On the Efficiency of Long Intermediation Chains

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Abstract

We study a classic problem in economics where an agent uses his market power to inefficiently screen his privately informed counterparty. We show that, generically, if efficient trade is implementable, either by adding competition or more broadly by allowing for incentive-compatible mechanisms that eliminate market power, it is also implementable via a trading network that takes the form of a long intermediation chain in which each trader's information set is similar to those of his direct counterparties.

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1 Introduction

Long intermediation chains (i.e., sequential trading of an asset by several intermediaries) can be observed in many decentralized markets. 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, Neklyudov, and Spatt (2014) find that transactions sometimes involve up to 10 intermediaries. Shen, Wei, and Yan (2015) 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.

In this paper, we study a classic problem in economics where an agent uses his market power to inefficiently screen a privately informed counterparty. We already know from Glode and Opp (2016) that it is possible to improve the efficiency of trade by involving moderately informed intermediaries, each endowed with their own market power, as part of an intermediation chain in which each trader's information set is similar to those of his direct counterparties.[1] In this paper, we show a stronger result: whenever there exist incentive-compatible mechanisms that can implement efficient trade between a buyer and a seller, there also exist (except for a knife-edge case) intermediation chains that achieve the same result.

We initially consider a standard bilateral trading situation where one agent has market power in pricing the asset and his counterparty is privately informed about the (private or common) value of the asset. When the surplus of trade is small relative to the degree of information asymmetry, inefficient screening leads to destruction of the

[1]Zhang (2016) also shows that mechanisms that use a third party's information about traders' private valuations can help implement efficient trade, which is otherwise impossible without subsidies in the setting with two-sided asymmetric information of Myerson and Satterthwaite (1983).

surplus. We first highlight how the allocation of market power is a key driver of this inefficiency. For example, if we added competition among uninformed agents pricing the asset, efficient trade would be sustained in a greater parametric region. More broadly, incentive-compatible mechanisms that simply eliminate the market power problem would also facilitate efficient trade.

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, although not identical, to those of his direct counterparties. We show that a long enough intermediation chain can eliminate all inefficiencies associated with imperfect competition. When market power leads to inefficient trade, we typically expect that adding sequential layers of intermediation would reduce efficiency due to problems of double marginalization (e.g., Spengler (1950) and more recently Gofman (2014)). However, Glode and Opp (2016) show that if the intermediaries are partially informed, the reduction of incentives to screen in every stage of the intermediation chain can, somewhat paradoxically, improve efficiency. Yet, Glode and Opp (2016) do not evaluate under which general conditions intermediation chains — if not restricted in their length— can achieve full efficiency. In this paper, we show that the mechanism uncovered by Glode and Opp (2016), when extended to long enough chains of intermediaries, can generically replicate the implementation of full efficiency by any bilateral incentive-compatible mechanism (Hurwicz (1972)).

Our new result that sequentially involving a large number of heterogeneously informed intermediaries may eliminate all trading inefficiencies caused by imperfect competition and asymmetric information sheds light on the earlier evidence of long intermediation chains in many decentralized markets. More broadly, it may also explain why the U.S. financial system, which used to follow a traditional, centralized model of financial intermediation, shifted in recent decades toward a more complex, market-based model characterized by "the long chain of financial intermediaries involved in channeling funds" (Adrian and Shin (2010, p.604)). [2]

2 The Inefficiency of Trade

We initially consider a standard bilateral transaction between two risk-neutral agents as in Glode and Opp (2016). The monopolist seller of an asset (or good) must choose the price he will quote to a potential buyer (or customer) 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.

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.

[2] See also Kroszner and Melick (2009), Cetorelli, Mandel, and Mollineaux (2012), and Pozsar et al. (2013).

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 by quoting a price p is thus given by:

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

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 of increasing the price p is:

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

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

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

We impose the following 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 is closely related to the definition of a strictly regular environment by Fuchs and Skrzypacz (2015) as well as a standard assumption in auction theory that bidders' virtual valuation functions are strictly increasing (Myerson (1981)).[3] When the gains to trade are independent of v, that is, when $v - c(v) = \Delta > 0$ for all $v \in [v_L, v_H]$, Assumption 1 simplifies to imposing that the hazard rate function $h(v) \equiv f(v)/[1 - F(v)]$ is strictly increasing.

Socially efficient trade requires that the seller quotes 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 as summarized in the following proposition.

Proposition 1. *With a monopolistic seller, efficient trade can be 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.

2.2 Market power

Before discussing a solution to this problem of inefficient trade, it is important to emphasize that the seller's market power is a key driver of potentially inefficient behavior.

[3] To see this, we 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.

Suppose that instead of having a monopolistic seller, we have two identical, competing sellers. Each seller quotes a price to the buyer who is only willing to acquire one unit of the asset. The buyer observes both prices before deciding whether to buy from a seller. In this scenario, a classic result is that (Bertrand) competition will drive both sellers to quote prices equal to their marginal cost. Since we are interested in conditions where efficient trade can be sustained (i.e., the buyer obtains the asset with probability 1), each seller's valuation of the asset is given by $\mathbb{E}[c(v)]$ as the buyer's decision to accept does not provide additional information on v in this case. Thus, the condition for efficient trade is $v_L \geq \mathbb{E}[c(v)]$, i.e., the lowest-type buyer accepts the seller's quoted price, which is $\mathbb{E}[c(v)]$. We summarize the result in the following proposition.

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

We can compare this condition to that when there is only one seller who has market power and derive the following result.

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

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

Example 1. *Suppose the buyer values the asset at* $v \sim U[1, 2]$ *and the seller values the asset at a constant* $c < 1$. *If the seller has market power, his optimization problem* *when picking 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, trade is efficient if and only if* $c \leq 0$*. If the seller does not have market power, the condition for efficient trade becomes* $c \leq 1$ *as Bertrand competition drives the seller's quoted price to* c*, which is strictly less than the lowest possible buyer valuation. So when* $c \in (0, 1]$*, the seller's market power yields inefficient trading outcomes.*

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:* $v_L \geq \mathbb{E}[c(v)]$.

Thus, increasing seller competition sustains efficient trade as much as any incentive-compatible mechanism would in our model. In cases where the asset is in scarce supply, however, adding competition on the seller side can be impossible. Moreover, in many contexts market power is not something that can simply be reallocated. In the next section, we generically show however that, whenever trading inefficiencies can be eliminated by the two solutions above, trading networks that involve long intermediation chains can equivalently sustain efficient trade.

3 Intermediation chains

We now consider the involvement of M intermediaries, indexed by m based on their position in a trading chain. To simplify the notation, 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 rounds, we assume that in every transaction the asset holder makes an ultimatum offer to his counterparty. In addition, we propose the following signal structure that allows proving our main existence result and maintains the tractability of the analysis: each intermediary observes a signal that partitions the domain $[v_L, v_H]$ into sub-intervals and intermediary $(m+1)$'s signal creates a strictly finer conditional partition than intermediary m's signal. Nesting sequential traders' information sets eliminates signaling concerns and implies a generically unique subgame perfect Nash equilibrium in our model, even though there are $(M+1)$ bargaining problems among $(M+2)$ heterogeneously informed agents.

In particular, the information structure is modeled 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 $[v_M, v_H]$.
- $\cdots$
- Intermediary M knows whether v belongs to $[v_L, v_1)$, $\cdots$, $[v_{M-1}, v_M)$, or $[v_M, v_H]$.

Before deriving our main results, it is useful to state the following lemma.

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 $\varphi(\cdot)$. Unlike with 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 to the buyer and that we have, generically, a unique subgame perfect Nash equilibrium under intermediated trade.

The following proposition characterizes our main existence result.

Proposition 4. *If $v_L > \mathbb{E}[c(v)]$, there exists an $\bar{M}$ such that the involvement of $M \geq \bar{M}$ intermediaries sustains efficient trade.*

We now return to our parameterized example to illustrate this result.

Example 2. *As in Example 1, the buyer values the asset at $v \sim U[1,2]$ and the seller values it at a constant $c(v) = c$. We focus on the case where $c \in (0,1]$, that is, when direct trade is inefficient due to the seller's market power. We denote $\epsilon \equiv \frac{1}{M+1}$ and construct a chain of M intermediaries who are informed as follows:*

- *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 $[1, 2-M\epsilon)$, $\cdots$, $[2-2\epsilon, 2-\epsilon)$, or $[2-\epsilon, 2]$.*

For $0 \le m \le M-1$, 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. We thus need:

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

As we can see 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 $c \le 1-\epsilon$, which holds as long as $M \ge \bar{M} \equiv \frac{c}{1-c}$. For any other signal trader m receives, he knows that his counterparty is identically informed and trade is efficient.

Now consider trader M who knows that $v \in [1+i\epsilon, 1+(i+1)\epsilon)$ for some $i = 0, 1, 2, \cdots, M$. 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 $1+i\epsilon \ge c + \frac{1}{1/\epsilon}$, which always holds if $c \le 1-\epsilon$, or equivalently if $M \ge \bar{M} \equiv \frac{c}{1-c}$.

Overall, this chain of M intermediaries sustains efficient trade if $c \le 1 - \frac{1}{M+1}$. Hence, sufficiently long intermediation chains (i.e., with $M \ge \bar{M}$ intermediaries) can sustain efficient trade whenever $c < 1$.

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 solution to the problem involves multiple intermediaries who are each endowed with their own market power, once they acquire the asset.[4] The key idea is that a trader who holds the asset faces, for high realiza-

[4]Glode and Opp (2016) formalize the network-formation game that precedes the trading game con-

tions of v, a symmetrically informed counterparty, which makes efficient trade trivial to achieve, and for low realizations of v, he faces a steep trade-off between trading efficiently at conservative prices and trading inefficiently at slightly higher prices. This long intermediation chain thus limits each trader's incentives to inefficiently screen his better informed counterparty and it promotes efficient behavior by all agents involved.

Our final result shows that the sufficient condition for long intermediation chains to yield trade efficiency is also a necessary condition.

Proposition 5. *If involving M intermediaries, whose information are characterized by the above partitions with $v_L = v_0 < v_1 < v_2 < \cdots < v_M < v_{M+1} = v_H$, can implement efficient trade, then it must be that $v_L > \mathbb{E}[c(v)]$.*

Except for the knife-edge case where $v_L = \mathbb{E}[c(v)]$, a long, yet finite, chain of intermediaries can support efficient trade despite imperfect competition as long as there exists an efficient incentive-compatible mechanism, or equivalently as long as efficient trade is possible under perfect competition.

4 Conclusion

We study a classic problem in economics where an agent uses his market power to inefficiently screen a privately informed counterparty. We show that trading through long chains of heterogenously informed intermediaries can generically eliminate all trading inefficiencies due to imperfect competition and asymmetric information. If efficient trade can be achieved by adding competition that shuts down the inefficient use

sidered here and characterize order-flow agreements that traders commit to ex ante, that is, before information is obtained and trading occurs. These order-flow agreements ensure that no trader involved in an intermediation chain that sustains efficient trade is tempted to form an alternative trading network.

of market power or, more broadly, by allowing for incentive-compatible mechanisms that simply eliminate market power problems, it can also be achieved by setting up a trading network that takes the form of a sufficiently long intermediation chain.

The uninformed agent's market power plays an important role in our environment — it is the seller's ability to potentially appropriate additional rents by charging higher prices that creates the social inefficiency that intermediation chains might help alleviate. 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 assumed away. The mechanism we propose, however, differs from interventions aimed at increasing competition. Specifically, the intermediaries we involve in the chain are each endowed with monopoly power once they obtain the asset, potentially creating problems of double marginalization (Spengler (1950)). Moreover, if instead of adding heterogenously informed monopolists, we added several monopolists who are 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. To improve trading efficiency via the involvement of *homogeneously informed* traders, traders need to compete simultaneously rather than sequentially. This form of mechanism thus relies on different forces than the intermediation chains we consider here.

More generally, if we allowed for any mechanism, adding moderately informed agents could help the seller extract more surplus and improve the efficiency of trade (Zhang (2016)). In particular, if multiple informed traders were to bid simultaneously for the seller's asset, the seller could use competition, as suggested by Cremer and McLean (1988), to effectively extract information from these bidders, leaving less information rents to these agents. This competition effect is, however, absent in our setting where trade is bilateral and the asset moves through each trader sequentially. The seller does not extract any information from competing bidders, but rather faces a single intermediary who is less informed than the expert buyer. This smaller information gap between the seller and his counterparty can strengthen the seller's incentives to quote an efficient price. Overall, our solution to the problem features decentralized, sequential trading among heterogeneously informed agents and is thus different from these other types of mechanisms.

Appendix

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

Proof of Proposition 2: Directly follows from the arguments that precede the proposition. $\square$

Proof of Lemma 1: The condition $v_L \geq c(v_L) + \frac{1}{f(v_L)}$ can be rewritten as $H(v_L) \geq 1$. By Assumption 1, $H(v_L) \geq 1$ implies that $H(v) > 1, \forall v \in (v_L, v_H)$. Using the definition of $H(\cdot)$, we obtain $v - c(v) > \frac{1-F(v)}{f(v)}$. Taking expectation on each side, we have $\mathbb{E}v - \mathbb{E}[c(v)] > \mathbb{E}\frac{1-F(v)}{f(v)} = \int_{v_L}^{v_H}(1-F(v))dv = (1-F(v))v|_{v_L}^{v_H} - \int_{v_L}^{v_H} vd(1 - F(v)) = \mathbb{E}v - v_L$. Thus, $v_L > \mathbb{E}[c(v)]$. $\square$

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. $\square$

Proof of Lemma 2: See proof of Lemma 1 in the online appendix for Glode and Opp (2016). $\square$

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 $i = 0, 1, \cdots, M$, 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 $v_L > \mathbb{E}[c(v)]$. $\square$

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