Regulation of Differentiated Stock Exchanges*

Carsten S. Nielsen[†] Peter N. Sørensen[‡]

April 22, 2015

Abstract

Horizontally differentiated asset exchanges split the order flow from liquidity traders. These traders have heterogeneous preferences over exchange characteristics and experience a positive liquidity externality from trading in the same place. We show that the co-existence of suitably differentiated exchanges is stable once heterogeneity is sufficiently great. Stability is neither sufficient nor necessary for co-existence to yield optimal liquidity trader welfare. This leaves a role for careful regulation of exchange differentiation.

1 Introduction

In recent years, financial asset traders around the world have witnessed considerable repositioning of the market institutions that facilitate their trades. Technological progress has allowed existing major exchanges to offer better and cheaper trading platforms to their customers. International mergers of exchanges have allowed easier trading in foreign markets, while the merged exchanges seek to coordinate on their best technological standard. New trading platforms have emerged with different trading technologies.

We analyze how such trading platform changes may affect the welfare of traders. Market places improve trading efficiency by bringing together counterparties. They create positive network externalities among traders, tending to support single market places as natural monopolies. On the other hand, co-existence of exchanges is thought to provide traders with a healthy choice among different technological solutions. We formalize the trade-off among these two opposite effects of exchange co-existence, to better address the problem of regulating new positions sought by exchanges.

*We are grateful for comments from Luis Corchón, Toker Doganoglu, Albert Menkveld and Ulf Nielsson, as well as seminar audiences of Aarhus Universiry, the Center for Industrial Economics (Copenhagen), Collegio Carlo Alberto (Turin), Copenhagen University, Danish Center for Accounting and Finance, European Economic Association Annual Congress, LMU Munich, Oxford, and Southern Denmark University.

[†]Department of Economics, University of Copenhagen.

[‡]Corresponding author. Department of Economics, University of Copenhagen, Øster Farimagsgade 5 Building 26, DK–1353 Copenhagen K, Denmark. E-mail: peter.sorensen@econ.ku.dk.

The force towards natural monopoly is more pronounced when liquidity costs are more important relatively to the benefits of differentiation. This has two implications. First, the regulator is more likely to seek efficient trade through a monopolistic exchange. Second, differentiated exchanges are less likely to be able to sustain a stable split of the trader population in equilibrium. However, it is a key finding of our analysis that the conditions for these two outcomes are not perfectly nested. Parameters can be such that there exists a stable equilibrium split of the population, yet it is not efficient, but also such that a split is efficient but unstable. Our analysis of the criteria may support the regulator trying to incorporate a consideration of exchange differentiation.

The European Commission expressed its concerns over exchange monopoly on January 31, 2012, when it rejected a merger proposal from the NYSE Euronext and Deutsche Börse. The US Department of Justice likewise stated in May 2011 that it would file an antitrust lawsuit to block the proposed joint takeover offer from NASDAQ OMX and ICE for the NYSE Euronext. The Department cited several reasons for this intended move, emphasizing the negative consequences for companies seeking a public listing, but drawing also attention to the effects on incentives for high quality of service and innovation in trading and data services provided to traders.[1] On the other hand, BATS Global Market and Direct Edge announced in October 2013 that their proposed merger had been cleared by the US Department of Justice, and Tokyo and Osaka stock exchanges completed their merger in January 2013.

As regulators thus face a mounting pressure to take actions concerning dominant exchanges, only relatively little is known about the welfare effects of imperfect exchange competition. To illustrate how our model can be used to assess the welfare of traders with a network externality deriving from trade, we follow the lead of Admati and Pfleiderer (1988) and focus on the trading costs borne by the group of liquidity traders in the prominent asset trading model of Kyle (1985).[2] To incorporate heterogeneous trader liquidity preferences for trading platform technology, we follow Economides and Siow (1988) to apply a version of the Hotelling location model. This combination of leading models from financial market microstructure and industrial organization is well suited to address the division of order flow among differentiated exchanges. As we will explain below, most earlier literature on exchange competition has rested on the assumption that all traders have identical preferences.

With transaction fees already very low, it is natural for stock exchanges to derive their competitive edge through the development of technological platforms appealing to traders. Our version of Hotelling's location model captures this dimension of compe-

[1]Most theoretical literature tends to focus on the companies' listing decisions or the entry decisions of professional market makers. We focus on the trading platforms' antecedent concern of attracting liquidity traders. Related literature is reviewed in Section 2.

[2]Our conclusion includes a discussion of other possible regulator objectives.

tition.[3] Exchanges tend to emphasize the special characteristics of their trading platforms, not least when repositioning in connection with mergers. For instance, NYSE and Deutsche mentioned in their press release in February 2011, that "The combined group will offer clients global scale, product innovation, operational and capital efficiencies, and an enhanced range of technology and market information solutions." Likewise, when the London Stock Exchange and TMX proposed a merger in February 2011, they claimed that "The combined transatlantic group ... will offer an international gateway, leading global pools of capital formation and liquidity together with a unique portfolio of highly complementary markets, products, technologies and services. ... the merger is strategically compelling and will create a more diversified business with greater scale, scope, reach and efficiencies, generating substantial benefits for all stakeholders." When BATS Global Market committed in February 2011 to acquire Chi-X, it claimed that "This transaction ... will be a tremendous boost for competition in pan-European trading in the face of increasing consolidation among incumbent exchanges. ... BATS was drawn to Chi-X Europe because of our many similarities, particularly in the areas of culture, technology, market structure and innovation."

To capture heterogeneous traders' preferences for technological features such as order transparency, priority rules, execution speed, and decimalization, we let the preference of each liquidity traders depend on a parameter located on an interval. The technologies adopted by two competing exchanges are also described by a location in this interval. Traders dislike distance from their own location to that of an exchange. We consider the regulator's ideal problem where the exchanges' locations can be decided, and characterize the welfare issues that determine the regulator's optimal choice.

Liquidity traders represent the investors who are end-users of the stock exchanges and who do not trade for speculative reasons. Trade is intermediated by a set of risk-neutral, competitive market makers in each exchange. Liquidity traders are subject to adverse selection as a large, informed speculator can be present in each exchange. The positive network externality among liquidity traders derives from their sharing the expected losses from trading against the speculator.

This positive externality underlies the intuition that exchanges are natural monopolies. However, the technological cost of visiting a more liquid market can make some traders prefer a closer, less liquid market. In equilibrium, the liquidity on each market is jointly determined with the decision of liquidity traders choosing to visit one or the other exchange. This decision follows a cut-off rule in the location interval (Lemma 1).

We show that for given locations, two markets can be active, and that this can be a

[3] One disadvantage of monopoly could be the absence of competitive pressure on fees. We ignore this pricing effect because there's little evidence that regulators have difficulties keeping exchange fees in check. From a technical point of view, we see no a priori reason why the incorporation of a fee setting stage in the model should render a duopolistic equilibrium more or less stable, and stability is a key focus point of our analysis.

stable Nash equilibrium of our trading game (Proposition 1). Respecting the important constraint that multiple exchanges are useful only when there exists a stable equilibrium of divided order flow, we can provide a first analysis of the welfare consequences of multiple markets over unique markets.[4]

When technology preferences are stronger relative to liquidity costs, it is more likely that a duopoly is stable, and more likely that a duopoly is better than a monopoly. However, the criterion for duopoly stability is generally different from the the criterion for duopoly optimality. The analysis points to differences that can be important for the regulation of exchange mergers. Stability depends on a local condition that rather few traders are close to indifferent among the two exchanges in a duopoly, whereas the welfare evaluation depends on more global properties of the trader preference distribution. Our analysis further points to the possibility that an asymmetric division of traders to two asymmetrically located exchanges may be better for trader welfare than a relocation of exchanges to symmetric locations.

The static Kyle model predicts how liquid is each exchange as a function of the liquidity trader volume. The model requires that the amount of liquidity-motivated trade on the exchange is uncertain, following a normal distribution. As a technical contribution, we show how to fulfill this normality assumption when traders are located on a Hotelling model. We specify that the cumulative net supply of the asset by traders to the left of points on the interval follow time-changed Brownian motion. When each liquidity trader demands or supplies the same fixed trade size, this assumption has the heuristic meaning that liquidity traders are small and randomly located over the preference interval.[5]

As the liquidity parameters in each exchange are potentially different, we are implicitly assuming a barrier to arbitrage among the two exchanges. If arbitrage is very easy, we can expect the two exchanges to become equally liquid, and the location question becomes merely an issue of minimizing the distances to traders. One instrument of regulators may be to encourage such inter-market consolidation, but our welfare analysis is more relevant to the case when this instrument is weak. On the other hand, the original idea of Admati and Pfleiderer (1988) was precisely to consider the cost of illiquidity in fragmented markets.[6] A manifestation of illiquidity is the short-run price deviations in a market around an equilibrium value. The relevant short time horizon is often precisely such that different market places exhibit independent fluctuations. The co-location of high-frequent traders at exchange servers make it impossible to route orders between exchanges without significant trading delay.

After a review of related literature in Section 2, we detail the model with a first

[4]We are able to exhibit the main possible relations among stability and welfare already under some technical assumptions about the distribution of liquidity traders over the interval — these assumptions simplify some calculations.

[5]We further discuss this interpretation in the conclusion.

[6]See also Stoll.

analysis of existence, stability and welfare in Section 3. Section 4 provides a complete welfare analysis for the case where the distribution of liquidity traders' preference types satisfies symmetry properties. We conclude with a discussion of results in Section 5.

2 Literature Review

Combining the Kyle and Hotelling models to study the fragmentation of trade, we contribute to two main lines of literature. One line is rooted in financial market microstructure, but does not consider that traders can have heterogeneous preferences over differentiated exchanges. As we will see below, this usually leads to the theoretical conclusion that a monopoly is better than a duopoly, and that a duopoly is unstable.[7] The other line focuses on platform competition with network externalities. We add to this literature the more explicit application to stock exchanges, by founding the non-linear externality payoff function on Kyle's celebrated liquidity model. We also differ by emphasizing the regulator's power to influence the location of trading platforms. We now elaborate on these two streams of literature, first on microstructure.

Stable co-existence is a requirement for a valid theoretical model to address the difference between co-existence and monopoly of exchanges. The literature on exchange fragmentation has been somewhat inhibited by the difficulty of modeling such stability. In the landmark paper by Pagano (1989), liquidity traders have common preferences over exchanges, and two markets can coexist only in the knife-edge case where they are identical. The equilibrium is unstable, since a slight perturbation in conjectures is sufficient to revert the economy to the one-market equilibrium.[8] In contrast, we show that when trader preferences over technology differentiation are sufficiently important, such a co-existence equilibrium is stable.[9]

Further literature has considered alternatives to Pagano's model in such a way that stable co-existence is possible. The variations have come in the form of changing the types or timing of market places, or the timing and motivation of liquidity trades. Hendershott and Mendelson (2000) analyze competition between a dealer market and a faster crossing network under the assumption that trader patience is heterogeneous. Madhavan (1995) argues that larger liquidity traders prefer to avoid each others' market power. In the model of Foucault and Menkveld (2008), building on Parlour and Seppi (2003), liquidity traders prefer a smaller market if this increases the probability that their limit order is

[7]However, we believe that we are the first to simultaneously address the stability and welfare analysis in a single model, thereby providing a more satisfying welfare analysis.

[8]Chowhdry and Nanda (1991) follow Admati and Pfleiderer (1988) to generalize Pagano's model. Small liquidity traders visit a single exchange while large liquidity traders can split trades across markets. Once again, all the free-to-move large liquidity traders concentrate, in equilibrium, in the market that has the largest amount of trading by small liquidity traders who are unable to move between markets. See also Hoffmann (2010).

[9]Di Noia (2001) focuses on the different aspect of exchange competition to attract new asset listings.

executed. Ellison and Fudenberg (2003) suppose that traders are ex-ante asymmetric in terms of being buyers or sellers. The connection of stability and welfare has however not been systematically pursued.

Compared to these contributions, we return to the more basic situation first considered by Admati and Pfleiderer (1988). Traders choose their location at an ex ante stage when their trading intentions (buy or sell) are not yet realized. When it comes to the choice of trading platforms operating different technologies, we find this setup very natural. We are able to obtain stability of exchange co-existence through the new channel of heterogeneous trader preferences over platform technologies.

In the model of Ramos and von Thadden (2008), traders hold portfolios of assets traded in various national exchanges, characterized by different transactions costs. They predict that the market power of an exchange is weaker when asset returns exhibit higher correlation.[10] In parallel to this, instability of a duopoly in our model arises when exchange differentiation is low and exchanges thus wield less market power. We endogenize the liquidity traders' transaction costs in terms of illiquidity in the Kyle model.

We now turn to the second part of the literature, focused on network effects, following the pioneering work of Katz and Shapiro (1985). This literature does not derive the network externality from Kyle's model. Agents' preferences more generally exhibit network effects when they are directly affected by the number of other agents using their platform. Platforms compete in order to attract more usage, and intensifies when traders place a higher value on the the size of the network. Under these conditions social welfare can be improved from locating platforms close to each other.

If the network effects are zero, then the network externality model collapses to Hotelling's location model. Hotelling's claim was that the process of spatial competition leads platforms to agglomerate at the market center. Relative to the large literature on this model, we focus on regulated locations of the platforms, and abstract from price competition.[11]

Another related application of Hotelling's location model, again with different modeling of the network externality, departs from the Tiebout (1956) theory of local public goods to consider the location of public facilities. For instance, Greenberg (1983) and Richter (1982) let a population with heterogeneous preferences self-select into groups with group-efficient provision of public goods financed by group members. In this branch of the literature, the network externality related to production of a public good is different from our liquidity-based network externality. Also, the equilibrium concept incorporates

[10] Pirrong (1999) focuses on the location decisions of intermediaries, corresponding to the market makers of the Kyle (1985) model. Again, exchanges may co-exist when the assets traded in different exchanges exhibit lower return correlation.

[11] Closest to us in this literature, De Palma *et al.* (1985) found that platform location at the center can be stable with linear transportation cost as long as the distribution in preferences is sufficiently dispersed.

a notion of coalitional stability which is stronger than our stability notion which relates to the local incentives of nearly indifferent population members.[12]

The tradeoff between liquidity and travel costs in a (simplified) search model was considered by Economides and Siow (1988). They directly assume traders prefer to trade in more liquid markets and that market liquidity is an increasing function of the number of traders at that market. They establish the equilibrium co-existence of markets, and discuss the relations of equilibria and welfare, but they do not turn to the issue of equilibrium stability that was later highlighted by Pagano (1989). Further work on the provision of services with network externalities usually posits a simple linear dependence of individual utility on the number of users adopting the same service.[13] Our model of stock exchanges arrives at a different functional form for the dependence of liquidity on the number of traders, with deeper roots in Kyle (1985)'s classic market microstructure model. This allows us to arrive at better founded conclusions about stability and welfare in the context of multiple asset markets.

The idea that liquidity arises in search markets has recently been revived in the literature on financial markets. Building on Duffie *et al.* (2005), Vayanos and Wang (2007) show that illiquidity, measured by search costs, can differ across otherwise identical assets. We consider the concentration of liquidity across market venues, rather than across assets, and focus our main analysis on the optimal number of market venues.

3 Model

The regulator places exchanges at fixed locations on a Hotelling line, and liquidity traders self-select into exchanges (Section 3.1). Imperfect liquidity gives rise to trading costs, which are lower at exchanges visited by more liquidity traders (Section 3.2). In a Nash equilibrium, liquidity traders non-cooperatively decide which exchange to visit, trading off the inconvenience of traveling a greater distance against the benefit of better liquidity. We discuss the existence and stability of equilibria (Section 3.3).

A regulator uses a welfare measure of total travel costs plus total trading costs experienced by liquidity traders. The welfare measure allows the regulator to evaluate the consequences of introducing more exchanges, as well as the consequences of changing their location (Section 3.4).

3.1 Location

We consider two exchanges $i \in \{0, 1\}$ that are located on the interval $[0, 1]$. Exchange 0 is located at point $a \geq 0$ and exchange 1 at point $1 - b$, where $b \geq 0$ and $a < 1 - b$ (exchange

[12] Jehiel and Scotchmer (1997) analyze the optimal number of groups.

[13] A recent example in this line of literature is Griva and Vettas (2011).

0 is always to the left of exchange 1; $a = b = 0$ corresponds to maximal differentiation). A large population of small liquidity traders is randomly distributed over the interval $[0, 1]$. Each liquidity trader must trade (sell or buy) one unit of an asset in one of the two exchanges. A liquidity trader located at point $t \in [0, 1]$ on the line must privately bear the travel cost $c(|t-a|)$ to trade on exchange 0, and $c(|t-1+b|)$ to trade on exchange 1. We assume that $c(0) = 0$, and that $c(d)$ is a strictly increasing. Finally, we assume that $c(d)$ is either a strictly convex function of d, or $c(d)$ is linear. The cost of executing the unit trade at exchange i is denoted by λ_i, where each parameter λ_i will be determined endogenously. The total cost of trading at exchange 0 is therefore given by $c(|t-a|)+\lambda_0$, while the total cost of trading at exchange 1 is $c(|t-1+b|) + \lambda_1$.

Simple analysis of the cost functions gives us the following characterization of liquidity trader behavior:

Lemma 1. *If the difference in execution costs $\lambda_1 - \lambda_0 \in (c(a) - c(1-b), c(1-a) - c(b))$, then $\hat{t} \in (0, 1)$ defined by $c(|\hat{t} - a|) - c(|\hat{t} - 1 + b|) = \lambda_1 - \lambda_0$ is such that a liquidity trader with trading cost $t < \hat{t}$ prefers trading at exchange 0, while a trader for which $t > \hat{t}$ prefers exchange 1. If $\lambda_1 - \lambda_0 < c(a) - c(1-b)$, all liquidity traders prefer exchange 1. If $\lambda_1 - \lambda_0 > c(1-a) - c(b)$, all liquidity traders prefer exchange 0.*

Proof. The trader at t prefers exchange 1 if $c(|t-a|) + \lambda_0 > c(|t-1+b|) + \lambda_1$, i.e., if $c(|t-a|) - c(|t-1+b|) > \lambda_1 - \lambda_0$. We show that the difference $c(|t-a|) - c(|t-1+b|)$ is increasing in t, strictly so when $t \in (a, 1-b)$, and strictly everywhere when c is strictly convex. Consider first t in the interval $[0, a]$. The difference is here equal to $c(a-t) - c(1-b-t)$. By assumption on c, both $c(a-t)$ and $c(1-b-t)$ are decreasing functions of t. However, because c is a convex function, and because $1 - b > a$, the function $c(1-b-t)$ decreases at least as quickly as $c(a-t)$, and thus the difference $c(a-t) - c(1-b-t)$ is weakly increasing. When c is strictly convex, the difference is strictly increasing. When c is linear, the difference is a constant equal to $c(a) - c(1-b)$. A symmetric argument shows that $c(|t-a|) - c(|t-1+b|)$ is weakly increasing when $t \in [1-b, 1]$; strictly so when c is convex, but constantly $c(1-a) - c(b)$ when c is linear. Finally, when $t \in (a, 1-b)$, the cost difference is $c(|t-a|)-c(|t-1+b|) = c(t-a)-c(1-b-t)$ with the first term $c(t-a)$ strictly increasing and the second term $c(1-b-t)$ strictly decreasing. □

3.2 Liquidity

We derive our model of exchange liquidity from Kyle (1985)'s one-period model of informed insider trading.[14] Trading to exploit an informational advantage, in each exchange

[14] Details of this model are not very important for our analysis of exchange location and welfare. The crucial feature, present in most models of liquidity, is the positive externality by which each liquidity trader faces lower transactions costs when more such traders arrive at the exchange.

an insider partly reveals private information to the market. An exchange also receives orders from the liquidity traders who choose to visit it. In each exchange, a population of competitive, risk-neutral, Bayes-rational market makers observe the net incoming order flow and clear the market.

The ex post liquidation value of the asset, denoted $V \sim N(\bar{V}, \sigma_V^2)$, is normally distributed with mean $\bar{V}$ and variance σ_V^2. For any given $\hat{t} \in [0, 1]$, denote by z_0 the aggregate net order placed on exchange 0 by traders in $[0, \hat{t}]$, and by z_1 the aggregate net order by traders in $(\hat{t}, 1]$. The random location of liquidity traders over the line is such that z_0, z_1, V are jointly normally distributed and independent, with $z_0 \sim N\left(0, F(\hat{t})\sigma_z^2\right)$ and $z_1 \sim N\left(0, (1 - F(\hat{t}))\sigma_z^2\right)$. The increasing, continuous function F, with $F(0) = 1 - F(1) = 0$, captures the distribution of trader locations over the interval. It has an associated density f, such that $F(t_2) - F(t_1) = \int_{t_1}^{t_2} f(t)dt$ for all $t_2 > t_1$. On an interval $(t_1, t_2]$, the measure of liquidity traders is $F(t_2) - F(t_1)$, and the variance of their aggregate noise trade is proportional to this measure.[15] Observe that the aggregate net liquidity demand, denoted $z = z_0 + z_1$, is normally distributed with mean zero and variance σ_z^2. Thus, the threshold location $\hat{t}$ essentially determines the share of liquidity trade going to each exchange. Note that the assumptions can be satisfied if we start from a standard Brownian motion B_y over the interval $[0, 2]$, and let $z_0 = \sigma_z(B_{F(\hat{t})} - B_0)$, $z_1 = \sigma_z(B_1 - B_{F(\hat{t})})$, and $V = \bar{V} + \sigma_V(B_2 - B_1)$.[16]

The risk-neutral insider on exchange i observes V and chooses the net demand x_i. Market makers on exchange i observe $w_i = x_i + z_i$ and price the asset at $p_i = E[V|w_i]$. The insider correctly conjectures the pricing function, and chooses x_i to maximize the expected gain $E(x_i(V - p_i)|V)$ before knowing the clearing price p_i. Kyle (1985) shows that there exists a linear equilibrium of this market model, i.e., p_i is an affine function of w_i.

Lemma 2. *Given any $\hat{t} \in (0, 1)$, there exists a unique linear equilibrium on each exchange. The price functions $p_i = \bar{V} + \lambda_i w_i$ have*

$$\lambda_0 = \frac{\sigma_V}{2\sigma_z\sqrt{F(\hat{t})}} \text{ and } \lambda_1 = \frac{\sigma_V}{2\sigma_z\sqrt{1 - F(\hat{t})}}. \tag{1}$$

A liquidity trader's expected cost of executing a unit trade on exchange i with liquidity parameter λ_i, is equal to λ_i. The insider's expected profit at exchange 0 is $\lambda_0 F(\hat{t})\sigma_z^2$, while the insider's profit at exchange 1 is $\lambda_1(1 - F(\hat{t}))\sigma_z^2$. Insider behavior is not affected by the existence of two exchanges, since the expected profit is additive over exchanges.[17] The

[15] We discuss the interpretation of this model of liquidity trader location in the conclusion.

[16] There is no direct use of the feature of Brownian motion that increments over non-overlapping intervals are jointly normal and independent, yet this justifies that the variance of noise trade is proportional to the measure of traders, regardless where we divide the trader population.

[17] By assumption, the insider must use market orders, and hence cannot move liquidity to the less liquid exchange.

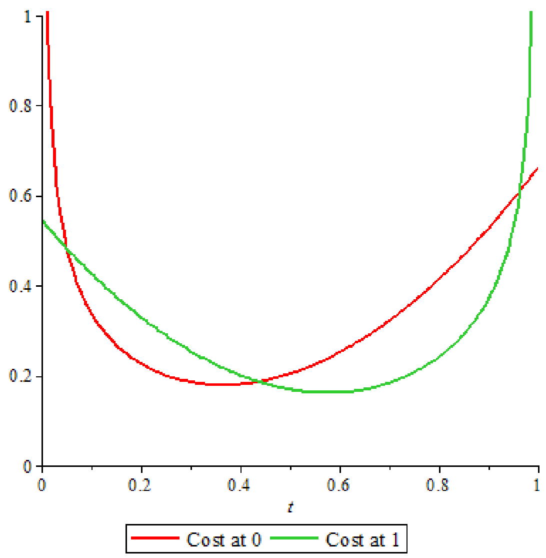

Figure 1: Equilibria of the model with $\frac{\sigma_V}{2\sigma_z} = 0.1$, $a = 1/4$, and $b = 1/3$, f uniform.

insider's profit is the counterpart of aggregate liquidity costs borne by liquidity traders. This is precisely the costs deriving from price volatility due to price discovery, and it is precisely the costs which are lower for traders who choose to agglomerate in an exchange. The explicit form of these costs derived from Kyle's model provides a well established foundation for our network externality payoff function.

3.3 Equilibrium and Stability

We now turn to the question of how liquidity is distributed across exchanges, which in turn depends on the travel costs of liquidity traders.

Lemma 3. *For any $\hat{t} \in (0, 1)$, there exists an equilibrium of the model where traders in $[0, \hat{t}]$ visit exchange 0 and traders in $(\hat{t}, 1]$ visit exchange 1 if and only if*

$$\frac{\sigma_V}{2\sigma_z} \frac{1}{\sqrt{F(\hat{t})}} + c(|\hat{t} - a|) = \frac{\sigma_V}{2\sigma_z} \frac{1}{\sqrt{1 - F(\hat{t})}} + c(|\hat{t} - 1 + b)|). \tag{2}$$

Furthermore, it is an equilibrium that all traders visit exchange 0. It is also an equilibrium that all trades visit exchange 1.

Proof. Follows from inserting Lemma 1 into Lemma 2. □

The leading constant, $\sigma_V/(2\sigma_z)$, appearing on both sides of (2) is equal to λ_0 when $\hat{t} = 1$. Thus, it represents the degree of illiquidity in the aggregated market.

Note that the model is at equilibrium when $\hat{t} \in \{0, 1\}$ — one exchange is then empty, and all liquidity traders prefer to visit the de facto monopoly exchange with non-zero provision of liquidity. Further, as illustrated by Figure 1, there always exists at least one interior equilibrium, $\hat{t} \in (0,1)$. This follows from the fact that both sides of (2) are continuous functions of $\hat{t}$, such that the right hand side exceeds the left hand side at $\hat{t}$ near 1, and vice versa near 0. Thus, there always exist at least three equilibria, one of which features coexistence of the two markets.

An equilibrium is locally stable if the best response dynamic brings us back towards the equilibrium. The two extreme equilibria, market monopolies, are always stable. Recall that the right hand side of (2) exceeds the left hand side at $\hat{t}$ near 1. Near the monopoly of exchange 0, thus traders at the margin between the two exchanges have strictly higher trading costs at exchange 1 than at exchange 0. This best-response force in favor of exchange 0 will drive the threshold $\hat{t}$ up to the limit 1, when starting near it. A similar argument shows that 0 is locally stable.

Continuity of both sides of (2), with the fact that they are ranked oppositely at the two boundaries of $[0,1]$, implies that there exists generically, with respect to a, b, an odd number of solutions which are strict crossings of the two curves (i.e., tangencies are non-generic). Ranking these strict crossings, every other equilibrium is stable, with the first and last equilibrium stable.

A local condition for stability of an interior equilibrium is that the right hand side of (2) crosses the left hand side from below. This condition can be expressed in terms of the derivatives of the two sides. Let sgn denote the sign function, $\text{sgn}(x) = 1$ when $x > 0$, $\text{sgn}(x) = -1$ when $x < 0$, and $\text{sgn}(0) = 0$.

Proposition 1. *Suppose c is differentiable at zero. Strictly crossing solution $\hat{t} \in (0,1)$ to (2) is a locally stable equilibrium if and only if*

$$-\frac{\sigma_V}{4\sigma_z}\frac{f(\hat{t})}{\left[F(\hat{t})\right]^{3/2}}+c'(|\hat{t}-a|)\text{sgn}(\hat{t}-a) > \frac{\sigma_V}{4\sigma_z}\frac{f(\hat{t})}{\left[1-F(\hat{t})\right]^{3/2}}+c'(|\hat{t}-1+b)|)\text{sgn}(\hat{t}-1+b). \quad (3)$$

The first term on either side of inequality (3) pull in the direction of violating the condition. This effect is particularly pronounced when many traders are nearly indifferent, so $f(\hat{t})$ is large. Verifying Pagano's observation, in the absence of travel costs, there is no stable interior equilibrium in this model.

A focus on stable equilibrium allows us a direction on important comparative statics results. For instance, suppose that the regulator moves exchange location a in the direction of $\hat{t}$: this reduces the costs of exchange 0 relative to 1, and at this up-crossing of 0-costs, the equilibrium value of $\hat{t}$ must rise in response. More traders travel to the cheaper market in equilibrium, as would be expected.

Figure 1 illustrates an example with three interior equilibria. The middle interior equilibrium is stable, as are the monopolies. The other two interior equilibria are unstable.

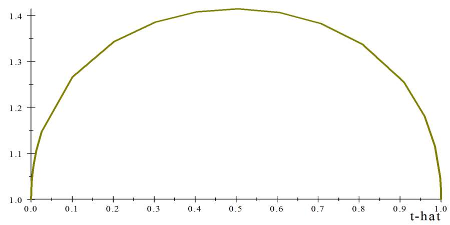

Figure 2: Total liquidity cost when traders divide at $\hat{t}$, with $\sigma_V \sigma_z = 2$.

3.4 Welfare

The regulator evaluates the situation by the welfare criterion that aggregate liquidity trader costs should be as small as possible. To evaluate the welfare consequences of letting two rather than one exchange serve the market, the regulator must trade off the higher transactions costs against the lower travel costs.

Note that although each trader visiting exchange i has expected trading cost λ_i, aggregate expected trading costs at exchange i equals the insider's expected profit, $\lambda_0 F(\hat{t})\sigma_z^2$ at exchange 0 and $\lambda_1(1 - F(\hat{t}))\sigma_z^2$ at exchange 1. Aggregate costs are σ_z^2 times greater than the individual costs, consistent with an interpretation that the total trader population is of size σ_z^2. Summing over the two exchanges, and substituting for λ_i, aggregate liquidity costs are,

$$\Lambda(\hat{t}|a,b) = \frac{\sigma_V \sigma_z}{2}\left(\sqrt{F(\hat{t})} + \sqrt{1 - F(\hat{t})}\right). \tag{4}$$

Aggregate costs are a concave function of the measure $F(\hat{t})$ of traders visiting exchange 0. The costs are maximal when traders are equally divided, $F(\hat{t}) = 1/2$.

The other source of aggregate cost comes from travel. Consider exchanges located at a and $1 - b > a$, and suppose that traders $t < \hat{t}$ travel to exchange 0. Aggregate travel costs, in the population of size σ_z^2 , are

$$C(\hat{t}|a,b) = \int_0^{\hat{t}} c(|t-a|)\sigma_z^2 f(t)dt + \int_{\hat{t}}^1 c(|t-1+b|)\sigma_z^2 f(t)dt. \tag{5}$$

Figure 3 illustrates quadratic travel costs as a function of trader location t. If traders are uniformly distributed, $f(t) = 1$, the areas under the two curves sum to $C(\hat{t}|a,b)$.

We assume that the regulator chooses whether the market should be served by a monopoly or a duopoly. In the latter case, the regulator can also affect exchange differentiation directly, by setting location parameters a and b. Once the duopoly is in place, traders self-select where to trade, so $\hat{t}$ must be an endogenously determined stable equilibrium.

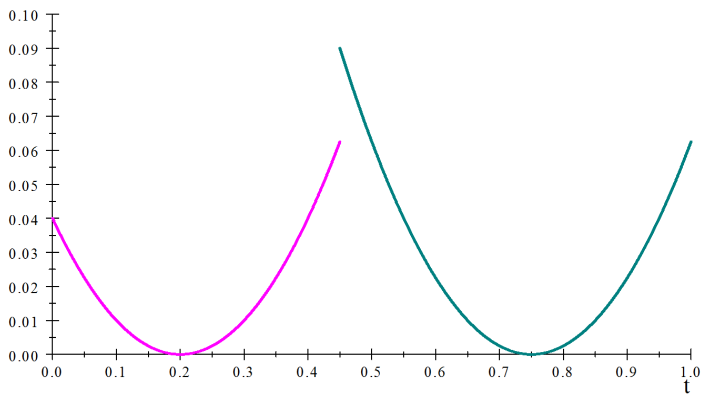

Figure 3: Quadratic travel costs experienced by traders at t when exchanges are located at $a = .2$, and $1 - b = .75$, and they split at $\hat{t} = .45$.

4 Symmetric Model

To illustrate the regulator's problem, we proceed to analyze the model under assumptions of symmetry. Precisely, we confine attention to exchange locations $a = b$, and assume that the trader distribution F has the two properties that (i) for every $t \in (0, 3/4)$, $F(t + 1/4) = F(t) + 1/4$, and (ii) for every $t \in (0, 1/4)$, $F(t) + F(1/4 - t) = 1/4$. Condition (i) expresses that the density of traders over the first quarter interval $(0, 1/4)$ is identically copied on the next three quarter intervals. Condition (ii) expresses that the density over a quarter interval is symmetric around its mid-point. Note that symmetry implies that $F(t + 1/2) = F(t) + 1/2$ and $F(t) + F(1/2 - t) = 1/2$ for all $t \in (0, 1/2)$, and that $F(t) + F(1 - t) = 1$ for all $t \in (0, 1)$.

The assumptions are satisfied by the uniform distribution $F(t) = t$. Considerably greater generality is allowed, however. Choose an arbitrary increasing, continuous function F over the interval $t \in [0, 1/8]$, with $F(0) = 0$ and $F(1/8) = 1/8$. Extend this to any $t \in [1/8, 1/4]$ by the symmetry relation $F(t) = 1/4 - F(1/4 - t)$. Extend to $t \in [1/4, 1/2]$ by the invariance relation $F(t) = 1/4 + F(t - 1/4)$. Finally, extend to $t \in [1/2, 1]$ by the invariance relation $F(t) = 1/2 + F(t - 1/2)$. The function F over $[0, 1]$ constructed in this way satisfies the symmetry property.

4.1 Duopoly

In this symmetric case, it is simple to see that $\hat{t} = 1/2$ defines an equilibrium — the two markets are equally liquid, and they are located equally far from the threshold trader at 1/2. Stability of 1/2 requires satisfaction of criterion (3),

$$\sqrt{2}\frac{\sigma_V}{\sigma_z} f(\frac{1}{2}) < c' \left(\left| \frac{1}{2} - a \right| \right). \tag{6}$$

This is more likely to be satisfied when there is less adverse selection (σ_V/σ_z is smaller), fewer traders live near the margin ($f(1/2)$ is smaller), the exchanges are farther apart ($1/2-a$ is greater) and travel costs are more sensitive to location (c' is greater).

The model permits in principle the existence of stable interior equilibria apart from $\hat{t}=1/2$. However, given the symmetry of the model, it is natural to assume that the regulator confines attention to this symmetric trader population split, in case of duopoly.

Lemma 4. *In the symmetric model, if the regulator desires to implement a stable duopoly with $\hat{t}=1/2$, the optimal exchange locations are $a=b=1/4$.*

Proof. Given $\hat{t}=1/2$, the aggregate liquidity costs do not depend on the exchange location. It remains to minimize aggregate travel costs. Symmetry condition (i) implies that these costs are twice the cost of traders visiting exchange 0. The problem is thus to choose $a\in(0,1/2)$ to minimize $\int_0^{1/2} c(|t-a|)f(t)dt$, since the positive constant factor σ_z^2 is irrelevant for the minimization. For any $a<1/4$, we have

$$\begin{aligned}
&\int_0^{1/2} c(|t-a|)f(t)dt-\int_0^{1/2} c(|t-1/4|)f(t)dt\\
&= \int_0^{(4a+1)/8}[c(|t-a|)-c(|t-1/4|)]f(t)dt+\int_{(4a+1)/8}^{(3-4a)/8}[c(|t-a|)-c(|t-1/4|)]f(t)dt\\
&\quad+\int_{(3-4a)/8}^{1}[c(|t-a|)-c(|t-1/4|)]f(t)dt\\
&= \int_0^{(4a+1)/8}[c(|t-a|)-c(|t-1/4|)]f(t)dt+\int_{(4a+1)/8}^{(3-4a)/8}[c(|t-a|)-c(|t-1/4|)]f(t)dt\\
&\quad+\int_0^{(4a+1)/8}[c(|1/2-t-a|)-c(|1/2-t-1/4|)]f(1/2-t)dt\\
&= \int_0^{(4a+1)/8}[c(|t-a|)+c(|1/2-a-t|)-2c(|t-1/4|)]f(t)dt \qquad (7)\\
&\quad+\int_{(4a+1)/8}^{(3-4a)/8}[c(|t-a|)-c(|t-1/4|)]f(t)dt, \qquad (8)
\end{aligned}$$

where the second manipulation follows from a change of variable in the third term, and the last manipulation employs the symmetry property $f(1/2-t)=f(t)$. Note that $(4a+1)/8$ is the mid point between a and $1/4$. The integral in (7) is positive because $c(|1/2-a-t|)-c(|t-1/4|)>c(|t-1/4|)-c(|t-a|)$ when $t\in(0,(4a+1)/8)$. This is due to convexity of c, as we now confirm. Where $t<a$, note that $t<a<1/4<1/2-a$ and that $(1/2-a-t)-(1/4-t)=(1/4-t)-(a-t)=1/4-a>0$, independent of t. But $c(d+1/4-a)-c(d)$ is an increasing function of $d>0$, since the derivative $c'(d+1/4-a)-c'(d)$ is positive by convexity of c. Where $t>a$, note that $c(|t-1/4|)-c(|t-a|)$ is decreasing in $t<1/4$, and hence everywhere less than $c(1/4-a)$. On the other hand, $c(|1/2-a-t|)-c(|t-1/4|)$ is increasing in $t<1/4$ by convexity of c, and hence everywhere larger than $c(1/4 - a)$, as desired. Turning to the integral in (8), this is positive because t is closer to $1/4$ than to a when t is above their mid point $(4a+1)/8$. Concluding, both integrals are positive, and hence the aggregate travel costs are larger to a than to $1/4$. A symmetric argument can be used when $a > 1/4$. □

A similar proof can be used to show that aggregate travel costs can never be lower than when $a = b = 1/4$ and $\hat{t} = 1/2$. Note that the minimized aggregate travel costs are

$$4\sigma_z^2 \int_0^{1/4} c(\frac{1}{4} - t) f(t) dt. \tag{9}$$

Thus far, the analysis did not exploit that the density is identical over every quarter interval, but only over half intervals, and symmetric around mid points.

Since $F(\hat{t}) = F(1/2) = 1/2$, aggregate liquidity costs are, from (4), given by $\sigma_V \sigma_z / \sqrt{2}$.

4.2 Monopoly

It is straightforward to extend the argument of Lemma 4 to show that the regulator prefers to locate a monopoly exchange at 1/2 The minimized aggregate travel costs are then

$$\begin{aligned}
& 2\sigma_z^2 \int_0^{1/2} c(\frac{1}{2} - t) f(t) dt \\
= \;& 2\sigma_z^2 \int_0^{1/4} c(\frac{1}{2} - t) f(t) dt + 2\sigma_z^2 \int_{1/4}^{1/2} c(\frac{1}{2} - t) f(t) dt \\
= \;& 2\sigma_z^2 \int_0^{1/4} c(\frac{1}{2} - t) f(t) dt + 2\sigma_z^2 \int_0^{1/4} c(\frac{1}{4} - t) f(t + 1/4) dt \\
= \;& 2\sigma_z^2 \int_0^{1/4} c(\frac{1}{2} - t) f(t) dt + 2\sigma_z^2 \int_0^{1/4} c(\frac{1}{4} - t) f(t) dt,
\end{aligned} \tag{10}$$

where the third line follows from a change of variables, and the last line from invariance over quarter intervals. Essentially, in the monopoly, the liquidity traders with types on the interval $[1/4, 3/4]$ travel to an exchange located at their mid point $1/2$. This is directly comparable to the traders in $[0, 1/2]$ who travel to $1/4$ in the duopoly case.

Aggregate liquidity costs can be computed from (4), using $\hat{t} = 0$, as $\sigma_V \sigma_z / 2$.

4.3 Comparison

When the primitives of our model, functions c and F and parameters σ_F and σ_V satisfy criterion (6), the regulator has a real choice to implement a stable duopoly. Our model predicts that the regulator prefers the market structure with lower aggregate costs to liquidity traders.

The cost of symmetric duopoly is lower than the cost of monopoly exactly when:

$$\frac{\sigma_V}{\sqrt{2}\sigma_z} - \frac{\sigma_V}{2\sigma_z} < 2\int_0^{1/4} [c(\frac{1}{2} - t) - c(\frac{1}{4} - t)]f(t)dt. \tag{11}$$

As should be intuitive, duopoly is more attractive when travel costs c are relatively important, i.e., when trader preferences are more heterogeneous. Duopoly is less attractive when liquidity is the prime concern.

In terms of the liquidity parameter σ_V/σ_z, note that when it is lower, both the stability criterion (6) and the efficiency criterion (11) are more likely to be satisfied. When liquidity is relatively unimportant, it is easier for co-existing exchanges to divide the market in equilibrium, and it is more appealing for the regulator to divide the market. This correlation of conditions is obviously good. However, it is crucial to notice that stable equilibrium outcomes do not exactly coincide with efficient outcomes. The two criteria are imperfectly aligned, and depending on the distribution F and the cost function c, it may occur that a stable duopoly is inefficient or that an efficient duopoly is unstable.

For numerical analysis, suppose that the cost function is quadratic, $c(d) = d^2$. The right hand side of the efficiency criterion (11) is then

$$2\int_0^{1/4} [(\frac{1}{2} - t)^2 - (\frac{1}{4} - t)^2]f(t)dt = \frac{3}{8} - \int_0^{1/4} tf(t)dt = \frac{3}{8} - \frac{1}{8} = \frac{1}{4},$$

where the symmetry assumption on f implies that the average t over the quarter interval $[0, 1/4]$ is the mid point $1/8$. Hence, symmetric duopoly is more efficient when

$$\frac{\sigma_V}{\sigma_z} < \frac{2}{\sqrt{2} - 1}.$$

With the quadratic cost function, $c'(d) = 2d$, and hence condition (6) for stability of a symmetric equilibrium with $a = 1/4$, reduces to

$$\frac{\sigma_V}{\sigma_z} < \frac{1}{2\sqrt{2}f(1/2)}.$$

As predicted in general, both criteria are satisfied when σ_V/σ_z is small, but the two criteria are not perfectly aligned.

Recall that a distribution satisfying symmetry could be constructed with an arbitrary density over $[0, 1/8]$. Since $f(\hat{t}) = f(1/2) = f(0)$, there is no restriction imposed on this number. When it is small, there exist stable duopolies which are not efficient. This occurs when few liquidity traders would move between exchanges if the threshold $\hat{t}$ were perturbed slightly away from the equilibrating $1/2$, i.e., when the liquidity conditions of both exchanges are quite stable. Conversely, when $f(0)$ is large, the efficient outcome may be a stable duopoly which is unstable.

4.4 Asymmetric Duopoly

Although we have imposed rather strict symmetry assumptions in this Section, we can show that it is possible that there exists an asymmetric duopoly which is preferred over a symmetric duopoly by the regulator. While minimization of the travel costs speaks in favour of the symmetric outcome, the fact that liquidity costs are concave in $\hat{t}$ and maximal at 1/2, speaks in favour of dividing the trader population asymmetrically (see Figure 2). The gain is lower liquidity costs enjoyed by the majority visiting the more popular exchange outweighs the loss experienced by the fewer traders visiting a less liquid exchange.

We merely aim to illustrate this possibility of the model, and hence are willing to make rather specific parameter assumptions. First, note that the asymmetric location is going to have the least possible impact on aggregate travel costs is the function c is linear. We assume $c(d) = d$. Second, let us choose parameters such that there is an equilibrium at $\hat{t} = 3/4$ when we locate exchange 0 at $a = 3/8$ and exchange 1 at $1-b = 7/8$. Plugging these features into equation (2), we find that it is solved provided $\sigma_V/\sigma_z = \sqrt{3}/(4\sqrt{3}-4)$. We assume this parameter condition is true.

The equilibrium at $\hat{t} = 3/4$ is stable provided (3) is satisfied. With the linear travel costs, the condition is

$$2 > \frac{3\sqrt{3}+1}{6\sqrt{3}-6} f(3/4),$$

thus satisfied when $f(3/4) = f(1/2)$ is small.

Aggregate liquidity costs in the asymmetric equilibrium are, from (4),

$$\frac{3+\sqrt{3}}{16\sqrt{3}-16}\sigma_z^2.$$

Aggregate travel costs depend on more details about the distribution function F. Note that

$$\int_0^{1/4} c(3/8-t)f(t)dt = \int_{1/2}^{3/4} c(t-3/8)f(t)dt = [5/8-3/8][F(3/4)-F(1/2)] = 1/16$$

by the linearity of the cost function. On the other two quarter intervals,

$$\int_{1/4}^{1/2} c(|t-3/8|)f(t)dt = \int_{3/4}^{1} c(|t-7/8|)f(t)dt = 2\int_0^{1/8} \left(\frac{1}{8}-t\right) f(t)dt,$$

where the latter integral can range from 0 if the traders in $[0, 1/4]$ are all located near the mid point 1/8, to 1/32 if instead the traders in $[0, 1/4]$ are located at the extremes. Going ahead, we note that the cost over this interval can be arbitrarily close to zero, and that this property is very consistent with the stability assumption that $f(1/2) = f(1/4) = f(0)$

is small. In sum, aggregate travel costs can be brought down to $\sigma_z^2/8$.

Since we have maintained the symmetry assumptions of this Section, there still exists a symmetric duopolistic equilibrium, with $\hat{t} = 1/2$. This equilibrium is stable provided

$$2 > \frac{\sqrt{6}}{4\sqrt{3}-4} f(1/2),$$

again satisfied when $f(1/2)$ is small. Aggregate liquidity costs are

$$\frac{\sqrt{6}}{8\sqrt{3}-8}\sigma_z^2.$$

As expected, these costs are greater than in the asymmetric equilibrium, since $2\sqrt{6} > 3+\sqrt{3}$, as $24 > 12+6\sqrt{3}$. With linear travel costs, we obtain

$$\int_0^{1/4} c(1/4-t)f(t)dt = 1/32,$$

and hence aggregate travel costs are, again, $\sigma_z^2/8$.

The regulator will prefer the asymmetric equilibrium in this case, because it significantly reduces liquidity costs without any significant increment in travel costs.

Finally, let us remark that the regulator also prefers the asymmetric equilibrium over monopoly in this example. In the monopoly, aggregate liquidity costs are $\sqrt{3}\sigma_z^2/(8\sqrt{3}-8)$. Aggregate travel costs to an exchange located at 1/2 are $\sigma_z^2/4$. The asymmetric duopoly is better because the travel cost saving of $\sigma_z^2/8$ exceeds the extra liquidity costs $\sqrt{3}\sigma_z^2/16$.

5 Discussion

According to this theory, the regulator should remember to assess heterogeneous trader preferences before making decisions on stock exchange mergers. These preferences may not be directly observable, but the crucial information about the marginal willingness of traders to move between exchanges can be extracted from variations in realized liquidity and order flow.

We have emphasized the trade off of valuable exchange technology differentiation against the positive network externality through improved liquidity derived from pooling trades. The literature has pointed to other relevant aspects of consolidation and fragmentation of exchanges. Consolidation of the order flow may allow exchanges to enjoy a more protected local monopoly situation, extracting more rents from traders. Fragmentation may render transaction prices less informative for outside observers of the market. One class of traders may be better equipped to trade across fragmented markets, profiting on arbitrage and manipulation opportunities at the expense of other traders.

We have emphasized that liquidity traders care about liquidity and platform technology. Implicitly, this suggests that the two assets are perfect substitutes. The extent of liquidity difference then depends on professional traders' willingness to connect the two markets to take advantage of any short-term price differences, and can also be influenced by transparency as well as requirements to route liquidity traders' orders. Our analysis thus emphasizes the observable liquidity difference that remains between stock exchanges which compete for order flow.

We have followed Admati and Pfleiderer (1988) in focusing the welfare analysis entirely on the liquidity traders. Another issue is to set up markets which encourage the acquisition of information. A sizable empirical literature, following Hamilton (1979) has empirically considered the impact of market fragmentation on price discovery as well as liquidity.

We have provided a first step towards formally combining market microstructure model of liquidity and trading externalities with a spatial model of imperfect competition. To be able to combine these models in a rigorous fashion, it was a very useful technical tool that the aggregate net order from traders living on an interval would be normally distributed with a variance proportional to the trader population. This might seem justified by an idea that liquidity traders with arbitrarily small random orders are located continuously over the interval. However, to make traders care seriously about the liquidity of a market place in Kyle's model, an individual's order needs to be non-trivial to induce a price impact. A better interpretation of our model is therefore that traders are not arbitrarily small, but are randomly located on the interval. The normality of the aggregate net order is then taken as an approximation to its actual distribution.

It would be theoretically desirable to let larger liquidity traders be more willing to connect to more liquid exchanges. Possibly, liquidity traders could at some cost connect to multiple exchanges, and subsequently route large and small orders to different exchanges.[18] Likewise, it's an interesting way forward to allow exchanges to charge fees for order execution, and to let traders abstain from trading. These extensions are likely to break the linearity of Kyle's equilibrium. This will imply a need for new, crucial modeling choices. When the asset price is not linear in order flow, identical liquidity orders submitted to the exchange need not all carry the same price impact — this depends on the priority rules for execution of orders. This makes it harder to model the liquidity costs experienced by an individual trader at an exchange, a crucial ingredient in a model of endogenous market choice.

[18] Kim and Serfes (2006) allow individuals to split orders to multiple platforms.

References

Admati, A. and Pfleiderer, P. (1988). A theory of intraday patterns: Volume and price variability. *Review of Financial Studies*, **1** (1), 3–40.

Chowhdry, B. and Nanda, V. (1991). Multimarket trading and market liquidity. *Review of Financial Studies*, **4** (3), 483–511.

De Palma, A., Ginsburgh, V., Papageorgiou, Y. and Thisse, J. (1985). The principle of minimum differentiation holds under sufficient heterogeneity. *Econometrica*, **53**, 767–781.

Di Noia, C. (2001). Competition and integration among stock exchanges in europe: Network effects, implicit mergers and remote access. *European financial management*, **7** (1), 39–72.

Duffie, D., Gârleanu, N. and Pedersen, L. (2005). Over-the-counter markets. *Econometrica*, **73** (6), 1815–1847.

Economides, N. and Siow, A. (1988). The division of markets is limited by the extent of liquidity (spatial competition with externalities). *The American Economic Review*, **78** (1), 108–121.

Ellison, G. and Fudenberg, D. (2003). Knife-edge or plateau: When do market models tip? *Quarterly Journal of Economics*, **118** (4), 1249–1278.

Foucault, T. and Menkveld, A. (2008). Competition for order flow and smart order routing systems. *The Journal of Finance*, **63** (1), 119–158.

Greenberg, J. (1983). Local public goods with mobility: Existence and optimality of a general equilibrium. *Journal of Economic Theory*, **30** (1), 17–33.

Griva, K. and Vettas, N. (2011). Price competition in a differentiated products duopoly under network effects. *Information Economics and Policy*, **23** (1), 85–97.

Hamilton, J. L. (1979). Marketplace fragmentation, competition, and the efficiency of the stock exchange. *The Journal of Finance*, **34** (1), 171–187.

Hendershott, T. and Mendelson, H. (2000). Crossing networks and dealer markets: Competition and performance. *The Journal of Finance*, **55** (5), 2071–2115.

Hoffmann, P. (2010). Adverse selection transaction fees and multi-market trading, mimeo, Universitat Pompeu Fabra.

Jehiel, P. and Scotchmer, S. (1997). Free mobility and the optimal number of jurisdictions. *Annals of Economics and Statistics / Annales d'Économie et de Statistique*, **45**, 219–231.

Katz, M. and Shapiro, C. (1985). Network externalities, competition, and compatibility. *The American Economic Review*, **75** (3), 424–440.

Kim, H. and Serfes, K. (2006). A location model with preference for variety. *The Journal of Industrial Economics*, **54** (4), 569–595.

KYLE, A. (1985). Continuous auctions and insider trading. *Econometrica*, **53**, 1315–1335.

MADHAVAN, A. (1995). Consolidation, fragmentation, and the disclosure of trading information. *Review of Financial Studies*, **8** (3), 579–603.

PAGANO, M. (1989). Trading volume and asset liquidity. *The Quarterly Journal of Economics*, **104** (2), 255–274.

PARLOUR, C. and SEPPI, D. (2003). Liquidity-based competition for order flow. *Review of Financial Studies*, **16** (2), 301–343.

PIRRONG, C. (1999). The organization of financial exchange markets: Theory and evidence. *Journal of Financial Markets*, **2** (4), 329–357.

RAMOS, S. B. and VON THADDEN, E.-L. (2008). Stock exchange competition in a simple model of capital market equilibrium. *Journal of Financial Markets*, **11** (3), 284–307.

RICHTER, D. K. (1982). Weakly democratic regular tax equilibria in a local public goods economy with perfect consumer mobility. *Journal of Economic Theory*, **27** (1), 137–162.

TIEBOUT, C. M. (1956). A pure theory of local expenditures. *Journal of Political Economy*, **64** (5), 416–424.

VAYANOS, D. and WANG, T. (2007). Search and endogenous concentration of liquidity in asset markets. *Journal of Economic Theory*, **136** (1), 66–104.