J. Finan. Intermediation 38 (2019) 11–18

Contents lists available at ScienceDirect

J. Finan. Intermediation

journal homepage: www.elsevier.com/locate/jfi

On the efficiency of long intermediation chains

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ARTICLE INFO

Article history:
Received 18 April 2017
Revised 21 August 2017
Accepted 25 August 2017
Available online 31 August 2017

JEL classification:
D82
D85
G23
L12

Keywords:
Intermediation Chains
Monopoly Power
Asymmetric Information
Over-the-Counter Trading Networks

ABSTRACT

Intermediation chains represent a common pattern of trade in over-the-counter markets. We study a classic problem impeding trade in these markets: an agent uses his market power to inefficiently screen a privately informed counterparty. We show that, generically, if efficient trade is implementable via any incentive-compatible mechanism, it is also implementable via a trading network that takes the form of a sufficiently long intermediation chain. We characterize information sets of intermediaries that ensure this striking result. Sparse trading networks featuring long intermediation chains might thus constitute an efficient market response to frictions, in which case no regulatory action is warranted.

1. Introduction

In the United States, roughly half of financial securities are traded in over-the-counter (OTC) markets.[1] Corporate bonds, municipal bonds, and securitized products are prime examples of securities typically traded in a decentralized manner. In these markets, intermediation chains – the sequential trading of assets by multiple intermediaries – are a pervasive empirical phenomenon.[2] For instance, a pension plan trying to sell bonds that were recently downgraded will rarely trade directly with a fixed income hedge fund, even though this hedge fund might be the efficient holder of the bonds. Instead, the pension plan might sell the bonds to a local bond dealer (i.e., intermediary (1)), that will then sell them to a large Wall Street trading desk (i.e., intermediary (2)), which will, in turn, trade with the hedge fund. Given the size of a pension fund's bond portfolio, transactions of this type might occur repeatedly over time, with similar chains arising persistently.

Yet, many existing models of OTC trading suggest that such chains are the result of frictions that lead to inefficiencies. For example, in models of OTC markets that feature search frictions, sequential trade emerges due to traders' inability to locate the efficient holder of an asset quickly, leading to the destruction of trade surplus.[3] In contrast, a recent literature has shown that intermediation chains can help alleviate inefficiencies associated with information asymmetries and market power.[4] In the initial example above, smaller information asymmetries between counterparties in each transaction along the chain (e.g., between the Wall Street trading desk and the hedge fund) can result in greater trade efficiency than an alternative trading encounter where the pension plan directly quotes prices to the much better informed hedge fund. The underlying economic forces shaping the patterns of trade observed in OTC markets are thus essential for interpreting empirical data, and for gauging the potential benefits of regulating these markets.

In this paper, we follow the above-mentioned literature that considers information asymmetries and market power as key

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[1] See Neklyudov and Sambalaibat (2017).

[2] For example, Li and Schürhoff (2014) report that 10% of municipal bond transactions involve a chain of 3 or more intermediaries. In the market for securitized products, Hollifield et al. (2017) find that transactions sometimes involve up to 10 intermediaries. Shen et al. (2016) show that the average transaction in the corporate bond market involves 1.81 intermediaries and that chains in the 99th percentile involve, on average, 7.53 intermediaries.

[3] See, e.g., Wright and Wong (2014), Hugonnier et al. (2016), and Shen et al. (2016). See also Viswanathan and Wang (2004) and Collard and Demange (2017) for alternative theories of intermediation chains.

[4] See Glode and Opp (2016).

http://dx.doi.org/10.1016/j.jfi.2017.08.006
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frictions impeding the efficiency of trade in OTC markets, and establish a novel result in this environment: we show that whenever there exist incentive-compatible mechanisms that implement efficient trade between a buyer and a seller, there also exist intermediation chains that achieve the same result, except for in a knife-edge case. Establishing this result is important as it shows that whenever efficient trade would be attainable with any market/mechanism design tool, it can also be attained with a *decentralized solution* which involves trading the asset through a sufficiently long intermediation chain. In contrast, the existing literature has only established that introducing and lengthening chains can improve efficiency, but has left open the question how far these improvements can go. A clear policy implication of our new result is that regulators may not have to search for (potentially more complex) market designs to eliminate trade inefficiencies associated with the classic frictions we study. Thus, observing long chains in practice does not necessarily suggest that regulatory action is required – instead, it may reflect that market participants efficiently respond to the underlying frictions in the economy. In particular, policy proposals that have been put forward after the financial crisis – such as centralizing trade or increasing traders' access to many counterparties – might in fact reduce the efficiency of trade relative to the status quo.[5]

Our setup initially considers a standard bilateral trading encounter where one agent has market power in pricing the asset and his counterparty is privately informed about the value of the asset. In this environment, screening leads to inefficient rationing when the surplus from trade is small relative to the degree of information asymmetry. We first highlight how the allocation of market power is a key driver of this inefficiency. In particular, we show that incentive-compatible mechanisms designed to maximize social surplus from trade effectively eliminate market power, and thereby facilitate efficient trade in a greater parametric region. However, in many real-world contexts market power is not something that can be easily reallocated. For example, in cases where few agents are "natural" sellers (e.g., due to their current asset holdings and liquidity positions) simply adding competitors can be infeasible.

We then consider the involvement of multiple intermediaries who trade the asset sequentially, as part of an intermediation chain in which each trader's information set is similar to those of his direct counterparties. When market power leads to inefficient trade, adding sequential layers of intermediation could reduce efficiency due to problems of double marginalization (e.g., Spengler (1950) and more recently Gofman (2014)). However, if the intermediaries are partially informed, the reduction of incentives to screen in every stage of the intermediation chain could also improve efficiency, as highlighted in Glode and Opp (2016). In this paper, we specifically show how intermediaries' information sets can be designed such that long enough intermediation chains generically replicate the implementation of full efficiency by *any* bilateral incentive-compatible mechanism (Hurwicz, 1972). Hence, there exist intermediation chains that eliminate all inefficiencies associated with screening and the associated rationing.

Our theory builds on the following three characteristic features of OTC markets for financial securities: (i) *bilateral* trade between counterparties, (ii) *information asymmetries* across traders regarding the "value" of an asset, and (iii) *market power*, which is reflected by the fact that some traders quote their counterparties ultimatum offers. Feature (i) follows from the fact that over-the-counter trades typically involve a buyer and a seller who privately agree on the terms of a deal (see Duffie, 2012). Regarding feature (ii), it is worth emphasizing that traders may have asymmetric access to pieces of information that affect *all* agents' asset valuations equally (i.e., "common value components"), but also to information that determines trader-specific valuations (i.e., "private value components"). Information asymmetries with respect to common value components generically arise whenever traders have heterogenous expertise in evaluating the fundamental payoffs of a security. Information asymmetries with respect to private value components typically arise when some traders have better knowledge of agents' trading motives, including liquidity or hedging needs. Both types of information asymmetry are relevant in all major asset classes that are traded in OTC markets.[6] Feature (iii) – ultimatum offers – is consistent with how Duffie (2012) describes the negotiation process in OTC markets, where a dealer typically aims to maintain "a reputation for standing firm on its original quotes," and the characterization of inter-dealer trading by Viswanathan and Wang (2004) as "very quick interactions." Accounting for market power in OTC markets is particularly relevant in light of the fact that a few large players account for a significant fraction of the trading volume in key asset classes traded in these markets.[7] In an environment with these three characteristic features of OTC trade, we show the potential social optimality of intermediation chains, particularly of long ones.

Consistent with our model's predictions, intermediation chains are not only common patterns of trade in OTC markets, but also appear to be more prevalent when information asymmetries become more severe. For example, Di Maggio et al. (2017) find that the average chain in the corporate bond market became significantly longer following Lehman Brothers' collapse, a time when information asymmetries likely increased. Moreover, Li and Schürhoff (2014) show that municipal bonds without credit ratings or with speculative ratings tend to be traded through longer intermediation chains than municipal bonds with investment-grade ratings, where the latter are less likely to be subject to significant information asymmetries. Finally, Hollifield et al. (2017) show that securitized products traded both by sophisticated and unsophisticated investors (i.e., "registered" instruments) are subject to more severe adverse selection and tend to be traded through longer chains than products only traded by sophisticated investors (i.e., "rule 144a" instruments). These findings are all consistent with the insight that larger information asymmetries require longer intermediation chains, but would not necessarily emerge from alternative channels that can lead to sequential trade, such as inventory risk sharing motives. In addition, the fact that trading networks tend to be extremely persistent[8] is also hard to reconcile with the standard search models of OTC trade, where agents randomly meet each other. Overall, our parsimonious model thus matches key aspects of real-world OTC markets not only in terms of its assumptions, but also in terms of its predictions.

[5] See, for example, the Financial Economists Roundtable's statements on "The Structure of Trading in Bond Markets" released in May 2015 and on "Reforming the OTC Derivatives Markets" released in June 2010, "Implementing the Dodd-Frank Act," a speech given by U.S. CFTC's chairman Gary Gensler in January 2011, "Comparing G-20 Reform of the Over-the-Counter Derivatives Markets," a Congressional Report prepared by James K. Jackson and Rena S. Miller in February 2013, or "Canadian regulators push toward more transparency, oversight for huge fixed income market" by Barbara Shecter in the September 17, 2015 issue of the Financial Post.

[6] For evidence of heterogenous expertise among traders in OTC markets, see Green et al. (2007) for municipal bonds, Hollifield et al. (2017) for securitized products, Jiang and Sun (2015) for corporate bonds, and Menkhoff et al. (2016) for foreign exchange instruments.

[7] For evidence of trading concentration and imperfect competition in OTC markets, see Li and Schürhoff (2014) and Hendershott et al. (2015) for municipal bonds, Di Maggio et al. (2017) for corporate bonds, Atkeson et al. (2013), Begenau et al. (2015), and Siriwardane (2016) for credit and interest-rate derivatives, and King et al. (2012) for foreign exchange instruments.

[8] For example, Li and Schürhoff (2014) estimate the probability that a given directional trade (buy vs. sell) between two dealers is repeated in the following month to be 62%, compared to a probability of 1.4% if network relationships were random.

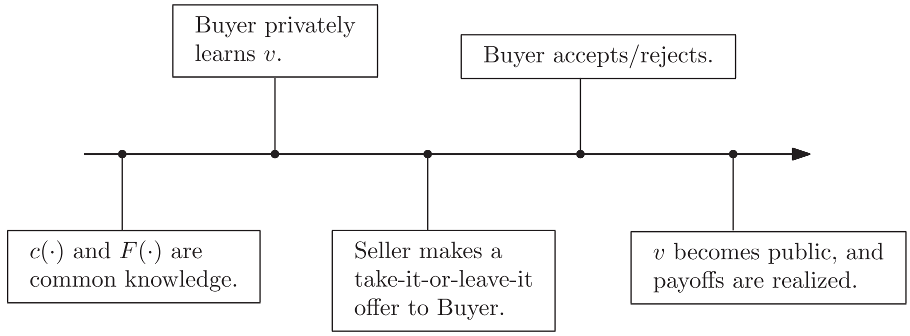

Fig. 1. Timeline (direct trade). The graph illustrates the logical sequence of events of the game when the buyer and the seller trade directly.

2. The bilateral transaction

We initially consider a standard bilateral transaction between two risk-neutral agents as in Glode and Opp (2016). The monopolist seller of an asset must choose the price he will quote to a potential buyer as a take-it-or-leave-it offer. The seller is, however, uncertain about how much the buyer is willing to pay for the asset. In particular, the seller only knows that the buyer's valuation of the asset, which we denote by v, has a cumulative distribution function (CDF) denoted by $F(v)$. This CDF is continuous and differentiable and the probability density function (PDF), denoted by $f(v)$, takes strictly positive values everywhere on the support $[v_L, v_H]$. The buyer only accepts to pay the seller's quoted price p if $v \geq p$; otherwise, the seller must retain the asset, which is worth $c(v)$ to him. The function $c(v)$ is assumed to be weakly increasing, continuous, and to satisfy $c(v) < v$ for all $v \in [v_L, v_H]$. The functions $c(\cdot)$ and $F(\cdot)$ are common knowledge. Fig. 1 illustrates the timeline of the game when the buyer and the seller trade directly.

Since the buyer always values the asset more than the seller does, trade creates a surplus for any realization of v and is therefore efficient if and only if the buyer obtains the asset with probability 1. However, the seller may find it privately optimal to use his market power and inefficiently screen the informed buyer, thus jeopardizing the gains to trade.[9]

2.1. Direct trade

A subgame-perfect Nash equilibrium in this bilateral transaction consists of a price that the seller quotes and an acceptance rule for each possible buyer type v that are mutual best responses in every subgame. The seller's expected payoff from quoting a price p is thus given by:

$$\Pi(p) = [1 - F(p)]p + F(p)\mathbb{E}[c(v)|v < p]. \quad (1)$$

By picking a price, the seller trades off his payoff when a sale occurs and the probability that a sale occurs. The seller's marginal profit from increasing the price p is:

$$\Pi'(p) = [1 - F(p)][1 - H(p)], \quad (2)$$

where we define the $H(\cdot)$ function as:

$$H(v) = \frac{f(v)}{1 - F(v)}[v - c(v)], \forall v \in [v_L, v_H). \quad (3)$$

Consistent with Glode and Opp (2016), we impose a regularity condition on the function $H(\cdot)$ to guarantee that the marginal profit function $\Pi'(\cdot)$ crosses zero from above at most in one point. The condition thus ensures that we obtain a unique subgame-perfect Nash equilibrium under direct trade.

Assumption 1. $H(v)$ is strictly increasing in v for $v \in [v_L, v_H)$.

Assumption 1 resembles the definition of a strictly regular environment by Fuchs and Skrzypacz (2015) and the standard assumption in auction theory that bidders' virtual valuation functions are strictly increasing.[10] This assumption allows our setup to capture a private value environment, where the seller's valuation for the asset is a constant $c(v) = c$, and the buyer is privately informed about his own valuation v, which might differ from the seller's valuation due to liquidity or hedging concerns. It can also capture a common value environment, where the buyer and the seller share a common value component v, but the seller only values the asset at $c(v) = v - \Delta$, while the buyer values it at v and has access to superior information (e.g., through better data, models, or human capital) about the fundamental value of the asset.[11] Another specification that is common in the literature on OTC trading assumes that the seller's and the buyer's discount rate differ,[12] say $c(v) = \beta v$, which is also subsumed by our setup.

For trade to be socially efficient, the seller has to quote a price that is accepted by the buyer with probability 1. The maximum price that maintains efficient trade is thus $p = v_L$, and direct trade is efficient if and only if $\Pi'(v_L) \leq 0$. For later derivations, it is helpful to rewrite this last condition, which mimics a condition in Glode and Opp (2016), and summarize it in a proposition.

Proposition 1. *With a monopolistic seller, efficient trade is achieved if and only if:* $v_L \geq c(v_L) + \frac{1}{f(v_L)}$.

If instead $v_L < c(v_L) + \frac{1}{f(v_L)}$, the monopolistic seller quotes an inefficient price $p > v_L$ that sets $\Pi'(p) = 0$ and jeopardizes the surplus from trade. We illustrate the inefficiency of trade in our environment through a simple parameterized example.

[9] Most of the analysis in this paper would remain unchanged if we instead considered an alternative setting where the buyer/seller roles were reversed. An uninformed buyer would make an ultimatum offer to a privately informed seller and, in some cases, the buyer's market power would lead to inefficient trading.

[10] See, e.g., Myerson (1981). Specifically, we can define the function $\varphi(p)$ as the derivative of the seller's expected payoff with respect to the probability of trade when quoting a price p:

$$\varphi(p) \equiv \Pi'(p)\frac{dp}{d(1 - F(p))} = p - c(p) - \frac{1 - F(p)}{f(p)}.$$

The function $\varphi(p)$ represents the difference between the buyer's virtual valuation and the seller's marginal valuation when $v = p$. If we assume constant gains to trade $v - c(v) = \Delta > 0$, a strictly increasing $\varphi(\cdot)$ simplifies to a strictly increasing hazard rate and is thus equivalent to Assumption 1. With general definitions of $c(v)$, these two conditions are mathematically different, yet they yield the same results in our model for the case of direct trade. As will become clear later, imposing Assumption 1 will, however, yield an additional useful property when we introduce intermediaries and analyze their impact on trade efficiency.

[11] See, e.g., Glode et al. (2012).

[12] See, e.g., Daley and Green (2016).

Example 1. Suppose the buyer values the asset at $v \sim U[1, 2]$ and the seller values the asset at a constant $c < 1$. A monopolistic seller's optimization problem when choosing a price is:

$$\max_{p \in [1,2]} \Pi(p) = Pr(v \geq p)p + Pr(v < p)c = (2-p)p + (p-1)c. \quad (4)$$

When $\Pi'(1) \leq 0$, the seller quotes a price $p = 1$ that is always accepted by the buyer. Thus, efficient trade is achieved if and only if $c \leq 0$.

2.2. Market power

So far, we have focused on the same problem of inefficient trade as in Glode and Opp (2016). Before discussing a solution to this problem, it is important to extend their analysis and show how the seller's market power is a key driver of potentially inefficient behavior. Suppose that there are two identical competing sellers, instead of one monopolistic seller. Each seller owns one unit of the asset, values it at $c(v)$, and quotes a price to the buyer who can acquire one unit. The buyer observes both prices before deciding whether to buy from a seller. In this scenario, a classic result is that (Bertrand) competition will lead both sellers to quote prices equal to their own valuations for the asset. Since we are interested in conditions where efficient trade can be sustained, we focus on cases where a seller quotes a price that is low enough for the buyer to accept it with probability one. In other words, it is required that $p \leq v_L$. Given that the buyer always accepts to pay such a price p, regardless of his private information about v, a seller does not learn new information from the buyer's acceptance. As a result, each seller's expected valuation of the asset, conditional on trade occurring at such a price $p \leq v_L$, is still the unconditional expectation $\mathbb{E}[c(v)]$. Moreover, a seller is willing to quote an efficient price $p \leq v_L$ only if that price satisfies: $p \geq \mathbb{E}[c(v)]$. Under Bertrand competition, the condition for efficient trade thus becomes $v_L \geq \mathbb{E}[c(v)]$, that is, the lowest buyer type accepts the price quoted by both sellers, which is $p = \mathbb{E}[c(v)]$. We summarize this result in the following proposition.

Proposition 2. *With two competing sellers, efficient trade is achieved if and only if:* $v_L \geq \mathbb{E}[c(v)]$.

We can compare this condition to the one applying when there is only one monopolistic seller. This yields the following result.

Lemma 1. *If* $v_L \geq c(v_L) + \frac{1}{f(v_L)}$, *then* $v_L > \mathbb{E}[c(v)]$.

That is, the condition for efficient trade is strictly less restrictive when the seller does not possess market power. Thus, when $\mathbb{E}[c(v)] \leq v_L < c(v_L) + \frac{1}{f(v_L)}$, competing sellers behave efficiently but a monopolistic seller inefficiently screens the buyer and jeopardizes gains to trade.

Example 2. As in Example 1, the buyer values one unit of the asset at $v \sim U[1, 2]$. We now consider the case where there are two identical sellers who each own one unit of the asset and value it at a constant $c(v) = c$. Under Bertrand competition, the condition for efficient trade becomes $c \leq 1$, as competition drives the seller's quoted price to his own valuation c, and efficient trade requires that the buyer accepts to pay this price c even when he has the lowest possible valuation for the asset (i.e., $v = 1$). Recall that the condition for efficient trade with a monopolistic seller was $c \leq 0$. Thus, there exists a region $c \in (0, 1]$, where only a seller with market power inefficiently screens his counterparty.

We have shown that efficient trade is easier to achieve if the seller does not have market power. Below we show that the condition $v_L \geq \mathbb{E}[c(v)]$ is also the necessary and sufficient condition for an efficient, incentive-compatible mechanism to exist.

Proposition 3. *An incentive-compatible mechanism that achieves efficient trade exists if and only if:* $v_L \geq \mathbb{E}[c(v)]$.

Eliminating market power on the seller's side thus ensures that efficient trade obtains whenever any incentive-compatible mechanism can achieve it. However, in many cases, market power cannot simply be reallocated – this is particularly relevant when few agents are "natural" counterparties (e.g., given their current asset holdings and liquidity positions). Nevertheless, our mechanism design approach allows us to show that any other type of "intervention" – whether it is a contracting agreement between the seller and the buyer or a regulation crafted by an external agency – will fail to implement efficient trade if $v_L < \mathbb{E}[c(v)]$ and this intervention must be incentive compatible for all agents, budget balanced, and require no private information when designed (consistent with Myerson and Satterthwaite, 1983).[13] In the next section, we show however that, whenever trading inefficiencies can be eliminated by such an intervention, there also generically exists a decentralized solution which involves trading the asset through a long intermediation chain.

3. Intermediation chains

We now consider the involvement of M intermediaries, indexed by m based on their position in a trading chain. For notational convenience, we label the seller as trader 0 and the buyer as trader $(M+1)$. All intermediaries are risk-neutral and value the asset at $c(v)$ just like the seller does. To keep the model tractable despite the presence of several intermediation layers, we assume that in every transaction the asset holder makes an ultimatum offer to his counterparty. As an example, Fig. 2 illustrates the timeline of the game when the buyer and the seller trade through one intermediary (i.e., $M = 1$).

We depart from Glode and Opp (2016) by specifying a signal structure that allows us to prove our main existence result while maintaining the tractability of the analysis. Each intermediary observes a signal that partitions the domain $[v_L, v_H]$ into subintervals, and intermediary $(m+1)$'s signal creates a strictly finer conditional partition than intermediary m's signal. The resulting nesting of sequential traders' information sets eliminates signaling concerns and implies a generically unique subgame perfect Nash equilibrium in our model, even though it involves $(M+1)$ bargaining problems among $(M+2)$ heterogeneously informed agents. The particular information structure we construct is a "partition rule" that can be defined as follows: suppose $v_L = v_0 < v_1 < v_2 < \cdots < v_M < v_{M+1} = v_H$ and

- Intermediary 1 knows whether v belongs to $[v_L, v_M)$ or $[v_M, v_H]$.
- Intermediary 2 knows whether v belongs to $[v_L, v_{M-1})$, $[v_{M-1}, v_M)$, or $[v_M, v_H]$.
- ...
- Intermediary M knows whether v belongs to $[v_L, v_1)$, ..., $[v_{M-1}, v_M)$, or $[v_M, v_H]$.

While benefits of moderately informed intermediaries are emphasized in Glode and Opp (2016), the main contribution of our paper is to show that there exist information sets for intermediaries that allow (long enough) intermediation chains to achieve full efficiency whenever any alternative mechanism can do so. Thus, the current analysis requires us to be more specific about the type of information with which each trader is endowed. It is convenient to introduce the following definition.

[13] See Zhang (2016) who generalizes Myerson and Satterthwaite's (1983) framework by allowing the mechanism designer to have his own private information about the traders' valuations for the asset.

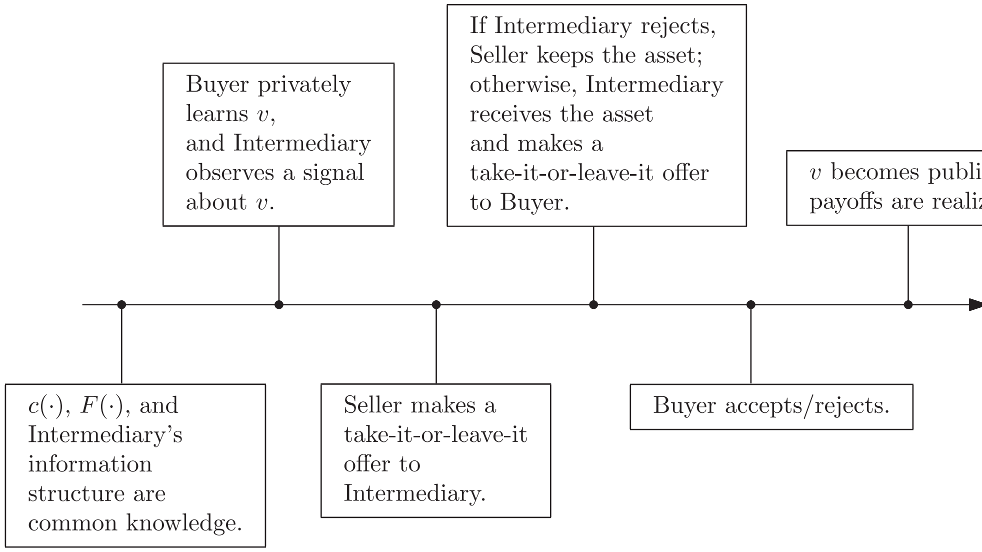

Fig. 2. Timeline (intermediated trade). The graph illustrates the logical sequence of events in the game when the buyer and the seller trade through one intermediary (i.e., $M = 1$).

Definition 1. A "chain implementation" of efficient trade is said to exist if there exists a chain of intermediaries such that trading through this intermediation chain implements the efficient allocation of the asset.

Before deriving our main results, it is useful to restate a lemma from Glode and Opp (2016).

Lemma 2. *If Assumption 1 is satisfied under distribution $F(v)$, it is also satisfied under any truncated version of that distribution.*

Lemma 2 is the reason why we imposed a regularity condition on $H(\cdot)$ rather than on $\varphi(\cdot)$ (see footnote 10). Unlike a strictly increasing $H(\cdot)$ function, a strictly increasing $\varphi(\cdot)$ function does not guarantee that an analogous property holds for the truncated version of $F(v)$. As in the case with direct trade, Assumption 1 guarantees that the marginal profit function for each intermediary crosses zero (from above) at most once when quoting a price. As a result we obtain, generically, a unique subgame perfect Nash equilibrium under intermediated trade.

The following proposition characterizes our main existence result.

Proposition 4. *If $v_L > \mathbb{E}[c(v)]$, a chain implementation of efficient trade exists. Specifically, there exists a partition rule and a threshold $\bar{M}$ such that the involvement of $M \geq \bar{M}$ intermediaries with information sets satisfying this partition rule sustains efficient trade.*

We now return to our parameterized example with a monopolistic seller to illustrate this result.

Example 3. As in Example 1, the buyer values the asset at $v \sim U[1, 2]$, and a monopolistic seller values it at a constant $c(v) = c$. We focus on the case with $c \in (0, 1)$ where direct trade is inefficient due to the seller's market power (the knife-edge case with $c = 1$ violates the condition in Proposition 4). We define $\epsilon \equiv \frac{1}{M+1}$ and construct a chain of M intermediaries who have the following information sets:

- Intermediary 1 knows whether v belongs to $[1, 2-\epsilon)$ or $[2-\epsilon, 2]$.
- Intermediary 2 knows whether v belongs to $[1, 2-2\epsilon)$, $[2-2\epsilon, 2-\epsilon)$, or $[2-\epsilon, 2]$.
- $\cdots$
- Intermediary M knows whether v belongs to $[1, 2-M\epsilon)$, $\ldots$, $[2-2\epsilon, 2-\epsilon)$, or $[2-\epsilon, 2]$.

For $0 \leq m \leq (M-1)$, we first observe that if trader m knows that $v \in [1, 2-m\epsilon)$, he must prefer quoting a price $p = 1$ over $p = 2-(m+1)\epsilon$ to his better informed counterparty, who knows whether v belongs to $[1, 2-(m+1)\epsilon)$, or to $[2-(m+1)\epsilon, 2-m\epsilon]$, for trade to be efficient. Thus, the following condition has to be satisfied:

$$1 \geq \left(\frac{\epsilon}{2-m\epsilon-1}\right)[2-(m+1)\epsilon] + \left(1-\frac{\epsilon}{2-m\epsilon-1}\right)c. \tag{5}$$

Given that $\epsilon \equiv \frac{1}{M+1}$, a larger number of intermediaries implies that deviating to the inefficient price $p = 2-(m+1)\epsilon$ becomes less profitable. Moreover, we can show that the condition above simplifies to $c \leq (1-\epsilon)$, which holds as long as $M \geq \bar{M} \equiv \frac{c}{1-c}$. For any other signal that trader m receives, he knows that his counterparty is identically informed, such that trade is efficient. Each intermediary m then extracts an expected surplus of $(1-m\epsilon)\epsilon$ when trade is efficient.

Now consider trader M who knows that $v \in [1+i\epsilon, 1+(i+1)\epsilon)$ for some $i = 0, 1, 2, \ldots, M$. Using the same reasoning as under direct trade, we know that trader M will prefer to quote a price $p = 1+i\epsilon$ over any inefficient price $p > 1+i\epsilon$ as long as $1+i\epsilon \geq c + \frac{1}{1/\epsilon}$, which always holds if $c \leq 1-\epsilon$, or equivalently if $M \geq \bar{M} \equiv \frac{c}{1-c}$.

Overall, this chain of M intermediaries sustains efficient trade if $c \leq 1-\frac{1}{M+1}$. Hence, whenever $c < 1$ there exist long intermediation chains (i.e., with $M \geq \bar{M}$ intermediaries) that sustain efficient trade.

We have shown that if $v_L > \mathbb{E}[c(v)]$ the sequential involvement of intermediaries can eliminate all inefficiencies caused by the monopolistic seller's incentives to screen his privately informed counterparty. This mechanism involves multiple intermediaries who also quote ultimatum offers, once they hold the asset. With such an intermediation chain, a trader who holds the asset faces, for high realizations of v, a symmetrically informed counterparty, which makes efficient trade trivial to achieve. For low realizations of v, the trader faces a steep trade-off between trading efficiently at "conservative" prices and trading inefficiently at higher prices. By making this intermediation chain sufficiently long, we limit each trader's incentives to inefficiently screen his better informed counterparty, and promote efficient behavior by all agents involved.

While all we needed to show for our main result is the existence of one information structure allowing for efficient trade to arise in equilibrium, it should not be deduced that alternative information structures could not yield a similar outcome. Clearly, other types of information structures can implement efficient trade through an intermediation chain, but they might necessitate the chain to be longer than under the partition rule specified above.

Our final result shows that the sufficient condition for the existence of a chain implementation of efficient trade is also a necessary condition.

Proposition 5. *If involving M intermediaries with information sets as characterized by the partition rule above allows for a chain implementation of efficient trade, then it must be that* $v_L > \mathbb{E}[c(v)]$.

Going beyond the main result in Glode and Opp (2016) (Proposition 2), we have now established the existence of chains of intermediaries that not only improve the efficiency of trade, but are also generically as good as any incentive-compatible mechanism in implementing efficient trade. This form of intermediation can thus replicate the social benefits of competition, or any other incentive-compatible intervention, in eliminating the welfare losses caused by private information and market power. This result has relevant policy implications since it shows that whenever efficient trade would be attainable with any market/mechanism design intervention, it can also be attained with a decentralized solution that can be implemented by the traders themselves.

4. Discussion

We now discuss important features of the environment we analyze and of the mechanism we propose. Market power plays an important role in our environment – inefficiencies arise due to the seller's ability to potentially appropriate additional rents by charging prices that can lead to inefficient rationing. When the seller has no ability to seek additional rents in the first place (because there are multiple sellers making simultaneous offers to a unique buyer), this inefficiency is by assumption absent. The solution we propose, however, differs from interventions that assume that market power can simply be eliminated. In fact, the intermediaries we involve in the chain are also each endowed with monopoly power once they obtain the asset.

In addition, the heterogeneous expertise of intermediaries is a key feature of the market structure we study. If intermediaries were either uninformed like the seller or perfectly informed like the buyer, intermediation chains would not improve the efficiency of trade relative to direct trade. In this case, most pairs of counterparties would be trading without an information asymmetry, but whenever an uninformed trader would have to quote a price to a perfectly informed counterparty, trade would still break down, much like under direct trade.

Finally, note that the implementation of a socially optimal intermediation chain can be formalized in our model by adding the network-formation game described in Glode and Opp (2016). This game precedes the trading game discussed above, and characterizes order-flow agreements to which traders commit before information is obtained and trading occurs. Any intermediation chain sustaining efficient trade can be part of a "coalition-proof equilibrium" of this network-formation game, given appropriate ex ante transfers that incentivize traders to commit to specific counterparties. Such order-flow agreements are commonly used in financial markets and either take the form of explicit agreements involving cash payments, or implicit arrangements promising profitable IPO allocations or subsidies on other services (see, e.g., Blume, 1993; Chordia and Subrahmanyam, 1995; Reuter, 2006; Nimalendran et al., 2007). The social benefits of these types of agreements in our setting cast doubt on recent proposals by regulatory agencies and stock exchange officials to ban related practices.[14] Indeed, an unintended consequence of these suggested reforms could be that restricting the contracting space among traders could prevent the implementation of a decentralized solution eliminating inefficiencies caused by market power and private information in OTC markets.

5. Conclusion

In this paper, we study a classic problem impeding efficient trade in OTC markets – an agent uses his market power to inefficiently screen a privately informed counterparty. We show the existence of long chains of heterogeneously informed intermediaries that can generically eliminate all trading inefficiencies due to market power and asymmetric information. In particular, if efficient trade can be achieved by allowing for any incentive-compatible mechanism designed to maximize social efficiency of trade, it can also be achieved by setting up a trading network that takes the form of a sufficiently long intermediation chain. We characterize specific information sets of intermediaries that ensure this striking result. Our results have relevant policy implications, highlighting that the prevalence of long intermediation chains in OTC markets does not necessarily suggest inefficiencies or require regulatory action. Instead, it might be evidence that market participants use a decentralized solution to address inefficiencies associated with market power and asymmetric information.

Acknowledgment

The authors thank the editor (Murillo Campello) and an anonymous referee for their valuable feedback.

Appendix A. Proofs

Proof of Proposition 1. Directly follows from $\Pi'(v_L) \leq 0$. □

Proof of Proposition 2. Directly follows from the arguments that precede the proposition. □

Proof of Lemma 1. This lemma relies on the condition that $v_L \geq c(v_L) + \frac{1}{f(v_L)}$. We can rearrange this condition as the equivalent condition: $f(v_L)[v_L - c(v_L)] \geq 1$. Our definition of the function $H(\cdot)$ implies that $H(v_L) = \frac{f(v_L)}{1-F(v_L)}[v_L - c(v_L)] = f(v_L)[v_L - c(v_L)]$. Thus, the condition stated in the lemma can also be written as $H(v_L) \geq 1$. Next, note that Assumption 1 imposes that $H(v)$ is strictly increasing in v for $v \in [v_L, v_H)$. Thus, it follows that $H(v) > H(v_L)$ for all $v > v_L$. Moreover, if $H(\cdot)$ evaluated at the lower bound v_L is already weakly greater than 1 (i.e., $H(v_L) \geq 1$), then it also follows that $H(v) > H(v_L) \geq 1$ for all $v > v_L$. Given the definition of $H(\cdot)$, we know that the inequality $H(v) > 1$ for $v > v_L$ also implies that $v - c(v) > \frac{1-F(v)}{f(v)}$ for $v > v_L$. Taking expectations on each side, we obtain $\mathbb{E}[v] - \mathbb{E}[c(v)] > \mathbb{E}\left[\frac{1-F(v)}{f(v)}\right] = \int_{v_L}^{v_H} (1 - F(v))dv = (1 - F(v))v|_{v_L}^{v_H} - \int_{v_L}^{v_H} v d(1 - F(v)) = \mathbb{E}[v] - v_L$. Thus, $v_L > \mathbb{E}[c(v)]$. □

[14] For example, see the comments made by Jeffrey Sprecher, CEO of Intercontinental Exchange (owner of the New York Stock Exchange), reported in "ICE CEO Sprecher wants regulators to look at 'maker-taker' trading" by Christine Stebbins on Reuters.com (January 26, 2014), the memo "Guidance on the practice of 'Payment for Order Flow'" prepared by the Financial Services Authority (May 2012), and the comments made by Harvey Pitt, former Securities and Exchange Commission Chairman, reported in "Options Payment for Order Flow Ripped" by Isabelle Clary in Securities Technology Monitor (May 3, 2004).

Proof of Proposition 3. Without loss of generality, we can consider a direct mechanism (Myerson, 1981). In our setting, only the buyer holds private information. Thus, in the direct mechanism, the buyer reports his value of v and this report directly determines the outcome. In the direct mechanism, we need to specify $(p(v), t(v))$, where p is the probability that the asset is transferred from the seller to the buyer, and t is the transfer payment from the buyer to the seller, if v is the buyer's reported valuation.

Since we assume $c(v) < v$ for all $v \in [v_L, v_H]$, trade always creates a surplus. Thus, the mechanism is efficient if and only if the buyer obtains the asset with probability 1. We must therefore consider mechanisms where $p(v) = 1, \forall v \in [v_L, v_H]$.

In order to implement efficient trade, it must give the buyer proper incentives to report his true valuation for the asset. The buyer's expected profit from reporting $\hat{v}$ is given by

$$p(\hat{v})v - t(\hat{v}) = v - t(\hat{v}). \tag{A1}$$

Then the buyer always wants to report $\hat{v} = \arg\min_v t(v)$. So it must be the case that the transaction price is a constant, which we denote by t. The buyer always pays t for the asset and v_L must therefore be greater than or equal to t for the lowest type buyer to be willing to trade. On the other hand, the seller is willing to participate if and only if $t \geq \mathbb{E}[c(v)]$. Thus, we need $v_L \geq \mathbb{E}[c(v)]$.

To prove the sufficiency, consider a direct mechanism where the probability of trade $p(v) = 1$ and the transfer payment $t(v)$ is a constant $\mathbb{E}[c(v)]$. Under this mechanism, the buyer does not have any profitable deviations from truth-telling and all individually rational constraints are satisfied. □

Proof of Lemma 2. See proof of Lemma 1 in the online appendix for Glode and Opp (2016). □

Proof of Proposition 4. Since the PDF $f(\cdot)$ is continuous and strictly positive on the compact set $[v_L, v_H]$, there exists $a > 0$ such that $f(v) \geq a, \forall v \in [v_L, v_H]$. Since $v - c(v) > 0$ for all $v \in [v_L, v_H]$, there exists $b > 0$ such that $v - c(v) \geq b, \forall v \in [v_L, v_H]$. Since $v_L > \mathbb{E}c(v)$, we have

$$\frac{v_H - v_L}{v_H - \mathbb{E}c(v)} < 1. \tag{A2}$$

We can choose A such that

$$\max\left(1 - ab, \frac{v_H - v_L}{v_H - \mathbb{E}c(v)}\right) < A < 1. \tag{A3}$$

We then choose M such that $A^M \leq ab$, which exists since $A < 1$ and $A^M \to 0$ as $M \to +\infty$. We construct the corresponding cutoffs v_m's such that for any m that satisfies $1 \leq m \leq M$ we have:

$$F(v_m) = A^{M+1-m}. \tag{A4}$$

We are left to show that this intermediation chain implements efficient trade.

Trade between trader M and the buyer. For any signal that trader M receives, $[v_i, v_{i+1})$, for $i = 0, 1, \ldots, M$, efficient trade requires that he quotes a price $p = v_i$. Similarly to the case of direct bilateral trade, the seller makes a take-it-or-leave-it offer to his counterparty whose valuation now follows the PDF $\frac{f(x)}{F(v_{i+1}) - F(v_i)}$ where $v_i \leq x < v_{i+1}$. To implement efficient trade, we thus need given Lemma 2:

$$v_i \geq c(v_i) + \frac{F(v_{i+1}) - F(v_i)}{f(v_i)}. \tag{A5}$$

Since $\min f(v) \geq a$ and $\min(v - c(v)) \geq b$, it is sufficient to show that:

$$ab \geq F(v_{i+1}) - F(v_i). \tag{A6}$$

For $1 \leq i \leq M$, we know that $F(v_{i+1}) - F(v_i) = A^{M-i}(1 - A) \leq 1 - A < ab$. When $i = 0$, $F(v_{i+1}) - F(v_i) = F(v_1) - F(v_0) = A^M \leq ab$ by the definition of M. Thus (A5) always holds and trade occurs with probability 1 between trader M and the buyer.

Trade between trader m and trader m + 1, where $0 \leq m < M$. Consider trader m, who knows that $v \in [v_L, v_{M-m+1})$. Trader m knows that the signal received by trader $(m+1)$ either locates v in $[v_L, v_{M-m})$ or in $[v_{M-m}, v_{M-m+1})$. To have efficient trade, we need trader m to quote a price $p = v_L$ instead of $p = v_{M-m}$. Thus, we need:

$$v_L \geq \left[1 - \frac{F(v_{M-m})}{F(v_{M-m+1})}\right]v_{M-m} + \frac{F(v_{M-m})}{F(v_{M-m+1})}\mathbb{E}[c(v)|v < v_{M-m}], \tag{A7}$$

which simplifies to:

$$\frac{F(v_{M-m})}{F(v_{M-m+1})} \geq \frac{v_{M-m} - v_L}{v_{M-m} - \mathbb{E}[c(v)|v < v_{M-m}]}. \tag{A8}$$

This last condition holds since:

$$\begin{aligned}\frac{F(v_{M-m})}{F(v_{M-m+1})} = A &> \frac{v_H - v_L}{v_H - \mathbb{E}c(v)} \\ &\geq \frac{v_{M-m} - v_L}{v_{M-m} - \mathbb{E}[c(v)]} \\ &\geq \frac{v_{M-m} - v_L}{v_{M-m} - \mathbb{E}[c(v)|v < v_{M-m}]}.\end{aligned} \tag{A9}$$

For any other signal trader m may receive, i.e., $v \notin [v_L, v_{M-m+1})$, he finds it optimal to quote a price equal to the lowest bound of the interval since trader $m+1$ has the same information as him and he is expected to quote a price equal to the lowest bound of the interval to his counterparty (for trade to be efficient). Thus, trade also occurs with probability 1 between traders m and $m+1$. □

Proof of Proposition 5. If $M = 0$, then $H(v_L) \geq 1$ and by Lemma 1, we know that $v_L > \mathbb{E}[c(v)]$.

Now suppose that $M \geq 1$. If the chain implements efficient trade, we first show that $H(v_M) \geq 1$. Intermediary M, if he knows that $v \in [v_M, v_H]$, must quote a price $p = v_M$ to achieve efficiency. Similarly to the direct trading game where the seller was making a take-it-or-leave-it offer to the buyer, we need:

$$v_M \geq c(v_M) + \frac{1 - F(v_M)}{f(v_M)}, \tag{A10}$$

which reduces to $H(v_M) \geq 1$. We also need the seller to quote $p = v_L$ to intermediary 1, that is:

$$v_L \geq (1 - F(v_M))v_M + F(v_M)\mathbb{E}[c(v)|v < v_M]. \tag{A11}$$

Recall that: $\Pi(p) = (1 - F(p))p + F(p)\mathbb{E}[c(v)|v < p]$. Condition (A11) can thus be rewritten as: $v_L \geq \Pi(v_M)$. Moreover, since $H(p) > H(v_M) \geq 1$ for $p > v_M$, we have $\Pi'(p) < 0$ for $p > v_M$ and therefore $\Pi(v_M) > \Pi(v_H) = \mathbb{E}[c(v)]$, which implies that $v_L > \mathbb{E}[c(v)]$. □

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