of the traders involved (Easley, Kiefer, and O'Hara 1996). This characterization distinguishes these ex ante transfers from the transfers that occur later as part of the trading process (i.e., transaction prices p_i^m).

For any set $\{\beta_0, \beta_1, ..., \beta_{M+1}\}$ *such that* $\beta_m > 0$ *for all* $m \in \{0, 1, ..., M+1\}$ *and* $\sum_{m=0}^{M+1} \beta_m = 1$, *a system of ex ante transfers exists such that each agent* m *extracts* $\beta_m \theta$ *more surplus with the intermediation chain than without.*

Proof. Let $\alpha(\Delta - \theta)$ and $(1-\alpha)(\Delta - \theta)$ respectively be defined as the surplus that the seller and the buyer extract when trading without intermediaries. Since direct trade is assumed to be inefficient here, we know that $\theta > 0$. Consider the following system of transfers taking place before agents observe factor realizations and begin trading. Each intermediary $m \in \{1, 2, ...M\}$ involved in the chain pays:

$$\left(\frac{N_m - N_{m-1}}{2}\right)\sigma - \beta_m \theta,$$

the buyer receives:

$$(1-\alpha)(\Delta - \theta) + \beta_{M+1}\theta - \left(\frac{N - N_M}{2}\right)\sigma,$$

and the seller receives:

$$\alpha(\Delta - \theta) + \beta_0 \theta - \Delta + \frac{N}{2}\sigma.$$

All agents are made better off by the intermediation chain and the above system of transfers, implying that it is a Pareto improvement over the inefficient trading that occurs without intermediaries.

■

The system of transfers proposed in the proposition above is budget balanced and guarantees that every agent, including the ultimate buyer and seller, strictly prefers the socially efficient trading network. Without these payments, the intermediary sector extracts too much rents for both of these agents to simultaneously benefit from the efficiency gain θ. The payments intermediaries make in the proposition ensure that the seller and the buyer capture a positive fraction of θ in expectation, resulting in a lower, yet still positive, surplus of $(1 - \beta_0 - \beta_{M+1})\theta$ going to the intermediary sector as a whole. In our model, deal-flow is valuable to any intermediary included in an efficient trading network, since his informational advantage over his counterparty allows him to extract a fraction of the gains to trade Δ. Hence, intermediaries are willing to offer cash payments, or subsidized services, to the ultimate buyer and seller of the asset if these are required concessions for being involved in the trading network.

4.2 Information Percolation

We now discuss how the intuition developed in our baseline model extends to situations in which intermediaries' information sets are non-nested initially, but information percolates through trade as in Duffie, Malamud, and Manso (2009, 2013). To illustrate this argument, we revisit the three-factor case analyzed in Section 3 and prove the existence of a perfect Bayesian equilibrium in which intermediation chains improve trade efficiency just as they do in our baseline setup where information sets are nested by construction.

In the three-factor case, the common value component is given by $v = \phi_1\sigma + \phi_2\sigma + \phi_3\sigma$. Recall that in Section 3 we showed that involving two intermediaries who observe the sets of factors $\{\phi_1\}$ and $\{\phi_1, \phi_2\}$ respectively allows for efficient trade as long as: $\frac{\sigma}{\Delta} \leq 1/2$. Further, if $1/3 < \frac{\sigma}{\Delta} \leq 1/2$, trade is inefficient with one or no intermediary, which highlights the benefits of forming an intermediation chain with two heterogeneously informed traders.

In the current analysis, we deviate from the intermediation chain assumed earlier and consider instead the involvement of two intermediaries who observe *disjoint* sets of factors before trading occurs. Traders can, however, learn the information of their respective counterparty after trading has occurred, which is analogous to the notion of information percolation studied in Duffie, Malamud, and Manso (2009, 2013).[8]

Specifically, we consider a trading network in which the uninformed seller trades with trader 1, who observes ϕ_1, and who then trades with trader 2, who observes ϕ_2. Finally, trader 2 trades with the expert buyer. Because information percolates once traders 1 and 2 have finalized their transaction, trader 2 knows the realizations of factors $\{\phi_1, \phi_2\}$ by the time he quotes a price to the expert buyer. Since we are now considering a bargaining game in which a proposer (trader 1) possesses private information not known to a responder (trader 2), we no longer have a unique equilibrium. The purpose of the current analysis is to show the existence of at least one equilibrium

[8] As in Duffie, Malamud, and Manso (2009, 2013) the traders in our model do not have any reason to refrain from sharing their information with their counterparty once a transaction has been finalized. Sharing information prior to the transaction occurring would, however, not be optimal for informed traders. A prospective seller does not want to share a bad private signal about v prior to the transaction, but he has no reason not to do so once the transaction has been finalized. As in Duffie, Malamud, and Manso (2009, 2013) we abstract away from the specific process through which information sharing occurs. Instead, we focus on the implications of this information structure on trade efficiency.

in which intermediation chains improve efficiency. We conjecture an equilibrium that sustains efficient trade and satisfies the following properties:

- Trader 2 quotes a price $\phi_1\sigma + \phi_2\sigma + \Delta$ to the expert buyer, who always accepts.
- Regardless of the realization of ϕ_1, trader 1 quotes the highest price at which trader 2, knowing nothing about trader 1's information, always accepts: $\bar{p} = \frac{\sigma}{2} + \Delta$.
- Trader 2 believes any price quote higher than $\bar{p}$ is uninformative about trader 1's information.
- The uninformed seller quotes a price $\bar{p}$ to trader 1, who always accepts.

Arguably, trader 2's off-equilibrium beliefs are reasonable here, since any seller would strictly prefer to collect more than the equilibrium price if possible. The marginal profit when collecting a higher price for trader 1 is the same, irrespective of his information about ϕ_1. (Many other off-equilibrium beliefs would allow our results to survive qualitatively, but the region over which intermediation chains preserve efficient trade would change.) As such, the beliefs we use here allow our equilibrium to satisfy the Intuitive Criterion from Cho and Kreps (1987). In our context, the Intuitive Criterion requires that the trader 2 ascribes zero probability to any trader-1 type who would be worse off by quoting a higher price regardless of the trader 2's actions. Clearly, either trader-1 type would be better off with a higher price should trader 2 accept.

We prove in Appendix B the existence of such perfect Bayesian equilibrium as long as $\frac{\sigma}{\Delta} \leq \frac{1}{2}$. This condition is *identical* to the one that emerges in the three-factor case when information sets are nested (see Section 3). Nested information sets are thus not necessary to show that intermediation chains allow trading to occur more efficiently when information asymmetries impede direct trading between asymmetrically informed agents. In fact, the analysis of a special case shows that in the presence of information percolation, replacing an intermediation chain with nested information sets by a chain with non-nested information may very well produce the same efficiency gains.

5 Conclusion

This paper shows that chains of heterogeneously informed intermediaries can help alleviate adverse selection problems that impede efficient trading between asymmetrically informed agents. Complex trading networks that involve multiple intermediaries may be the socially optimal response to information asymmetries as reallocating a large adverse selection problem over several transactions reduces agents' incentives to inefficiently limit trade when facing better informed counterparties. Thus, greater information asymmetries require longer intermediation chains to sustain efficient trade. Moreover, if market participants implement efficient networks, our theory predicts that larger information asymmetries are associated with more trading being observed, which contrasts with the conventional wisdom that empirically, large information asymmetries should be associated with low trading volume (as in Akerlof 1970).

Appendix A: Proofs

Lemma 2 (Necessary and sufficient condition for efficient trade) *Given that trade is efficient in all subsequent transactions, trader m finds optimal to quote p_0^m rather than any other price if and only if he prefers to quote p_0^m over p_1^m.*

Proof. Consider a situation in which trader m currently holds the asset and wants to sell it to trader $m+1$. Trader m knows that out of the N_m factors ϕ_n he observes, G_m realizations have a value of 1. Similarly, trader $m+1$ knows that out of the N_{m+1} factors ϕ_n he observes, G_{m+1} realizations have a value of 1. Assume that whenever trader $m+1$ acquires the asset, subsequent trading is efficient, which requires that all subsequent traders $k \in \{m+1, m+2, ..., M\}$ charge prices:

$$p_0^k = G_k \sigma + \Delta,$$

which maximize trade probability. Trader m then chooses to quote one of $(N_{m+1} - N_m + 1)$ price candidates, defined as:

$$p_i^m = (G_m + i)\,\sigma + \Delta, \quad i \in \{0, ..., N_{m+1} - N_m\}.$$

The weakly better informed trader $m+1$ only accepts to pay a price p_i^m if $G_{m+1}\sigma + \Delta \geq p_i^m$, which occurs with probability π_i^m.

Trader m prefers quoting p_i^m over p_{i+1}^m if and only if:

$$\begin{aligned}
& \pi_i^m p_i^m + (1 - \pi_i^m)\, E\left[v | G_{m+1} < G_m + i\right] \geq \pi_{i+1}^m p_{i+1}^m + \left(1 - \pi_{i+1}^m\right) E\left[v | G_{m+1} < G_m + i + 1\right] \\
\Leftrightarrow \quad & \pi_i^m p_i^m - \pi_{i+1}^m p_{i+1}^m \geq \left(1 - \pi_{i+1}^m\right) E\left[v | G_{m+1} < G_m + i + 1\right] - (1 - \pi_i^m)\, E\left[v | G_{m+1} < G_m + i\right] \\
\Leftrightarrow \quad & \left(\pi_i^m - \pi_{i+1}^m\right)\left[(G_m + i)\,\sigma + \Delta\right] - \pi_{i+1}^m \sigma \geq \left(\pi_i^m - \pi_{i+1}^m\right)(G_m + i)\sigma \\
\Leftrightarrow \quad & \frac{\sigma}{\Delta} \leq \frac{\pi_i^m - \pi_{i+1}^m}{\pi_{i+1}^m}. \qquad (3)
\end{aligned}$$

When the probability distribution that characterizes the information asymmetry between traders m and $m+1$ is such that the (discrete) hazard rate (i.e., the RHS in (3)) reaches its global minimum at $i = 0$, trader m quotes p_0^m if and only if he prefers to quote p_0^m over p_1^m.[9] The binomial distribution has a (discrete) hazard rate that reaches its global minimum at $i = 0$: the probability mass function $\pi_i^m - \pi_{i+1}^m$ is minimized at the two extremes of the distribution, that is, at $i = 0$ and at $i = N_{m+1} - N_m - 1$ and the complementary cumulative distribution function π_{i+1}^m is decreasing in i. ■

Appendix B: Efficient Trade with Information Percolation

We conjecture a perfect Bayesian equilibrium in which trade is efficient and the following properties apply:

- Trader 2 quotes a price $\phi_1\sigma + \phi_2\sigma + \Delta$ to the expert buyer, who always accepts.
- Regardless of the realization of ϕ_1, trader 1 quotes the highest price at which trader 2, knowing nothing about trader 1's information, always accepts: $\bar{p} = \frac{\sigma}{2} + \Delta$.
- Trader 2 believes any price quote higher than $\bar{p}$ is uninformative about trader 1's information.
- The uninformed seller quotes a price $\bar{p}$ to trader 1, who always accepts.

To prove the existence of such equilibrium, we first need to analyze the last stage of trading between trader 2 and the expert buyer, which is identical to the last stage of trading in the two-factor and three-factor cases from Section 3. If $\frac{\sigma}{\Delta} \leq 1$, trader 2 finds optimal to quote a price $\phi_1\sigma + \phi_2\sigma + \Delta$ to the expert, which he always accepts.

Trading between traders 1 and 2 is slightly more complex to analyze, since information sets are non-nested. Trader 1 quotes a price after observing ϕ_1 to trader 2 who only observes ϕ_2. Given the beliefs assumed above, the most attractive deviation by trader 1 from the conjectured equilibrium action is to quote a price $\bar{p} + \sigma$, which is accepted by trader 2 only if $\phi_2 = 1$. Such deviation is,

[9] More generally, a hazard rate function is defined as $\frac{pmf(x)}{1-cdf(x)}$, where pmf and cdf respectively denote the probability mass function and the cumulative distribution function.

however, dominated by the equilibrium strategy of quoting $\bar{p}$ if:

$$\begin{aligned} \bar{p} &\geq \frac{1}{2}(\bar{p}+\sigma)+\frac{1}{2}\left(\phi_1\sigma+\frac{\sigma}{2}\right) \\ \Leftrightarrow \frac{\sigma}{\Delta} &\leq \frac{1}{1+\phi_1}. \end{aligned}$$

Further, collecting $\bar{p}$ also dominates non-participation for trader 1, as long as $\frac{\sigma}{\Delta} \leq \frac{1}{\frac{1}{2}+\phi_1}$. When $\frac{\sigma}{\Delta} \leq 1/2$, quoting $\bar{p}$ is thus the equilibrium strategy for trader 1 in this stage.

Finally, the seller can quote $\bar{p}$ to trader 1, which is accepted with probability 1, but he might also be tempted to quote a higher price. If trader 2's beliefs about trader 1's information remain unchanged following a deviation by the seller (e.g., if trader 2 does not observe the seller's quoted price), trader 1 will find optimal to subsequently quote $\bar{p}$, regardless of his information, so no such higher price quoted by the seller can sustain trade with positive probability. Hence, the seller chooses to quote $\bar{p}$ as long as it dominates non-participation:

$$\begin{aligned} \bar{p} &\geq \frac{3}{2}\sigma \\ \Leftrightarrow \frac{\sigma}{\Delta} &\leq 1. \end{aligned}$$

Now, if trader 2's beliefs about trader 1's information adjust following a deviation by the seller (e.g., if trader 2 observes the seller's quoted price), a deviation by the seller to a high price quote that is only accepted by trader 1 if $\phi_1 = 1$ will lead trader 2 to infer that $\phi_1 = 1$ whenever trader 1 quotes a price to him. In such case, trader 1 will have no private information and trading will occur as in the two-factor case. Trader 1 finds optimal to quote the efficient low price $\sigma + \Delta$ if $\frac{\sigma}{\Delta} \leq 2/3$. The seller then chooses to quote $\bar{p}$ rather than $\sigma + \Delta$ if:

$$\begin{aligned} \bar{p} &\geq \frac{1}{2}(\sigma+\Delta)+\frac{1}{2}\sigma \\ \Leftrightarrow \frac{\sigma}{\Delta} &\leq 1. \end{aligned}$$

Overall, all the conditions required for the conjectured perfect Bayesian equilibrium to exist are verified if $\frac{\sigma}{\Delta} \leq 1/2$.

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