Internalization, Clearing and Settlement, and Stock Market Liquidity[1]

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Abstract

We introduce a model that links stock market liquidity to the costs of clearing and settlement. In particular, we model how differential pricing structures of the clearing and settlement agent stemming from the internalization of clearing and settlement affects stock market liquidity. We show that when the clearing and settlement agent sets prices such that it breaks even on the order flow per investment firm, different stock market equilibria result. With substantial costs of non-internalized trades, traders from a large investment firm announce unattractive prices that are interesting only for counterparties of their own investment firm. Traders originating from other brokers find these prices not attractive enough as the related costs of clearing and settlement are too large for them. In contrast, the quotes submitted by traders from smaller brokers remain quite liquid as they aim to attract counterparties from all brokers since this substantially increases their likelihood of execution. Further, we analyze the case where the clearing and settlement agent charges the marginal cost for non-internalized trades. For sufficiently high clearing and settlement costs, it may then happen that traders from both brokers target own-broker counterparties only. In this case, the stock market is relatively illiquid with traders from the large broker quoting more liquid prices than traders from the small broker. Finally, for sufficiently low costs of non-internalized trades, welfare is higher when traders target all possible counterparties, and not only those of their own broker.

JEL Codes: G10, G15

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1 Introduction

The organization of a financial market is an important determinant of its liquidity. Market microstructure, the process by which investors' latent demands are ultimately translated into prices and volumes, has mainly focused on price formation and price discovery, and on the market design of financial systems. Next to the implicit transaction costs related to trading, explicit transaction costs such as commissions and post-trading infrastructure costs are of considerable importance. Data from Elkins/McSherry, for example, show that explicit transaction costs constitute about three quarters of the total transaction costs (see e.g. Domowitz and Steil (2002)). Further, according to the European Commission, costs of the post-trading infrastructure represent 10 to 20% of total post-trading transaction costs. While it is well-known that post-trade transaction costs are considerable, the market microstructure literature has not yet studied its impact on the liquidity of financial markets. This paper makes a first step to fill this void by analyzing the impact of differences in pricing of clearing and settlement services on stock market liquidity. These price differences stem from different degrees of internalization of order flow by the post-trade infrastructure. In particular, we study how the potential of internalizing trades affects participants' willingness to supply and consume liquidity. Our paper thus studies how the pricing of back office activities influences the front office, i.e. the stock market liquidity.

Our research is motivated by the recent inclusion of internalization systems at several exchanges and the associated pricing schedules for trading services. Internalization occurs when buyer and seller originate from the same investment firm. This may happen when (i) the investment firm trades on its own account with his client ("client-to-house transaction"), (ii) two different counterparties trade through the same investment firm ("client-to-client transaction"), or (iii) transactions are carried out within the same investment firm ("house-to-house transaction"). In our setting, internalization reduces the costs of the post-trading infrastructure, i.e. the costs of clearing and settlement. In the US, the DTCC (Depositary Trust and Clearing Corporation) which clears and settles trades of all exchanges observed that an increasing number of investment firms pre-netted their trades such that the order flow observed by the DTCC was not representative for the entire market. One of the recommendations the DTCC made was to adapt the clearing and settlement fees in order to reduce the economic incentive for using pre-netting (see e.g. DTCC (2003)). In Europe, with the implementation of MiFID, the Markets in Financial Instruments Directive, several trading systems have introduced features allowing to internalize clearing and settlement. First, regulated markets have created possibilities for internalization. The London Stock Exchange for example started its SETS internalizer in April 2007. SETS internalizer prevents on-book self-executions from passing through to clearing and settlement, thus avoiding post-trade infrastructure costs. As a result, all order book executions where both sides of the trade originate from the same investment firm do not pass through to clearing and settlement. The tariff charged is 0.1 bp, which is 87.5% lower than the headline rate.[1] Similarly, Euronext has created an algorithm that induces buy and sell orders originating from the same investment firm to avoid the cost of clearing and settlement.[2] Second, systematic internalizers allow to avoid clearing and settlement costs when the trades originate from the same investment firm. A recent report by Oxera (2009) argues that brokers internalize about 10% of their trades and they expect this to increase over time. Our paper addresses how internalization of clearing and settlement may affect stock market liquidity.

Our main insights can be summarized as follows. First, we find that explicit transaction costs such as costs of clearing and settlement affect stock market liquidity. In general, higher costs of clearing and settlement appear to increase stock market liquidity. The reasoning is that higher costs of clearing and settlement induce more aggressive limit order pricing to induce incoming counterparties to trade. This is in line with empirical evidence of Berkowitz, Logue and Noser (1988) who find that larger explicit costs decrease implicit transaction costs. Second, internalization reduces the costs of clearing and settlement. Investment firms with larger market shares are therefore able to create some benefits as they allow to reduce costs of clearing and settlement. However, our results show that when more trades can be internalized stock market liquidity decreases. The intuition behind this result is that an increase in internalization opportunities corresponds to a drop in explicit transaction costs and therefore reduces the aggressiveness of limit order prices. Third, when the clearing and settlement agent sets prices such that it breaks even per broker, different equilibria result. Stock market liquidity is harmed when the costs of clearing and settlement are very high (causing the broker-specific break even prices to differ substantially). Traders linked to the large investment firm then announce prices that are only attractive to counterparties of their own investment firm (which do not bear the high clearing and settlement costs). In contrast, the quotes submitted by traders linked to smaller brokers remain quite liquid as they face another trade-off: submitting aggressive quotes allows them to attract counterparties from all brokers which substantially increases their likelihood of execution. Fourth, in addition to both above mentioned strategies, traders from both brokers may target their own counterparties only. This happens when the clearing and settlement agent charges the marginal and sufficiently high cost for non-internalized trades. In this case, the stock market is relatively illiquid with traders from the large broker quoting more liquid prices than traders from the small broker. Finally, we perform a welfare analysis comparing the different settings. We find that the equilibria where all traders target counterparties

[1] See page 8 on http://www.londonstockexchange.com/traders-and-brokers/rules-regulations/mifid/pre-trade.pdf

[2] See page 40 on http://www.nyse.com/pdfs/NYSE_Euronext_%20Analyst_Presentation.pdf

from all brokers (and not only their own broker) produce a higher welfare, compared to equilibria where some (or all) traders aim to attract only "internal" counterparties (i.e. from their own broker).

To our knowledge no papers exist linking the organization of the post-trading infrastructure to stock market liquidity. Taking a wider perspective, our paper is related to different sets of literature. First, it relates to the literature on order submission strategies in limit order markets such as Foucault (1995, 1999), Parlour (1998), Handa, Schwartz and Tiwari (2003), Foucault, Kadan and Kandel (2005), Goettler, Parlour and Rajan (2005), Roşu (2009) and Van Achter (2009). These papers model how traders choose between market orders and limit orders in different dynamic settings. We extend them by including the impact of heterogeneity in post-trade costs on the optimal quote setting behavior of traders belonging to different brokers. Our paper also relates to the literature on make/take fees as modeled in Foucault, Kadan and Kandel (2009). In many markets, providers of liquidity receive a "make fee", whereas consumers of liquidity pay a "take fee". Foucault, Kadan and Kandel (2009) show this may induce liquidity cycles to arise. Our paper contributes to this literature by highlighting that outstanding quotes by one broker in the limit order book may induce asymmetries for traders affiliated to different brokers. When the transaction is internalized and implies no costs of clearing and settlement, the post-trade cost is low and it is as if the payable take fee is small. In contrast, when a trader of another broker is the counterparty, post-trade costs are high and it is as if the payable take fee is large.

Second, our work contributes to the literature on clearing and settlement. The theoretical papers mostly deal with the optimal pricing strategies when central securities depositories (CSDs) interact, in order to explain the high markups for cross-border transfers of securities or the effects of different degrees of access to the CSDs (see e.g. Rochet (2005), Tapking and Yang (2006), Holthausen and Tapking (2007), Tapking (2007), and Koeppl, Monnet and Temzelides (2009)). We model how a cost-based post-trade infrastructure may affect stock market liquidity in two different ways. First, internalization of order flow reduces costs at the CSD and therefore changes the traders' aggressiveness in the stock market. Second, the way a cost-based pricing structure is implemented by the CSD may lead to different stock market equilibria. In particular, a pricing strategy fully reflecting the CSD's marginal cost may lead to an equilibrium where traders opt to only address counterparties from the same broker. This reduces the total number of transactions and decreases market liquidity. Further, the empirical papers on the post-trading infrastructure mainly investigate whether there are economies of scale and scope in the clearing and settlement industry (see e.g. Van Cayseele and Wuyts (2008)). Our paper shows that transactions may exhibit different degrees of difficulty (i.e. cheaper internalized clearing and settlement versus more expensive cross-broker clearing and settlement), hinging on the particular stock market equilibrium that is played.

Third, some papers connect different phases of the trading process. Foucault and Parlour (2004) model how competition between stock exchanges links listing fees and transaction costs on those exchanges. They find that competing exchanges relax competition by choosing different trading technologies and listing fees. Berkowitz, Logue and Noser (1988) link explicit transaction costs to implicit transaction costs and find that paying higher commissions yields lower execution costs (be it non-commensurate). Our paper also links two phases of the trading cycle, i.e. stock market liquidity and post-trade infrastructure.

The remainder of this paper is structured as follows. Section 2 introduces the setup of our model. Sections 3 to 5 present different pricing schemes implemented by the clearing and settlement agent, and the corresponding equilibria. Within Section 6, these equilibria are further compared and a welfare analysis is provided. Finally, Section 7 concludes.

2 Setup

We develop an infinite horizon model to analyze a continuous limit order market listing a single security. Before trading starts, the clearing and settlement agent decides upon the prices of clearing and settlement. Traders take these post-trade clearing and settlement prices as given during the subsequent trading day. Each period in time $t = 0, 1, ... + \infty$, a single trader arrives who is willing to trade one share of the asset. Traders are risk neutral and expected utility maximizers. Further, traders exhibit an exogenously determined trading orientation which makes them either a buyer or a seller. We assume that the proportion of buyers and sellers in the trader population is equal.[3] Buyers have a private valuation for the asset equal to V_h, whereas sellers have a private valuation V_l. We assume both valuations are non-negative and $V_h - V_l > 0$, which implies there are always gains from trade between both parties. These differences in valuation are an outcome of taxes, liquidity shocks, or other portfolio considerations such as differences in endowment, or in opinions on the expected value of the asset. Each trader is linked to one of two possible brokers which means their individual orders are always sent to the market through this particular broker. More specifically, a fraction γ of the total trader population is linked to broker 1, and a complementary fraction $1 - \gamma$ is linked to broker 2. Throughout this paper, we mainly focus on brokers of divergent sizes. Thus, we assume broker 1 is a "large" broker serving a relatively larger fraction of the trader base, whereas broker 2 is a

[3] Our model is easily adjusted for the case where the proportion of buyers and sellers is different from 0.5; however it becomes slightly more complex since buyers and sellers no longer choose symmetric strategies. We prefer equal probabilities as this allows us more easily to identify the impact of different pricing schemes implemented by the clearing and settlement agent.

"small" one (i.e. $\gamma > \frac{1}{2}$). Broker affiliations are indexed by subscript $j \in \{large, small\}$. Hence, for a trader arriving in a random period t, with probabilty $\gamma/2$ it is or a buyer or a seller from the large broker and with probability $(1-\gamma)/2$ it is or a buyer or a seller from the small broker.

The post-trading infrastructure, which from now on we denote as CSD (i.e. Central Securities Depository), handles clearing and settlement immediately after each transaction, and is considered to be risk neutral. The CSD has a cost c per leg of the trade for non-internalized trades, i.e. trades involving different brokers, and a lower cost for internalized trades, i.e. trades involving the same broker, which we normalize to zero. In implementing its pricing scheme, the CSD always aims to break even on average, but does not necessarily charge its true costs on each individual transaction. Overall, depending on the sophistication of the set pricing scheme, a CSD can charge different costs based on the size of the broker and on the type of transaction that is cleared and settled. The first distinction implies a different cost for trades from the large vs the small broker. The second distinction means that the CSD differentiates between internalized and non-internalized trades. To properly account for these distinctions, we consider three different pricing schemes implemented by the CSD. More specifically, micro-foundations are provided for various clearing and settlement costs c_j^i, with superscript $i \in \{I, NI\}$ indicating different cases regarding the pricing structure of the CSD for internalized (I) and non-internalized (NI) trades, and subscript $j \in \{large, small\}$ referring to broker size. The following table provides a summary of the three different pricing schemes:

Pricing Scheme CSD	Uniform	$c_{large}^{I} = c_{large}^{NI} = c_{small}^{I} = c_{small}^{NI}$
	Broker-Specific	$c_{large}^{I} = c_{large}^{NI}$ and $c_{small}^{I} = c_{small}^{NI}$
	Trade-Specific	$c_{large}^{I} = c_{small}^{I}$ and $c_{large}^{NI} = c_{small}^{NI}$

The "Uniform" pricing scheme means that the CSD charges the same cost to small and large brokers and to internalized and non-internalized trades. This cost is set optimally such that the CSD breaks even on average. The optimal cost and its impact on quotes will be analyzed in Section 3. Next, under "Broker-Specific" pricing, discussed in detail in Section 4, the CSD charges a different cost to the large broker, compared to the small broker. Within a broker, however, no distinction is made between internalized or non-internalized trades. The final scheme, "Trade-Specific" pricing, entails that an internalized trade will be charged a different cost, compared to a non-internalized trade. The CSD does not discriminate between brokers though. In Section 5, we analyze this pricing scheme in detail.

An arriving trader bases her order submission strategy on her observation of the standing limit order book (LOB). She has two options at her disposal to trade. On the one hand, she could post a quote by submitting a limit order (LO) which does not offer certainty of execution. Posted LOs stay in the market only for one period and are thus take-or-leave offers for the next trader (see Foucault (1999) for a similar approach). On the other hand, she could submit a market order (MO) which guarantees immediate execution but at the cost of a less favorable execution price. Liquidity-demanding MOs execute against standing liquidity-supplying LOs, so they can only be submitted if a counterparty LO is already present in the LOB. Clearly, the LO's execution probability is endogenous in the model as it depends on other traders' order placement strategies. We will further discuss this issue below in this section. Orders are for one unit of the asset, and once submitted cannot be modified or cancelled. New in our model and a key contribution to the existing literature (such as Foucault (1999), Handa, Schwartz and Tiwari (2003), and Van Achter (2009)) is that traders also account for the pricing scheme implemented by the CSD (and the implied clearing and settlement cost) in choosing their optimal strategy. More specifically, it is argued that conditional upon execution, the utility of trading the asset at price P for a buyer at broker j for a transaction of type i equals $U(V_h, P) = V_h - P - c_j^i$, while a seller's utility of trading at broker j with a transaction of type i is $U(V_l, P) = P - V_l - c_j^i$. Hence, as non-trading gains are normalized to zero, $V_h - c_j^i$ and $V_l + c_j^i$ reflect the reservation price under the appropriate pricing structure that buyers are willing to pay and that sellers are willing to receive for one share of the asset, respectively. Traders naturally aim to maximize the expected payoff of their trade:

$V_h - A - c_j^i$	for a buyer submitting a MO hitting a standing quote A;
$\Gamma(B).\left(V_h - B - c_j^i\right)$	for a buyer submitting a LO at quote B;
$B - V_l - c_j^i$	for a seller submitting a MO hitting a standing quote B;
$\Psi(A).\left(A - V_l - c_j^i\right)$	for a seller submitting a LO at quote A.

accounting for the appropriate clearing and settlement cost c_j^i, and with $\Gamma(B)$ the execution probability of a buy LO at quote B (the bid price), and $\Psi(A)$ the execution probability of a sell LO at quote A (the ask price), as determined by the respective buyer or seller. In setting the optimal bid or ask quotes when submitting a LO, a trader in general has two possibilities. She could determine quotes that only attract counterparties from her own broker (we label this strategy "*own*") or she can opt for a quote that is attractive to all possible counterparties, i.e. traders from her own and from the other broker (we label this strategy "*all*"). Do note that "attract" in this context means the targeted incoming trader is at least willing to hit the standing LO by submitting a MO. Thus, any trader submitting a LO needs to account for the MO strategy of the subsequently arriving trader.[4] Given traders are linked to either a large

[4] As such, the LO execution probabilities are endogenous, implying traders are in a game situation. In general, traders' optimal order submission strategies depend on their LO's probability of execution, which in turn is determined by their order submission strategies. To properly account for these endogenous linkages between the MO and the LO placement strategies, they will be determined simultaneously.

or a small broker, four possible combinations of strategies can be distinguished:[5]

I. traders of both brokers aim to address counterparties of all brokers: $\{all, all\}$;

II. traders of the large broker only aim to address counterparties of their own broker, traders of the small broker aim to address counterparties of all brokers: $\{own, all\}$;

III. traders of the large broker aim to address counterparties of all brokers, traders of the small broker only aim to address counterparties of their own broker: $\{all, own\}$;

IV. traders of both brokers only aim to address counterparties of their own broker: $\{own, own\}$.

Note that the first element within the mentioned $\{.,.\}$ always refers to the strategy of traders of the large broker, and the second element to the strategy of traders of the small broker. As will become clear below, these four possible combinations of strategies result in four possible sub-equilibria of our game. Indeed, for each combination, traders at different brokers may post different bid and ask quotes, and the CSD may charge a different cost. We will show below, however, that not every potential sub-equilibrium materializes under every pricing scheme, because some combination(s) will dominate others.

All parameters of the model, including V_h, V_l, γ, and c_j^i are known to the investors. Moreover, they are constant over time, hence the market is assumed to be in steady state. This allows to solve for a stationary equilibrium within each pricing scheme as in Foucault (1999) or Van Achter (2009). More specifically, a stationary market equilibrium is defined as a set of mutual order submission strategies (specifying an optimal order type, quote and corresponding execution probability to each possible state of the LOB) such that each trader's strategy is optimal given the strategies of all other traders. Divergences in pricing rules imply different types of equilibria arise. Both the magnitude of the costs for clearing and settlement as well as the type of equilibrium influence stock market liquidity. In Sections 3, 4 and 5 we provide a thorough analysis of each of the three derived stationary equilibria.

3 CSD Pricing Scheme 1: Uniform Pricing

Under the uniform pricing scheme, which is denoted by superscript U, all transactions are handled by the CSD which charges a uniform cost for both brokers to all orders upon execution. Furthermore, at the level of the CSD, we assume that internalized

[5] Do note that by assuming $k = 1/2$, within a broker we have that buyers and sellers have symmetric strategies. Thus, there is no need to further differentiate the strategies in this respect.

transactions entail a normalized zero marginal cost. In contrast, transactions stemming from traders from different brokers still imply a cost c for the CSD. Hence, within this particular pricing scheme, the CSD is argued to charge a uniform cost to both brokers such that it breaks even on average over all transactions. Thus, it compensates the losses it makes on the difficult (i.e. non-internalized) order flow stemming from different brokers with gains from the easy order flow stemming from trades that occur within the same broker (i.e. internalized). In fact, by charging a uniform break even cost per transaction, the CSD does neither differentiate between different types of transactions, nor between transactions stemming from different brokers. Denote this break even cost by c^U, this pricing scheme then implies that:

$$c^I_{large} = c^{NI}_{large} = c^I_{small} = c^{NI}_{small} = c^U$$

Under this pricing scheme, it is clear that traders from both brokers will always address all traders. This means that the $\{all, all\}$ combination of strategies dominates the three other combinations. The reason is that as all traders face a uniform cost c^U, it is impossible to set a quote only attractive to traders of one particular broker.[6] Therefore, when analyzing the equilibrium we only consider the $\{all, all\}$ combination of strategies.

3.1 Equilibrium

We now turn to the determination of the equilibrium quotes and the optimal c^U. How do traders set their quotes, taking c^U as given? Given that the $\{all, all\}$ sub-equilibrium will always prevail and that costs and gains are identical for traders of both brokers, we must have that bid and ask quotes, set by traders of the large and small broker are identical. We denote this as follows:

$$\begin{aligned} A^{U,\{all,all\}}_{large} &= A^{U,\{all,all\}}_{small} \equiv A^{U,\{all,all\}} \\ B^{U,\{all,all\}}_{large} &= B^{U,\{all,all\}}_{small} \equiv B^{U,\{all,all\}} \end{aligned}$$

where $A^{U,\{all,all\}}_{large}$ refers to the ask price (A) set by a trader from the large broker (subscript $large$) with uniform pricing by the CSD (superscript U) and under the $\{all, all\}$ sub-equilibrium (second superscript). The other prices have a similar notation.

Suppose now a buyer arrives in the market. She will set the bid price of her LO such that the next incoming seller is indifferent between hitting the LO (by submitting a sell MO) or submitting a sell LO herself. This implies the expected payoff for the incoming seller of submitting a MO or a LO must be the same. The following equation shows this

[6] Do note that if playing the *own*-strategy would be possible, this would still be a sub-optimal strategy as it only reduces execution probabilities without inducing any quote advantage.

indifference condition:

$$B^{U,\{all,all\}} - V_l - c^U = \frac{1}{2}\left[A^{U,\{all,all\}} - V_l - c^U\right]$$

The left hand side of this equation presents the gain from a sell MO, given the bid price set by the buyer in the previous period. The right hand side is the expected gain of a sell LO, which is the execution probability of this order (i.e. 1/2 or the probability that the next arriving trader is a buyer who will hit the standing sell LO since the seller optimally also sets her ask price to make the next arriving buyer indifferent) multiplied by the payoff upon execution of her order corrected for the appropriate clearing and settlement cost. Thus, the idea here is that $B^{U,\{all,all\}}$ is chosen at the lowest level at which the subsequently arriving seller is just willing to submit a MO, while both accounting for the clearing and settlement cost c^U. In other words, $B^{U,\{all,all\}}$ equals the seller's cutoff price and renders this seller indifferent between hitting the standing LO at $B^{U,\{all,all\}}$ and submitting her own LO at $A^{U,\{all,all\}}$. Submitting a LO at all other quotes is easily proven to be sub-optimal for this buyer.

Similarly an arriving seller sets her LO quote in order to make a subsequently arriving buyer indifferent between submitting a buy MO at $A^{U,\{all,all\}}$ or a buy LO at $B^{U,\{all,all\}}$:

$$V_h - A^{U,\{all,all\}} - c^U = \frac{1}{2}\left[V_h - B^{U,\{all,all\}} - c^U\right]$$

Solving the system of indifference equations, and recalling that the CSD sets c^U such that it breaks even on average over all transactions, we obtain the equilibrium for the uniform pricing scheme, as shown in Proposition 1:

Proposition 1 *When the CSD applies a uniform pricing scheme, i.e. it charges the same cost to both brokers and to internalized and non-internalized trades, the optimal cost announced by the CSD is:*

$$c^U = 2\gamma(1-\gamma)c$$

Traders always play the $\{all, all\}$ sub-equilibrium. The optimal ask and bid quotes of the trader are:

$$\begin{aligned} A_{large}^{U,\{all,all\}} &= A_{small}^{U,\{all,all\}} \equiv A^{U,\{all,all\}} = \frac{2V_h + V_l - 2\gamma(1-\gamma)c}{3} \\ B_{large}^{U,\{all,all\}} &= B_{small}^{U,\{all,all\}} \equiv B^{U,\{all,all\}} = \frac{V_h + 2V_l + 2\gamma(1-\gamma)c}{3} \end{aligned}$$

Proof. See Appendix. ■

By charging c^U on every transaction (internalized and non-internalized), the CSD on average indeed breaks even: it gains on transactions for which it does not face marginal costs and loses on transactions where active clearing and settlement takes place. While transactions received from the largest broker more often induce no costs, as they are more often internalized, the CSD still charges a uniform price to both brokers. We observe that the ask decreases in c, while the bid increases in c. Thus, larger costs of clearing and settlement appear to induce more liquid quote-setting behavior and thus improve stock market liquidity. The reasoning behind this remarkable result is that traders submit more aggressive LOs in order to induce the counterparty to submit a MO (which incurs the clearing and settlement cost with certainty). That is, it is as if the counterparty now has a lower willingness to trade resulting from the cost of clearing and settlement. Moreover, when both brokers exactly have the same market share (i.e. $\gamma = 0.5$), the quotes are most liquid. Indeed, if this condition is fulfilled, the cost charged by the CSD per trade is largest leading to a more aggressive pricing strategy in equilibrium. Further, as could be expected, when one broker attracts the entire market ($\gamma = 0$ or $\gamma = 1$), clearing and settlement costs do not play a role anymore as all trades are then internalized. This would imply we are in a model without clearing and settlement costs, comparable to Foucault (1999).

4 CSD Pricing Scheme 2: Broker-Specific Pricing

We now assume that the CSD price discriminates between brokers, i.e. sets prices c_{large}^{BS} for the large broker and c_{small}^{BS} for the small broker (where superscript BS indicates the analyzed pricing scheme). This means that in the notation of Section 2, we have:

$$\begin{aligned} c_{large}^{I} &= c_{large}^{NI} = c_{large}^{BS} \\ c_{small}^{I} &= c_{small}^{NI} = c_{small}^{BS} \end{aligned}$$

As $\gamma > 0.5$, trades stemming from the large broker are more likely to occur between two traders originating from the same broker as compared to trades stemming from the small broker. Therefore, it appears reasonable to assume that $c_{large}^{BS} \leq c_{small}^{BS}$, such that traders linked to a certain broker pay a broker-specific cost on any trade, and this broker-specific cost is lower for the large broker (we will verify and confirm this assumption later in this section). Further, we assume the CSD implements a pricing scheme such that it breaks even on average for each broker individually (and thus implicitly also overall). A novel implication is then that the quoting behavior of traders linked to the large broker may differ substantially from the strategies of traders affiliated to the small broker. Consider the following example to illustrate this point. Assume a buyer linked to the large broker arrives in the market. On the one hand, she could submit a LO. Her quote choice allows her to choose which counterparties she wants to address: (i) by posting a lower bid $B_{large}^{BS,\{own,all\}}$ she only attracts counterparties from the same broker (implying a higher payoff with a lower execution probability), whereas (ii) by posting a higher bid $B_{large}^{BS,\{all,all\}}$ she also attracts counterparties from the other broker (implying a lower payoff with a higher execution probability). Do note $B_{large}^{BS,\{own,all\}}$ is the lowest bid quote at which an incoming seller from the same (i.e. large) broker is willing to submit a MO, while accounting for her relatively low individual clearing and settlement cost and her own LO strategy quoting $A_{large}^{BS,\{own,all\}}$. In turn, $B_{large}^{BS,\{all,all\}}$ is the lowest bid quote at which an incoming seller from the other (i.e. small) broker is willing to submit a MO, while accounting for her relatively high individual clearing and settlement cost and her own LO strategy quoting $A_{small}^{BS,\{all,all\}}$. Submitting a LO at any other quote is easily proven to be sub-optimal for this buyer.[7] As we will see below, the choice between both quotes hinges on market parameters and on the trader's preferences in the trade-off between quote level, execution probability and clearing and settlement cost. Two distinct sub-equilibria will result, the resulting quotes of which reflect the underlying transaction costs. On the other hand, given the availability of a standing sell LO, she could also submit a MO. As $k = 1/2$, the actions of the sellers linked to the large broker are completely symmetric, and could be derived in a similar way. In turn, the possible strategies for traders linked to the small broker differ from those mentioned above as they cannot opt to only address counterparties merely stemming from their own broker by virtue of the higher broker-specific transaction costs they face. Counterparties from the large broker will always be willing to hit their quotes with a MO. This means that traders from the small broker will never (be able to) play the *own* strategy. We are thus left with two possible combinations of strategies:

I. traders of both brokers aim to address counterparties of all brokers (i.e. $\{all, all\}$)

II. traders of the large broker only aim to address counterparties of their own broker, traders of the small broker aim to address counterparties of all brokers (i.e. $\{own, all\}$);

For both combinations, we will now determine the according equilibrium quotes set by traders at both brokers and the optimal costs charged by the CSD.

4.1 Equilibrium

While setting its optimal cost, the CSD rationally anticipates the strategies of the traders at the different brokers, i.e. whether they play the $\{all, all\}$ or $\{own, all\}$ strategies. Therefore, the CSD will charge a different cost within each of the two combinations. We denote the cost charged to the large broker in both combinations as $c_{large}^{BS,\{all,all\}}$ and $c_{large}^{BS,\{own,all\}}$, respectively, while the costs charged to the small broker are $c_{small}^{BS,\{all,all\}}$ and

[7] That is, higher bid quotes do not increase the execution probability yielding lower expected payoffs.

$c_{small}^{BS,\{own,all\}}$. How does the CSD set these costs? Assume the sub-equilibrium corresponding to the $\{all, all\}$ combination of strategies holds. For the large broker, the CSD then determines the fraction of internalized and non-internalized trades for that broker under the $\{all, all\}$ combination of strategies. Next, each fraction is multiplied with the cost for the CSD of that type of trade, i.e. the proportion of internalized trades is multiplied by zero, and the proportion of non-internalized trades by c. The same procedure is applied for the small broker and for the $\{own, all\}$ combination. In this way, the CSD ensures that it breaks even on average for each broker individually within each combination. Do note all the underlying calculations are provided in detail in the proof of Proposition 2.

Now, we turn to the optimal order submission strategies of traders at both brokers. We determine their strategies given clearing and settlement costs $c_{large}^{BS,\{all,all\}}$, $c_{small}^{BS,\{all,all\}}$, $c_{large}^{BS,\{all,all\}}$ and $c_{small}^{BS,\{all,all\}}$. First, we discuss the $\{all, all\}$ case, in which traders at both brokers set their quotes to keep incoming counterparties of all brokers at least indifferent. Thus, a buyer at the large broker keeps the marginal incoming seller indifferent, i.e. a seller from the small broker since she faces the highest clearing and settlement cost when hitting this quote:

$$B_{large}^{BS,\{all,all\}} - V_l - c_{small}^{BS,\{all,all\}} = \frac{1}{2}\left[A_{small}^{BS,\{all,all\}} - V_l - c_{small}^{BS,\{all,all\}}\right].$$

Thus, the incoming seller from the small broker is kept indifferent between hitting the standing quote $B_{large}^{BS,\{all,all\}}$ (by submitting a MO sell) accounting for the appropriate clearing and settlement cost, and submitting her own sell LO (of which the execution probability, the quote and the clearing and settlement cost correctly correspond to the $\{all, all\}$ strategy this seller is playing). Similarly, a seller at the large broker keeps the marginal incoming buyer indifferent, i.e. a buyer from the small broker:

$$V_h - A_{large}^{BS,\{all,all\}} - c_{small}^{BS,\{all,all\}} = \frac{1}{2}\left[V_h - B_{small}^{BS,\{all,all\}} - c_{small}^{BS,\{all,all\}}\right].$$

Now, how will traders of the small broker set their LO quotes? Also a buyer from the small broker keeps the marginal incoming seller indifferent, i.e. the seller of the small broker since she faces the highest clearing and settlement cost when hitting this quote:

$$B_{small}^{BS,\{all,all\}} - V_l - c_{small}^{BS,\{all,all\}} = \frac{1}{2}\left[A_{small}^{BS,\{all,all\}} - V_l - c_{small}^{BS,\{all,all\}}\right].$$

Similarly, a seller of the small broker keeps the marginal incoming buyer indifferent, i.e. a buyer from the small broker:

$$V_h - A_{small}^{BS,\{all,all\}} - c_{small}^{BS,\{all,all\}} = \frac{1}{2}\left[V_h - B_{small}^{BS,\{all,all\}} - c_{small}^{BS,\{all,all\}}\right].$$

Next, we focus on the $\{own, all\}$ combination of strategies. Within this combination, traders at the large broker set their quotes only to keep the counterparties of their own broker indifferent. Thus, a buyer at the large broker keeps the incoming seller from her own broker indifferent:

$$B_{large}^{BS,\{own,all\}} - V_l - c_{large}^{BS,\{own,all\}} = \gamma\frac{1}{2}\left[A_{large}^{BS,\{own,all\}} - V_l - c_{large}^{BS,\{own,all\}}\right].$$

Hence, the incoming seller from the large broker is kept indifferent between hitting the standing quote $B_{large}^{BS,\{own,all\}}$ (by submitting a MO sell) accounting for the appropriate clearing and settlement cost, and submitting her own sell LO (of which the execution probability, the quote and the clearing and settlement cost correctly correspond to the $\{own, all\}$ strategy this seller is playing). Similarly, a seller at the large broker keeps the incoming buyer from her own broker indifferent:

$$V_h - A_{large}^{BS,\{own,all\}} - c_{large}^{BS,\{own,all\}} = \gamma\frac{1}{2}\left[V_h - B_{large}^{BS,\{own,all\}} - c_{large}^{BS,\{own,all\}}\right].$$

At these quotes, only incoming traders from the large broker are indifferent, and thus attracted to hit them with a MO. For the traders originating from the small broker, trading at these quotes is too costly given the higher transaction cost $c_{small}^{BS,\{own,all\}}$ they face. Therefore, the execution probabilities are only related to the own broker (i.e. γ).

Now, how will traders of the small broker set their LO quotes under the $\{own, all\}$ combination of strategies? We know that within this broker-specific pricing scheme these traders do not have the possibility to only address traders of their own broker, as traders from the large broker would automatically also be interested in any quote which makes traders from the small broker indifferent. Thus, traders at the small broker set their quote to keep incoming counterparties of all brokers at least indifferent: a buyer keeps the marginal seller indifferent, i.e. a seller from the small broker:

$$B_{small}^{BS,\{own,all\}} - V_l - c_{small}^{BS,\{own,all\}} = \frac{1}{2}\left[A_{small}^{BS,\{own,all\}} - V_l - c_{small}^{BS,\{own,all\}}\right].$$

Similarly a seller keeps the marginal buyer indifferent, i.e. a buyer from the small broker:

$$V_h - A_{small}^{BS,\{own,all\}} - c_{small}^{BS,\{own,all\}} = \frac{1}{2}\left[V_h - B_{small}^{BS,\{own,all\}} - c_{small}^{BS,\{own,all\}}\right].$$

Solving the systems of indifference equations for the traders at both brokers and computing the appropriate clearing and settlement costs charged by the CSD under both combinations, we obtain the equilibrium under the broker-specific pricing scheme as stated in Proposition 2.

Proposition 2 *Define the following two critical values:* $\widehat{c}^{BS,\{own,all\}} = \frac{2(1+\gamma)(1-\gamma)(2-\gamma)(V_h-V_l)}{6-17\gamma+18\gamma^2-4\gamma^3}$ *and* $\widehat{c}^{BS,\{all,all\}} = \frac{4(1-\gamma)(V_h-V_l)}{6-13\gamma+10\gamma^2}$*. With a CSD which price discriminates between brokers (i.e. broker-specific pricing scheme), traders at both brokers play the following LO strategies depending upon the value of the clearing and settlement cost* c*:*

- *For low values of* c*, i.e.* $c \leq \widehat{c}^{BS,\{all,all\}}$*, traders from both brokers target counterparties of all brokers, thus the* $\{all, all\}$ *sub-equilibrium is played. The CSD then announces clearing and settlement costs:*

$$\begin{aligned} c_{large}^{BS,\{all,all\}} &= (1-\gamma)c \\ c_{small}^{BS,\{all,all\}} &= \gamma c \end{aligned}$$

  for the large and the small broker, respectively. The optimal ask and bid quotes of the trader are:

$$\begin{aligned} A_{large}^{BS,\{all,all\}} &= A_{small}^{BS,\{all,all\}} = \frac{2V_h + V_l - \gamma c}{3} \\ B_{large}^{BS,\{all,all\}} &= B_{small}^{BS,\{all,all\}} = \frac{V_h + 2V_l + \gamma c}{3} \end{aligned}$$

- *For intermediate values of* c*, i.e.* $\widehat{c}^{BS,\{all,all\}} < c \leq \widehat{c}^{BS,\{own,all\}}$*, there is no pricing strategy such that the CSD breaks even.*

- *For high values of* c*, i.e.* $c > \widehat{c}^{BS,\{own,all\}}$*, traders from the large broker only target counterparties of their own broker, whereas traders from the small broker target counterparties of all brokers, thus the* $\{own, all\}$ *sub-equilibrium is played. The CSD then announces clearing and settlement costs:*

$$\begin{aligned} c_{large}^{BS,\{own,all\}} &= \frac{1-\gamma}{1+\gamma}c \\ c_{small}^{BS,\{own,all\}} &= \frac{\gamma}{2-\gamma}c \end{aligned}$$

  for the large and the small broker, respectively. The optimal ask and bid quotes are:

$$\begin{aligned} A_{large}^{BS,\{own,all\}} &= \frac{2V_h + \gamma V_l}{2+\gamma} - \frac{(2-\gamma)(1-\gamma)}{(2+\gamma)(1+\gamma)}c \\ B_{large}^{BS,\{own,all\}} &= \frac{\gamma V_h + 2V_l}{2+\gamma} + \frac{(2-\gamma)(1-\gamma)}{(2+\gamma)(1+\gamma)}c \\ A_{small}^{BS,\{own,all\}} &= \frac{2V_h + V_l}{3} - \frac{\gamma}{2-\gamma}c \\ B_{small}^{BS,\{own,all\}} &= \frac{V_h + 2V_l}{3} + \frac{\gamma}{2-\gamma}c \end{aligned}$$

Proof. See Appendix. ■

Thus, for low clearing and settlement costs, traders at both brokers target counterparties at all brokers. The marginal trader then needs to be convinced to hit the standing LO. This implies the transaction costs for the small broker, which are relatively high, are reflected in the quotes and the quotes are identical for traders from both brokers. The stock market's liquidity is then relatively high as the traders need to quote aggressively to induce the traders from the small broker (who face high clearing and settlement costs) to participate. In contrast, for sufficiently large costs of clearing and settlement (inducing larger cost savings from internalization), traders from the large broker address only their own counterparties and prefer not to target traders from the small broker: the gain from increased matching probabilities does not outweigh the concessions in terms of aggressive pricing. The quotes from traders from the large broker then imply a low stock market liquidity as they only address own counterparties with relatively low costs of clearing and settlement. In contrast, the quotes from traders of the small broker are quite aggressive as they need to convince the marginal traders facing large costs of clearing and settlement to hit their LOs.

5 CSD Pricing Scheme 3: Trade-Specific Pricing

Under the trade-specific pricing scheme, we assume the CSD prices according to the marginal costs that are associated with individual transactions. That is, clearing and settlement costs are set to zero for trades with both traders stemming from the same broker, and amount to c for trades with both traders originating from different brokers. As argued before, note that the zero cost attributed to internalized trades merely represents a normalization. More generally, as long as internalized trades imply lower marginal costs than non-internalized trades, all results mentioned below hold. In terms of the notation introduced in Section 2, this implies:

$$\begin{aligned} c^{I}_{large} &= c^{I}_{small} = 0 \\ c^{NI}_{large} &= c^{NI}_{small} = c \end{aligned}$$

In principle, all four possible combinations of strategies that can be played by traders from both brokers are feasible. In the proof of the equilibrium we will show, however, that the $\{all, own\}$ combination is never optimal. Therefore, we already exclude it in the discussion below.

5.1 Equilibrium

The pricing scheme of the CSD (i.e. zero cost for internalized trades, c for non-internalized trades), is again taken as given by the traders. Note that c represents the (exogenous) marginal cost for the CSD and thus we now do not need to compute it. In contrast to the two previous pricing schemes, we now only need to determine the optimal quotes for traders of both brokers. Again, we will consider each of the possible combinations of strategies separately.

Starting with the $\{all, all\}$ combination of strategies, traders at the large broker set their quote to keep the marginal trader indifferent as they want to address all traders. Thus, they account for the transaction cost c. So for buyers and sellers from the large broker, we respectively have:

$$\begin{aligned} B_{large}^{TS,\{all,all\}} - V_l - c &= \frac{1}{2}\left[A_{small}^{TS,\{all,all\}} - V_l - \gamma c\right] \\ V_h - A_{large}^{TS,\{all,all\}} - c &= \frac{1}{2}\left[V_h - B_{small}^{TS,\{all,all\}} - \gamma c\right] \end{aligned}$$

Thus, within the first indifference condition for instance, the incoming seller from the small broker is kept indifferent between hitting the standing quote $B_{large}^{TS,\{all,all\}}$ (by submitting a MO sell) accounting for the appropriate clearing and settlement cost, and submitting her own sell LO (of which the execution probability, the quote and the clearing and settlement cost correctly correspond to the $\{all, all\}$ strategy this seller is playing herself). Similarly, for traders from the small broker, who keep an incoming counterparty trader from the large broker indifferent (thus accounting for the transaction cost c), we have for buyers and sellers:

$$\begin{aligned} B_{small}^{TS,\{all,all\}} - V_l - c &= \frac{1}{2}\left[A_{large}^{TS,\{all,all\}} - V_l - (1-\gamma)\, c\right] \\ V_h - A_{small}^{TS,\{all,all\}} - c &= \frac{1}{2}\left[V_h - B_{large}^{TS,\{all,all\}} - (1-\gamma)\, c\right] \end{aligned}$$

Next, consider the $\{own, all\}$ combination of strategies. Traders at the large broker set their quote only to keep counterparties of their *own* broker indifferent (which implies the transaction cost c does not need to be accounted for). A buyer (seller) at the large broker keeps the incoming seller (buyer) from her *own* broker indifferent, such that:

$$\begin{aligned} B_{large}^{TS,\{own,all\}} - V_l &= \gamma\frac{1}{2}\left[A_{large}^{TS,\{own,all\}} - V_l\right] \\ V_h - A_{large}^{TS,\{own,all\}} &= \gamma\frac{1}{2}\left[V_h - B_{large}^{TS,\{own,all\}}\right] \end{aligned}$$

Thus, within the indifference condition stated first for instance, an incoming seller from the large broker is kept indifferent between hitting the standing quote $B_{large}^{TS,\{own,all\}}$ (by submitting a MO sell) accounting for the appropriate zero clearing and settlement cost, and submitting her own sell LO (of which the execution probability, the quote and the zero clearing and settlement cost correctly correspond to the $\{own, all\}$ strategy this seller is playing herself). In contrast, traders from the small broker still aim to keep the marginal trader indifferent. A buyer (seller) from the small broker will then keep an incoming seller (buyer) from the large broker indifferent, leading to:

$$\begin{aligned} B_{small}^{TS,\{own,all\}} - V_l - c &= \gamma\frac{1}{2}\left[A_{large}^{TS,\{own,all\}} - V_l\right] \\ V_h - A_{small}^{TS,\{own,all\}} - c &= \gamma\frac{1}{2}\left[V_h - B_{large}^{TS,\{own,all\}}\right]. \end{aligned}$$

The reasoning here is similar to that for the small broker traders under the $\{all, all\}$ combination of strategies, but now the expected LO payoffs of the targeted large broker traders correctly reflect the execution probability, the quote and the zero clearing and settlement cost corresponding to the $\{own, all\}$ strategy these traders are playing themselves.

Finally, within the $\{own, own\}$ combination of strategies, all traders only keep potential counterparties of their own broker indifferent. Hence, all trades are internalized and thus incur a zero clearing and settlement cost. The indifference equations for buyer and seller from the large broker then become:

$$\begin{aligned} B_{large}^{TS,\{own,own\}} - V_l &= \gamma\frac{1}{2}\left[A_{large}^{TS,\{own,own\}} - V_l\right] \\ V_h - A_{large}^{TS,\{own,own\}} &= \gamma\frac{1}{2}\left[V_h - B_{large}^{TS,\{own,own\}}\right] \end{aligned}$$

Thus, within the first indifference condition for instance, the incoming seller from the large broker is kept indifferent between hitting the standing quote $B_{large}^{TS,\{own,own\}}$ (by submitting a MO sell) accounting for the appropriate zero clearing and settlement cost, and submitting her own sell LO (of which the execution probability, the quote and the zero clearing and settlement cost correctly correspond to the $\{own, own\}$ strategy this seller is playing herself). At these quotes, only traders from the large broker are indifferent. For traders originating from the small broker trading at these quotes is too costly given their higher transaction cost c. Therefore, the execution probabilities are only related to the own broker (i.e. γ).

Similarly, the equations for buyer and seller from the small broker are:

$$\begin{aligned} B_{small}^{TS,\{own,own\}} - V_l &= (1-\gamma)\frac{1}{2}\left[A_{small}^{TS,\{own,own\}} - V_l\right] \\ V_h - A_{small}^{TS,\{own,own\}} &= (1-\gamma)\frac{1}{2}\left[V_h - B_{small}^{TS,\{own,own\}}\right] \end{aligned}$$

At these quotes, only traders from the small broker are indifferent. For traders stemming from the large broker trading at these quotes is too costly given their higher transaction cost c. Therefore, the execution probabilities are only related to the own broker (i.e. $1-\gamma$).

Solving the above systems of indifference conditions renders the equilibrium quotes and thus the three distinct sub-equilibria. Comparing expected profits for each of the sub-equilibria, we are also able to determine when each of the sub-equilibria is valid. All these elements are shown in the equilibrium presented in Proposition 3.

Proposition 3 *With a CSD applying trade-specific (marginal cost-based) pricing, traders at both brokers play the following LO strategies hinging on the value of the clearing and settlement cost c:*

- *For low values of c, i.e.* $c \leq \frac{2(V_h-V_l)}{3(2+\gamma)}$, *traders from both brokers target counterparties of all brokers, thus the* $\{all, all\}$ *sub-equilibrium is played. The equilibrium quotes are:*

$$
\begin{aligned}
A_{large}^{TS,\{all,all\}} &= \frac{2V_h+V_l}{3} - (1-\gamma)\,c \\
B_{large}^{TS,\{all,all\}} &= \frac{V_h+2V_l}{3} + (1-\gamma)\,c \\
A_{small}^{TS,\{all,all\}} &= \frac{2V_h+V_l}{3} - \gamma c \\
B_{small}^{TS,\{all,all\}} &= \frac{V_h+2V_l}{3} + \gamma c
\end{aligned}
$$

- *For intermediate values of c, i.e.* $\frac{2(V_h-V_l)}{3(2+\gamma)} < c \leq \frac{2(V_h-V_l)\left(1+\gamma^2\right)}{(1+\gamma)(2+\gamma)(3-\gamma)}$, *traders from the large broker only target counterparties of their own broker whereas traders from the small broker target counterparties of all brokers, thus the* $\{own, all\}$ *sub-equilibrium is played. The equilibrium quotes are:*

$$
\begin{aligned}
A_{large}^{TS,\{own,all\}} &= \frac{2V_h+\gamma V_l}{2+\gamma} \\
B_{large}^{TS,\{own,all\}} &= \frac{\gamma V_h+2V_l}{2+\gamma} \\
A_{small}^{TS,\{own,all\}} &= \frac{2V_h+\gamma V_l}{2+\gamma} - c = A_{large}^{TS,\{own,all\}} - c \\
B_{small}^{TS,\{own,all\}} &= \frac{\gamma V_h+2V_l}{2+\gamma} + c = B_{large}^{TS,\{own,all\}} + c
\end{aligned}
$$

- *For high values of c, i.e.* $c > \frac{2(V_h-V_l)\left(1+\gamma^2\right)}{(1+\gamma)(2+\gamma)(3-\gamma)}$, *traders from both brokers only target own counterparties, thus the* $\{own, own\}$ *sub-equilibrium is played. The equilibrium* *quotes are:*

$$
\begin{aligned}
A_{large}^{TS,\{own,own\}} &= \frac{2V_h + \gamma V_l}{2+\gamma} \\
B_{large}^{TS,\{own,own\}} &= \frac{\gamma V_h + 2V_l}{2+\gamma} \\
A_{small}^{TS,\{own,own\}} &= \frac{2V_h + (1-\gamma)V_l}{3-\gamma} \\
B_{small}^{TS,\{own,own\}} &= \frac{(1-\gamma)V_h + 2V_l}{3-\gamma}
\end{aligned}
$$

Proof. See Appendix. ■

For low clearing and settlement costs, traders at both brokers target counterparties at all brokers by quoting relatively liquid prices. Still, an interesting divergence arises, traders from the small broker have to quote more liquid prices (as compared to traders from the large broker) to attain this goal as they need to convince traders from the large broker (who face the opportunity to submit a LO featuring lower expected clearing and settlement costs) to accept their LO. Do note that given this quote setting behavior, in case a counterparty from the same broker hits a standing quote, both traders involved in the trade receive a "bonus" as they both do not have to pay c. An increase in the large broker's market share γ evidently induces traders from the large broker to quote relatively less liquid prices, whereas traders from the small broker are obliged to quote relatively more liquid prices to remain attractive to the traders from the large broker. Next, for an intermediate range of clearing and settlement costs, traders at the large broker alter their strategy and submit relatively illiquid quotes only targeting traders of their own broker. In contrast, traders from the small broker still prefer to target counterparties at both brokers and thus quote a very liquid quote fully compensating the clearing and settlement cost c a potentially arriving counterparty from the large broker would face. They do so because the gain from increased matching probabilities still outweighs the concessions in terms of aggressive pricing. Evidently, this entails that in case a counterparty from the small broker would hit this standing quote, both traders involved in the trade receive a "bonus" as they both do not have to pay c. Finally, for sufficiently large costs of clearing and settlement (inducing larger cost savings from internalization), both traders from the large and the small broker only address own-broker counterparties by quoting relatively illiquid prices, with the quotes from the small broker being more illiquid as they face a lower execution probability. All quoted prices are now independent of the cost of clearing and settlement as these strategies aim at targeting own-broker counterparties only.

6 Discussion of the Equilibria

6.1 Stock Market Liquidity and CSD Pricing

< TO BE COMPLETED >

6.2 Welfare Analysis

In this section, we characterize ex ante welfare for the different pricing schemes. Our ex ante welfare measure builds on rational trader behavior and is therefore identical to the "mean" realized ex post welfare. We focus on overall welfare (OW), i.e. the sum of all agents' expected utilities from trading (see Glosten (1998), Goettler, Parlour and Rajan (2005), Hollifield, Miller, Sandås and Slive (2006), and Degryse, Van Achter and Wuyts (2009) for a similar approach in quantifying welfare). As the CSD always breaks even, in our model, OW evidently equals trader welfare. OW is computed for a random sequence of two trader arrivals under the different pricing schemes and compared to a benchmark maximum overall welfare measure corresponding to the case featuring a single broker ($\gamma = 1$) and zero clearing and settlement costs ($c = 0$), or formally:

$$OW^{\max} = 2\left(\frac{1}{2}\right)^2 [V_h - V_l]$$

which represents the probability a buyer and a seller (or vice versa) sequentially match ($\left(\frac{1}{2}\right)^2$) multiplied by the total trading gains which could be made in case of a match.

First, for the uniform pricing scheme, overall welfare equals:

$$OW^U = 2\left(\frac{1}{2}\right)^2 [V_h - V_l - 4\gamma(1-\gamma)c]$$

Next, when the CSD applies broker-specific pricing, we need to make a distinction between the different sub-equilibria:

- For low values of c, i.e. $c \leq \widehat{c}^{BS,\{all,all\}}$, or the $\{all, all\}$ sub-equilibrium:

$$\begin{aligned} OW^{BS,\{all,all\}} &= 2\left(\frac{1}{2}\right)^2 \Big[(V_h - V_l) - \gamma^2 2(1-\gamma)c - 2\gamma(1-\gamma)((1-\gamma)c + \gamma c) \\ &\qquad - (1-\gamma)^2 2\gamma c\Big] \end{aligned}$$

- For intermediate values of c, i.e. $\widehat{c}^{BS,\{all,all\}} < c \leq \widehat{c}^{BS,\{own,all\}}$, we are not able to compute overall welfare as no pricing strategy exists such that the CSD breaks even for this interval.

- For high values of c, i.e. $c > \widehat{c}^{BS,\{own,all\}}$, or the $\{own, all\}$ sub-equilibrium:

$$\begin{aligned} OW^{BS,\{own,all\}} &= 2\left(\frac{1}{2}\right)^2 \left[\left(\gamma^2 + (1-\gamma)\right)(V_h - V_l) - \gamma^2 2\frac{1-\gamma}{1+\gamma}c \right. \\ &\left. - (1-\gamma)\gamma\left(\frac{1-\gamma}{1+\gamma}c + \frac{\gamma}{2-\gamma}.c\right) - (1-\gamma)^2\frac{2\gamma}{2-\gamma}c\right] \end{aligned}$$

Do note that when $V_h - V_l - 2c > 0$ (i.e. trading gains fully compensate for the maximum clearing and settlement cost corresponding to a transaction), we have that $OW^{BS,\{all,all\}} > OW^{BS,\{own,all\}}$. Thus, the $\{all, all\}$ sub-equilibrium results in higher overall welfare under this condition.

Finally, under trade-specific pricing by the CSD, overall welfare for the different sub-equilibria equals:

- For low values of c, i.e. $c \leq \frac{2(V_h - V_l)}{3(2+\gamma)}$ or the $\{all, all\}$ sub-equilibrium:

$$OW^{TS,\{all,all\}} = 2\left(\frac{1}{2}\right)^2 \left[(V_h - V_l) - 2\gamma(1-\gamma)2c\right]$$

- For intermediate values of c, i.e. $\frac{2(V_h - V_l)}{3(2+\gamma)} < c \leq \frac{2(V_h - V_l)(1+\gamma^2)}{(1+\gamma)(2+\gamma)(3-\gamma)}$, or the $\{own, all\}$ sub-equilibrium:

$$OW^{TS,\{own,all\}} = 2\left(\frac{1}{2}\right)^2 \left[\left(\gamma^2 + (1-\gamma)\right)(V_h - V_l) - ((1-\gamma)\gamma)2c\right]$$

- For high values of c, i.e. $c > \frac{2(V_h - V_l)(1+\gamma^2)}{(1+\gamma)(2+\gamma)(3-\gamma)}$, or the $\{own, own\}$ sub-equilibrium:

$$OW^{TS,\{own,own\}} = 2\left(\frac{1}{2}\right)^2 \left[\left(\gamma^2 + (1-\gamma)^2\right)(V_h - V_l)\right]$$

Again, do note under the assumption $V_h - V_l - 2c > 0$ it is easy to prove that $OW^{TS,\{all,all\}} > OW^{TS,\{own,all\}} > OW^{TS,\{own,own\}}$, implying the $\{all, all\}$ sub-equilibrium strictly dominates the two other ones in terms of overall welfare.

7 Concluding Remarks

Explicit transaction costs such as the costs related to clearing and settlement are still of considerable importance in today's financial markets. Both in the US and Europe, policies have been implemented in order to reduce the costs of clearing and settlement. In this paper, we model how internalization of clearing and settlement affects stock market liquidity. Our main insights can be summarized as follows. First, we find that explicit transaction costs such as the costs of clearing and settlement impact stock market liquidity. In general, higher costs of clearing and settlement tend to increase liquidity. The reasoning is that higher costs of clearing and settlement induce more aggressive limit order pricing to convince counterparties to trade. Second, internalization reduces the costs of clearing and settlement. Our results show that when more trades can be internalized stock market liquidity decreases. The reasoning behind this result is that it represents a drop in explicit transaction costs and therefore reduces the aggressiveness of limit order prices. Third, when the clearing and settlement agent sets prices such that it breaks even per broker, different equilibria result depending upon the magnitude of the costs of clearing and settlement. Stock market liquidity is harmed when the costs of clearing and settlement are substantial. In that case, the break even prices the clearing and settlement agent charges differ substantially between investment firms with a large amount of internalized trades and other investment firms. Traders from the large investment firm then announce unattractive prices that are considered only by counterparties of their own investment firm. Traders from other investment firms find these prices not attractive enough as costs of clearing and settlement are too large for them. The quotes from traders originating from smaller brokers remain quite liquid as they face another trade-off: they aim to attract counterparties from all brokers as they benefit more from aggressive quotes since this substantially increases their likelihood of execution. Finally, we analyze also the case where the clearing and settlement agent charges the marginal cost for non-internalized trades and zero costs for internalized trades. For sufficiently high marginal costs of non-internalized trades, it may then be optimal for traders from both brokers to target their own broker counterparties only. In this case, the stock market is relatively illiquid with traders from the large broker quoting more liquid prices than traders from the small broker. Our welfare analysis reveals that overall welfare is lower when some (or all) traders only target counterparties from their own broker, compared to the cases where all traders aim to attract all potential counterparties, i.e. traders from all brokers.

Appendix: Proofs

Proof of Proposition 1. The equilibrium ask and bid quotes follow immediately from solving the system of indifference conditions delineated in the main text.

Next, we derive the pricing strategy c^U for which the CSD breaks even when it charges a uniform per-transaction cost, while accounting for the fact that internalized order flow does not imply costs. The ratio of transactions with positive marginal costs for the CSD vis-à-vis all possible transactions sent to the CSD equals:

$$\begin{aligned} & \frac{0.5\left[0.5\gamma\left(1-\gamma\right)+0.5\left(1-\gamma\right)\gamma\right]+0.5\left[0.5\gamma\left(1-\gamma\right)+0.5\left(1-\gamma\right)\gamma\right]}{0.5} \\ = \;& 2\gamma\left(1-\gamma\right) \end{aligned}$$

Note that for each of these transactions, the CSD is active on both sides of the market, hence it charges a cost to both legs of the trade. In other words, out of every transaction, on average a fraction $2\gamma\left(1-\gamma\right)$ occurs between traders originating from different brokers, whereas the complementary fraction occurs between traders which are client at the same broker (i.e., $\gamma^2+\left(1-\gamma\right)^2$). A CSD charging

$$c^U = 2\gamma\left(1-\gamma\right)c$$

on both legs of every transaction (internalized and non-internalized) on average breaks even: it gains on transactions for which it does not face marginal costs and loses on transactions where active clearing and settlement takes place.

Q.e.d. ■

Proof of Proposition 2. Solving the system of indifference equations delineated in the main text, taking clearing and settlement costs as given, results immediately in the quotes for the two sub-equilibria.

For given c^{BS}_{large} and c^{BS}_{small}, we now analyze which sub-equilibrium holds. Given the cost structure (i.e. $c^{BS}_{large} < c^{BS}_{small}$, as we will show below), traders from the small broker have no alternative strategy than to target all counterparties. Traders of the large broker simply compare the expected profits they make across the two sub-equilibria, i.e. by setting $A^{BS,\{own,all\}}_{large}$ or $A^{BS,\{all,all\}}_{large}$ for a seller, or $B^{BS,\{own,all\}}_{large}$ or $B^{BS,\{all,all\}}_{large}$ for a buyer. A buyer prefers to set $B^{BS,\{own,all\}}_{large}$ if:[8]

$$\frac{1}{2}\gamma\left(V_h - B^{BS,\{own,all\}}_{large} - c^{BS}_{large}\right) > \frac{1}{2}\left(V_h - B^{BS,\{all,all\}}_{large} - c^{BS}_{large}\right)$$

[8] An underlying assumption in this derivation is that if traders are indifferent between the payoffs of the *all* and the *own*-strategy, the *all*-strategy is preferred.

and $B^{BS,\{all,all\}}_{large}$ otherwise. This translates into:

$$c^{BS}_{small} > \frac{c^{BS}_{large}(3\gamma - 2) + 4(1-\gamma)(V_h - V_l)}{\gamma + 2}. \tag{1}$$

As $k = 1/2$, the seller's case is completely symmetric. This condition shows that for a given c^{BS}_{large} and c^{BS}_{small}, a unique sub-equilibrium applies. If c^{BS}_{small} is larger than the right hand side of the stated expression, traders of the large broker maximize profits by going for sub-equilibrium $\{own, all\}$, i.e. to address counterparties of the own broker only. In other words, if the cost differential between the two brokers is too large, it is too costly to also address the traders of the small broker by submitting more liquid quotes. Otherwise they address all counterparties and $\{all, all\}$ is played.

In a final step of the proof, we now derive the equilibrium prices c^{BS}_{large} and c^{BS}_{small} charged by the CSD. The CSD rationally anticipates its set prices determine the strategies of the traders of the different brokers, i.e. the sub-equilibrium that applies. We first consider the equilibrium prices the CSD charges for the $\{own, all\}$ strategies. For the large broker, the transactions implying a cost as a proportion of all possible transactions at this broker is represented by the following fraction[9]

$$\frac{1-\gamma}{1+\gamma}$$

For the small broker, using a similar calculation, the transactions implying a cost as a proportion of all possible transactions is represented by

$$\frac{\gamma}{2-\gamma}$$

Do note that for both brokers transactions between traders of the same broker count double in these fractions as the broker is handling both sides of the transaction and thus reports two trades to the CSD. For $\gamma > 1/2$ we find that:

$$\frac{1-\gamma}{1+\gamma} < \frac{\gamma}{2-\gamma}$$

that is, the fraction of transactions implying a cost with respect to all possible transactions is evidently lower at the large broker. To compute the pricing strategy at which

[9] This is $\frac{0.5[0.5(1-\gamma)\gamma]+0.5[0.5(1-\gamma)\gamma]}{0.5[0.5(1-\gamma)\gamma]+0.5[0.5(1-\gamma)\gamma]+2*(0.5\gamma*0.5\gamma)+2*(0.5\gamma*0.5*\gamma)}$. The numerator gives all transactions in which both brokers are simultaneously involved (these transactions imply a cost c), and the denominator contains all transactions (so also transactions that are internalized within one broker and that do not imply a cost when sent to the CSD).

the CSD breaks even per broker, we multiply these individual fractions by c:

$$\begin{aligned} c_{large}^{BS,\{own,all\}} &= \frac{1-\gamma}{1+\gamma}.c \\ c_{small}^{BS,\{own,all\}} &= \frac{\gamma}{2-\gamma}.c \end{aligned}$$

with:

$$c_{large}^{BS,\{own,all\}} < c_{small}^{BS,\{own,all\}}$$

as can be expected. Thus, within this sub-equilibrium traders at the large broker bear a cost of $c_{small}^{BS,\{own,all\}}$ for a transaction, whereas traders at the small broker bear a cost of $c_{small}^{BS,\{own,all\}}$ for a transaction.

Next, we determine the pricing scheme at which the CSD breaks even on average for each broker individually within the $\{all, all\}$ combination of strategies. For the large broker, the transactions implying a cost as a proportion of all possible transactions at this broker is represented by the following fraction:

$$1-\gamma$$

For the small broker, the transactions implying a cost as a proportion of all possible transactions is represented by:

$$\gamma$$

Again, for both brokers transactions between traders of the same broker count double in these fractions as the broker is handling both sides of the transaction and thus reports two trades to the CSD. For $\gamma > 1/2$ we find that:

$$1-\gamma < \gamma$$

that is, the fraction of transactions implying a cost with respect to all possible transactions is evidently lower at the large broker. To compute the pricing strategy at which the CSD would break even per broker, we multiply these individual fractions by c:

$$\begin{aligned} c_{large}^{BS,\{all,all\}} &= (1-\gamma).c \\ c_{small}^{BS,\{all,all\}} &= \gamma.c \end{aligned}$$

with:

$$c_{large}^{BS,\{all,all\}} < c_{small}^{BS,\{all,all\}}$$

as can be expected. Thus, within this sub-equilibrium traders at the large broker bear a cost of $c_{large}^{BS,\{all,all\}}$ for a transaction, whereas traders at the small broker bear a cost of

$c_{small}^{BS,\{all,all\}}$ for a transaction.

A comparison of the potential break even prices charged by the CSD shows that for $\gamma > 1/2$:

$$c_{large}^{BS,\{own,all\}} < c_{large}^{BS,\{all,all\}} < c_{small}^{BS,\{all,all\}} < c_{small}^{BS,\{own,all\}}$$

Now, remember from Equation (1) the existence condition to have sub-equilibrium $\{own, all\}$ was

$$c_{small}^{BS,\{own,all\}} > \frac{c_{large}^{BS,\{own,all\}}(3\gamma - 2) + 4(1-\gamma)(V_h - V_l)}{\gamma + 2}.$$

Now, suppose the CSD prices assuming that the combination of strategies $\{own, all\}$ applies, i.e. it charges $c_{large}^{BS,\{own,all\}} = \frac{1-\gamma}{1+\gamma}.c$ and $c_{small}^{BS,\{own,all\}} = \frac{\gamma}{2-\gamma}.c$. By substituting in $c_{large}^{BS,\{own,all\}}$ and $c_{small}^{BS,\{own,all\}}$, the existence condition to have the combination of strategies $\{own, all\}$ then can be reformulated as

$$c > \frac{2(1+\gamma)(1-\gamma)(2-\gamma)(V_h - V_l)}{6 - 17\gamma + 18\gamma^2 - 4\gamma^3} = \widehat{c}^{BS,\{own,all\}}.$$

Similarly, remember from Equation (1) the existence condition to have sub-equilibrium $\{all, all\}$ was

$$c_{small}^{BS,\{all,all\}} \leq \frac{c_{large}^{BS,\{all,all\}}(3\gamma - 2) + 4(1-\gamma)(V_h - V_l)}{\gamma + 2}.$$

Now, suppose the CSD prices assuming that sub-equilibrium $\{all, all\}$ applies, i.e. it charges $c_{large}^{BS,\{all,all\}} = (1-\gamma).c$ and $c_{small}^{BS,\{all,all\}} = \gamma.c$. By substituting in $c_{large}^{BS,\{all,all\}}$ and $c_{small}^{BS,\{all,all\}}$, the existence condition to have sub-equilibrium $\{all, all\}$ can be rewritten as

$$c \leq \frac{4(1-\gamma)(V_h - V_l)}{6 - 13\gamma + 10\gamma^2} = \widehat{c}^{BS,\{all,all\}}.$$

For $\gamma > 1/2$, it can be shown that $\widehat{c}^{BS,\{all,all\}} < \widehat{c}^{BS,\{own,all\}}$.

Q.e.d. ■

Proof of Proposition 3. Solving the systems of indifference equations delineated in the main text, taking clearing and settlement costs as given, results immediately in the quotes for the sub-equilibria. We thus only need to prove existence.

Thus, we now investigate under which conditions the different possible combinations of strategies correspond to a sub-equilibrium. First, the expected limit order payoffs are computed for the different combinations of strategies. Next, we will demonstrate under which conditions the different sub-equilibria will hold. Three distinct possibilities for a sub-equilibrium arise, which one is played depends on the level of the cost of clearing and settlement. As in the main text, we assume $k = \frac{1}{2}$. This will imply we only have to analyze the expected payoffs of one market side as quotes and expected payoffs of the other market side are completely symmetric. We first compute the limit order payoffs under the four possible combinations of strategies:

- $\{all, all\}$:

  The expected payoff of a buyer linked to the large broker submitting $B_{large}^{TS,\{all,all\}}$ under this combination of strategies is:

$$\pi_{large}^{TS,\{all,all\}} = \frac{1}{2}\left[V_h - \left(\frac{V_h + 2V_l}{3} + (1-\gamma)\,c\right) - (1-\gamma)\,c\right]$$

  Similarly, the expected payoff of a buyer affiliated to the small broker submitting $B_{small}^{TS,\{all,all\}}$ under this combination of strategies is:

$$\pi_{small}^{TS,\{all,all\}} = \frac{1}{2}\left[V_h - \left(\frac{V_h + 2V_l}{3} + \gamma c\right) - \gamma c\right]$$

- $\{own, all\}$:

  The expected payoff of a buyer linked to the large broker submitting $B_{large}^{TS,\{own,all\}}$ under this combination of strategies is:

$$\pi_{large}^{TS,\{own,all\}} = \gamma\frac{1}{2}\left[V_h - \left(\frac{\gamma V_h + 2V_l}{2+\gamma}\right)\right]$$

  Similarly, the expected payoff of a buyer affiliated to the small broker submitting $B_{small}^{TS,\{own,all\}}$ under this combination of strategies is:

$$\pi_{small}^{TS,\{own,all\}} = \frac{1}{2}\left[V_h - \left(\frac{\gamma V_h + 2V_l}{2+\gamma} + c\right) - \gamma c\right]$$

- $\{all, own\}$:

  The expected payoff of a buyer linked to the large broker submitting $B_{large}^{TS,\{all,own\}}$ under this combination of strategies is:

$$\pi_{large}^{TS,\{all,own\}} = \frac{1}{2}\left[V_h - \left(\frac{(1-\gamma)\,V_h + 2V_l}{3-\gamma} + c\right) - (1-\gamma)\,c\right]$$

Similarly, the expected payoff of a buyer affiliated to the small broker submitting $B_{small}^{TS,\{all,own\}}$ under this combination of strategies is:

$$\pi_{small}^{TS,\{all,own\}} = (1-\gamma)\frac{1}{2}\left[V_h - \left(\frac{(1-\gamma)V_h + 2V_l}{3-\gamma}\right)\right]$$

- $\{own, own\}$:

  The expected payoff of a buyer linked to the large broker submitting $B_{large}^{TS,\{own,own\}}$ under this combination of strategies is:

$$\pi_{large}^{TS,\{own,own\}} = \gamma\frac{1}{2}\left[V_h - \left(\frac{\gamma V_h + 2V_l}{2+\gamma}\right)\right]$$

  Similarly, the expected payoff of a buyer affiliated to the small broker submitting $B_{small}^{TS,\{own,own\}}$ under this combination of strategies is:

$$\pi_{small}^{TS,\{own,own\}} = (1-\gamma)\frac{1}{2}\left[V_h - \left(\frac{(1-\gamma)V_h + 2V_l}{3-\gamma}\right)\right]$$

We now derive under which conditions the different sub-equilibria apply:[10]

1. Sub-equilibrium $\{all, all\}$ applies when two conditions are jointly satisfied. First, traders at the large broker should have no incentives to deviate to the *own*-strategy when traders at the small broker play the *all*-strategy, i.e. this applies when:

$$\pi_{large}^{TS,\{all,all\}} \geq \pi_{large}^{TS,\{own,all\}}, \text{ or } c \leq \frac{2(V_h - V_l)}{3(2+\gamma)}$$

   Secondly, traders at the small broker should have no incentives to deviate to the *own*-strategy when traders at the large broker play the *all*-strategy:

$$\pi_{small}^{TS,\{all,all\}} \geq \pi_{small}^{TS,\{all,own\}}, \text{ or } c \leq \frac{2(V_h - V_l)}{3(3-\gamma)}$$

   Given $\gamma > 0.5$, we have that $c \leq \frac{2(V_h - V_l)}{3(2+\gamma)}$ is binding. If this condition is satisfied, this sub-equilibrium holds.

2. Sub-equilibrium $\{own, all\}$ applies when two conditions are jointly satisfied. First, traders at the large broker should have no incentives to deviate to the *all*-strategy

[10] An underlying assumption in this derivation is that if traders are indifferent between the payoffs of the *all* and the *own*-strategy (which is the case at the cutoff values of c), the *all*-strategy is preferred.

when traders at the small broker play the *all*-strategy, i.e. this applies when:

$$\pi_{large}^{TS,\{own,all\}} > \pi_{large}^{TS,\{all,all\}}, \text{ or } c > \frac{2\left(V_h - V_l\right)}{3\left(2+\gamma\right)}$$

Secondly, traders at the small broker should have no incentives to deviate to the *own*-strategy when traders at the large broker play the *own*-strategy:

$$\pi_{small}^{TS,\{own,all\}} \geq \pi_{small}^{TS,\{own,own\}}, \text{ or } c \leq \frac{2\left(V_h - V_l\right)\left(1+\gamma^2\right)}{\left(1+\gamma\right)\left(2+\gamma\right)\left(3-\gamma\right)}$$

Thus, when $\frac{2(V_h - V_l)}{3(2+\gamma)} < c \leq \frac{2(V_h - V_l)\left(1+\gamma^2\right)}{(1+\gamma)(2+\gamma)(3-\gamma)}$ the strategies are deviation-proof, and thus this sub-equilibrium holds.

3. Sub-equilibrium $\{own, all\}$ applies (using similar reasoning) when:

$$\pi_{large}^{TS,\{all,own\}} \geq \pi_{large}^{TS,\{own,own\}}, \text{ or } c \leq \frac{2\left(V_h - V_l\right)\left(\gamma^2 - 2\gamma + 2\right)}{\left(2+\gamma\right)\left(2-\gamma\right)\left(3-\gamma\right)}$$

and

$$\pi_{small}^{TS,\{all,own\}} > \pi_{small}^{TS,\{all,all\}}, \text{ or } c > \frac{2\left(V_h - V_l\right)}{3\left(3-\gamma\right)}$$

For $\gamma > 0.5$, both conditions could never be jointly met, hence this combination of strategies will never realize and forms no sub-equilibrium.

4. Sub-equilibrium $\{own, own\}$ applies (using similar reasoning) when:

$$\pi_{large}^{TS,\{own,own\}} > \pi_{large}^{TS,\{all,own\}}, \text{ or } c > \frac{2\left(V_h - V_l\right)\left(\gamma^2 - 2\gamma + 2\right)}{\left(2+\gamma\right)\left(2-\gamma\right)\left(3-\gamma\right)}$$

and

$$\pi_{small}^{TS,\{own,own\}} > \pi_{small}^{TS,\{own,all\}}, \text{ or } c > \frac{2\left(V_h - V_l\right)\left(1+\gamma^2\right)}{\left(1+\gamma\right)\left(2+\gamma\right)\left(3-\gamma\right)}.$$

Further comparison shows that $c > \frac{2(V_h - V_l)\left(1+\gamma^2\right)}{(1+\gamma)(2+\gamma)(3-\gamma)}$ is the most stringent condition, thus if it is satisfied this sub-equilibrium holds.

Q.e.d. ■

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