

Price Theory I: Problem Set 5 Question 1

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Market Microstructure

- The term “market microstructure” came from Garman (1976).
- O’Hara (1995) defines market microstructure as “the study of the process and outcomes of exchanging assets under explicit trading rules. ... microstructure literature analyzes how specific trading mechanisms affect the price formation process.”
 - ▶ Both real and financial assets
 - ▶ Focus on how trading and market mechanisms affect asset prices, transaction costs, volumes and trading behavior.
 - ★ Different from asset pricing, which focuses on equilibrium value of assets.
 - ★ Implications for asset pricing, corporate finance, intermediation, macro...
- No stand-alone class on market microstructure at Chicago.
 - ▶ Two classes touch on this topic: BUSN 35913/ECON 39701 - Advanced Theory of Corporate Finance and Capital Markets; BUSN 33915/ECON 40603 - Market Design

Market Microstructure

- Golden age of market microstructure (late 1970s-80s)
 - ▶ Inventory cost models (Stoll (1978), Ho and Stoll (1981), Amihud and Mendelson (1980)); information asymmetry and adverse selection (Kyle (1985), Glosten and Milgrom (1985)); order-processing costs (Roll (1984)).
 - ▶ A second wave involving strategic agents and auction theory (e.g., Kyle (1989))
 - ▶ A few good surveys: O'Hara (1995), Madhavan (2000), Biais et al. (2005).
 - ▶ Theories already well-developed. Empirical studies extended into late 1990s. Some recent research on market design.

Market Microstructure

- Revival of market microstructure - OTC markets (mid-late 2000s)
 - ▶ Rely on tools from either search or network theory.
 - ▶ OTC search:
 - ★ Workhorse model: Duffie et al. (2005, 2007)
 - ★ Subsequent research introduced additional ingredients: e.g., unrestricted asset holdings (Garleanu (2009), Lagos and Rocheteau (2009)); asymmetric information (Zhu (2011), Guerrieri and Shimer (2014)); different matching technology (An (2019)); relationships (Hendershott et al. (2020))...
 - ★ A great survey paper: Weill (2020)
 - ★ This pset covers some current directions in the literature: endogenous emergence of market structure, liquidity provision during crises and systemic risk, endogenous venue choice.
 - ▶ Networks:
 - ★ Tools from operations research
 - ★ E.g., Malamud and Rostek (2017), Babus and Kondor (2018)

The Question

"Some financial assets are traded bilaterally (e.g., bespoke derivatives, real estate). No central exchange exists for such assets, and buyers and sellers meet bilaterally to haggle over prices. Suppose that an agent (buyer or seller) is not always met with a counterparty. Instead they are matched at random.

"(a) One way to increase the probability of meeting a counterparty is to engage a broker, who is more connected to a wider network of buyers and sellers. Sometimes (e.g., for real estate transactions), brokers charge a commission equal to a percentage of final sale price (if a sale materializes). In this case, do you expect the broker to maximize sale price?"

Part a

- This is a warm-up question to help you make sense of search friction.
- Brokers trade-off a higher commission against costly search.
 - ▶ To increase sale price, a broker can either increase search intensity or increase search time.
 - ▶ However, both are costly.
 - ★ For example, suppose that the broker can increase sale price by searching for longer. The broker incurs opportunity cost because they could have spent the time closing other transactions.
 - ▶ Empirically, studies have found that houses owned by real estate agents tend to stay on the market for longer.

Part a

- A very stylized setup to illustrate the intuition:
 - ▶ Consider broker's problem at time t .
 - ★ Suppose broker has received an offer w at time t . Commission rate is k .
 - ★ Each period, conditional on getting an offer, the offer w is drawn from the same distribution with c.d.f. $F(w)$ with support $[w, \bar{w}]$.
 - ★ Each period, broker who searches for a buyer is met with a buyer with probability λ .
 - ★ Both the sequential search nature and λ capture search friction.
 - ★ Cost of search is c , which could be interpreted as broker's outside option or opportunity cost.
 - ▶ Broker continues to search in $t + 1$ if

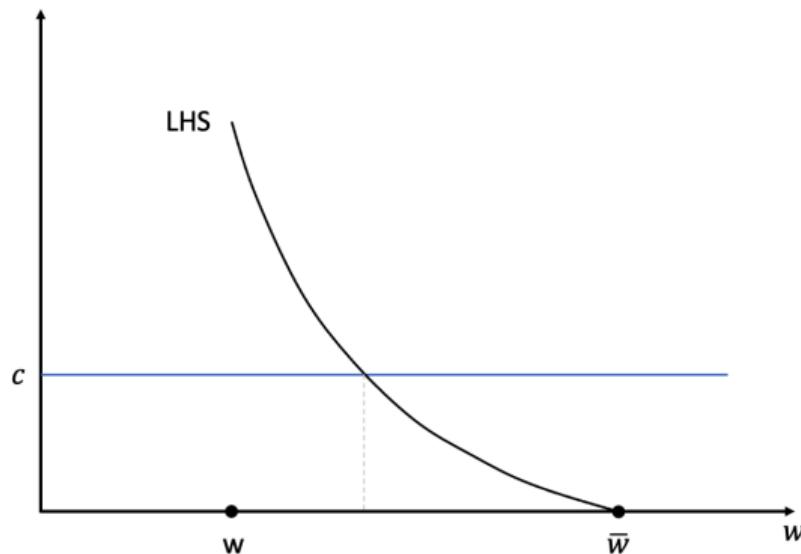
$$\begin{aligned}(1 - \lambda)kw + \lambda\mathbb{E}[\max\{kw, kw'\}] - kw &\geq c \\ \iff k\lambda(1 - F(w))\left[\mathbb{E}[w' | w' \geq w] - w\right] &\geq c\end{aligned}$$

LHS is decreasing in w .

[Derivation](#)

Part a

- Broker would sell at $w' < \bar{w}$ (does not maximize sale price).
 - Search longer if $\lambda \uparrow$ (lower search friction), $k \uparrow$ (higher commission rate).
 - Search longer if $c \downarrow$ (lower cost of search).



Part b

“Suppose due to a technological innovation, it has become much easier for buyers and sellers to be matched. How does the technological innovation affect asset prices?”

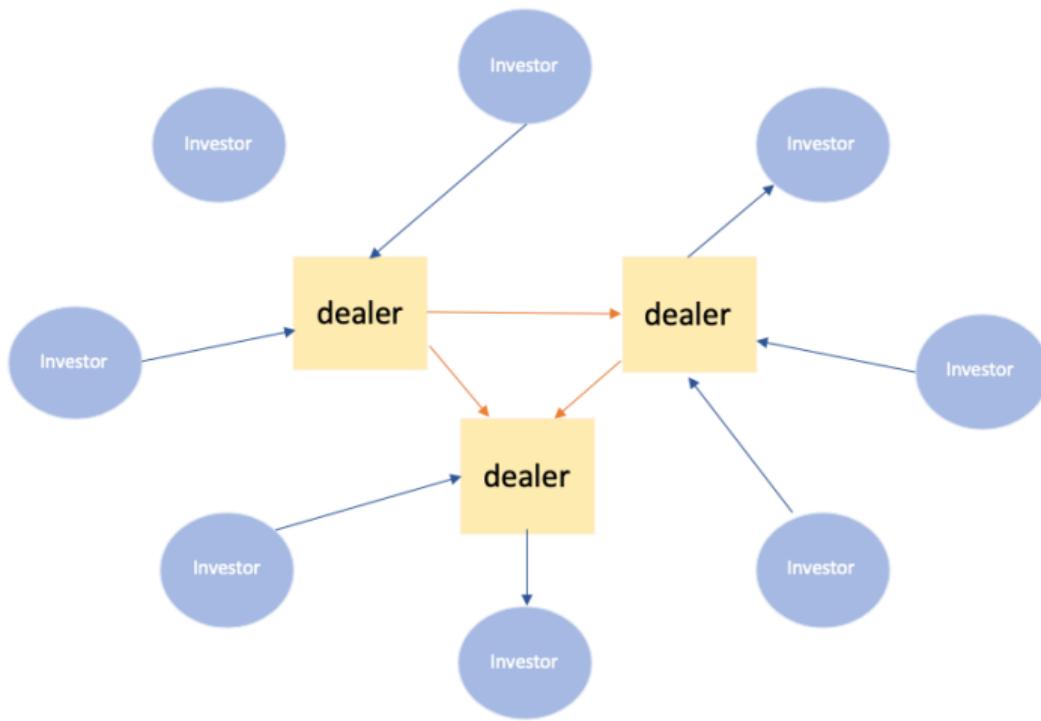
Part b

- From our setup in part a:
 - ▶ Suppose buyers and sellers transact through brokers (again, consider the real estate market).
 - ▶ Technological innovation increases λ . Thus, broker is willing to wait longer for a higher price. Equilibrium sale prices increase.
 - ▶ Intuitively, lower search friction makes it less costly to search longer (less costly to trade), resulting in higher transaction prices.
- Hopefully you have gained some basic intuition about search friction. Now let's apply it to the financial market context.

The Question

"In many asset markets, there are dealers who hold inventories of assets. Dealers provide liquidity to buyers and sellers by standing ready to transact at their quoted prices. One example is the corporate bond market in the U.S., which features a two-tier structure in the sense that investors must trade with dealers but dealers can trade with both investors and other dealers."

Background



Background

- Why study OTC markets?
 - ▶ Many asset classes are traded OTC. E.g., Treasury market (\$22 trillion), corporate bond market (\$10 trillion), asset-backed securities (\$13 trillion), municipal bond market (\$4 trillion)...
 - ★ Much larger than equity market.
 - ▶ Many OTC markets are systematically important, e.g., Treasury, repo, Fed funds markets are all OTC - important implications for monetary policy transmissions and financial stability/systemic risk.
 - ▶ Corporate debt securities (including syndicated loans and bonds) are important sources of financing for firms - implications for corporate finance.
- Here we focus on the financial market application. However, the question overlaps with matching markets and two-side markets, search models in macro and labor economics, and so on.

Background

- Why do economic agents wish to invest in assets?
 - ▶ Asset pricing in one slide: consumption-based model

$$\begin{aligned} \max_{\xi} \quad & u(c_t) + \mathbb{E}[\beta u(c_{t+1}) | \mathcal{F}_t] \\ \text{s.t.} \quad & c_t = e_t - p_t \xi \\ & c_{t+1} = e_{t+1} + x_{t+1} \xi \end{aligned}$$

- ▶ Investor's Euler equation:

$$p_t = \mathbb{E} \left[\underbrace{\beta \frac{u'(c_{t+1})}{u'(c_t)}}_{= m_{t+1} \text{ (MRS)}} x_{t+1} \middle| \mathcal{F}_t \right]$$

- ▶ SDF m_{t+1} prices assets (equilibrium pricing). Price is just discounted cash flows.
- ▶ The model we will build will look very different from this, but the basic idea is the same.

Background

- Who are investors?
 - ▶ Institutional investors: insurance companies, pension funds, mutual funds, hedge funds etc.
 - ★ E.g., Dimensional Fund Advisors, Fidelity, UChicago Endowment...
 - ▶ Why do they trade?
 - ★ Portfolio rebalancing, fund flows (subscriptions and redemptions), portfolio positioning and adjustments (e.g., to express investment views)
- Who are dealers (market-makers)?
 - ▶ Large investment banks: provide liquidity and facilitate trading
 - ★ E.g., Goldman Sachs, JP Morgan, Credit Suisse...
 - ★ Can engage in principal trading (leverage balance sheet to take down inventories)
 - ★ Generally prohibited from trading for own account (e.g., Volcker Rule)
 - ★ Core-periphery dealer sector: a handful of large dealers, many smaller broker-dealers ("boutiques") that act like matchmakers

Model

- Dynamic search model based on Duffie et al. (2005) and Weill (2020).
- Time is continuous and infinite: $t \in [0, \infty)$.
- Two types of infinitely-lived, risk-neutral agents:
 - ▶ A unit measure of investors and a unit measure of dealers (no entry or exit of agents).
 - ▶ Agents discount time at rate $r > 0$.
- Asset (tree):
 - ▶ Each tree produces a unit flow of perishable good (fruit).
 - ▶ There is a numeraire general consumption good, produced and consumed by all agents.
 - ▶ Tree is durable and indivisible, and has fixed supply $s \in (0, 1)$.
 - ▶ Tree is traded among agents in a decentralized market intermediated by dealers. No trading market exists for fruit.

- Investors:

- ▶ At $t = 0$, a measure s of investors are endowed with one unit of tree, and dealers do not hold any tree at time 0.
- ▶ Investors can hold either 0 or 1 unit of tree.
- ▶ When holding one unit of tree, investor derives utility flow δ from fruit consumption.
 - ★ Investor's instantaneous utility function is $q\delta + C$ where $q \in \{0, 1\}$ is investor's asset holding and C is investor's consumption of numeraire good.
 - ★ At independent Poisson arrival times with intensity γ , investor receives a preference shock and re-draws $\delta \sim F(\cdot)$ where $F(\cdot)$ is cdf and $\mathbb{E}[\delta] = 0$.
 - ★ Time-varying preferences are key to generate trading in steady state.
 - ★ Preference shocks can be interpreted as liquidity needs or heterogeneous valuations based on different beliefs etc.

- Dealers:

- ▶ Dealers do not derive utility from fruit.
 - ★ Hence, dealers' role in the market is to facilitate trades. E.g., Volcker Rule, dealers' balance sheet constraints (e.g., Du et al. (2017)).
- ▶ Assume dealers cannot hold inventory.
 - ★ If our goal is to study steady state under normal market conditions and the supply of asset s is small, this is a reasonable assumption as long as the inter-dealer market is relatively frictionless.
 - ★ If inter-dealer market is frictional (subject to search and bargaining frictions) or if we are interested in studying crises, we need to relax this assumption.

- Trading:

- ▶ Trading occurs in a decentralized market intermediated by dealers. Investors must trade with dealers, while dealers can trade with both investors and other dealers.
- ▶ Focus on principal trading.
- ▶ Investors randomly meet dealers at independent Poisson arrival times with intensity λ .
- ▶ Prices are determined by Nash bargaining. Dealers' bargaining power (against investors) is θ .
- ▶ Inter-dealer trading is frictionless.

Model

- Prices and Bargaining:

- ▶ $V_q(\delta)$ denotes max attainable utility of type- δ customer holding $q \in \{0, 1\}$ unit of tree.
- ▶ B denotes bid price, A denotes ask price, and P denotes inter-dealer price.
- ▶ $\Delta V(\delta) \equiv V_1(\delta) - V_0(\delta)$ is investor's reservation price.

$$B(\delta) = \theta \Delta V(\delta) + (1 - \theta)P \quad \text{investor sells when } P > \Delta V(\delta)$$
$$A(\delta) = \theta \Delta V(\delta) + (1 - \theta)P \quad \text{investor buys when } P < \Delta V(\delta)$$

Derivation

Model

- Investor HJB equations:

$$rV_0(\delta) = \underbrace{\gamma \int [V_0(\delta') - V_0(\delta)] dF(\delta')}_{\text{utility from preference change}} + \lambda \underbrace{\max\{\Delta V(\delta) - P, 0\}}_{\text{payoff from trading (if it occurs)}}$$

$$rV_1(\delta) = \delta + \gamma \int [V_1(\delta') - V_1(\delta)] dF(\delta') + \lambda \max\{P - \Delta V(\delta), 0\}$$

Thus,

$$\begin{aligned} r\Delta V(\delta) &= \delta + \gamma \int [\Delta V(\delta') - \Delta V(\delta)] dF(\delta') \\ &\quad + \lambda(1 - \theta) \left[\max\{P - \Delta V(\delta), 0\} - \max\{\Delta V(\delta) - P, 0\} \right] \\ &= \delta + \gamma \int [\Delta V(\delta') - \Delta V(\delta)] dF(\delta') + \lambda(1 - \theta)[P - \Delta V(\delta)] \end{aligned} \tag{1}$$

Derivation

Model

- Take expectations of both sides of (1):

$$\begin{aligned} r \int \Delta V(\delta) dF(\delta) &= \lambda(1 - \theta)P - \lambda(1 - \theta) \int \Delta V(\delta) dF(\delta) \\ \implies \int \Delta V(\delta) dF(\delta) &= \frac{\lambda(1 - \theta)P}{r + \lambda(1 - \theta)} \end{aligned}$$

- Substitute back into (1):

$$\Delta V(\delta) = \frac{\delta}{r + \gamma + \lambda(1 - \theta)} + \frac{\lambda(1 - \theta)}{r + \lambda(1 - \theta)} P$$

Model

- Denote the marginal type of investor by δ^* such that

$$\Delta V(\delta^*) = P \iff \frac{\delta^*}{r + \gamma + \lambda(1 - \theta)} + \frac{\lambda(1 - \theta)}{r + \lambda(1 - \theta)} P = P$$

- Conditional on meeting a dealer, a type- δ owner investor wishes to hold the asset if $\delta > \delta^*$; and wishes to sell the asset if $\delta < \delta^*$.
- Conditional on meeting a dealer, a type- δ non-owner investor wishes to buy the asset if $\delta > \delta^*$; and does not trade if $\delta < \delta^*$.
- Inter-dealer price is determined as a function of the marginal type δ^* :

$$P = \frac{1}{r} \frac{r + \lambda(1 - \theta)}{r + \gamma + \lambda(1 - \theta)} \delta^*$$

Model

- Bid and ask prices:

$$B(\delta) = \frac{\theta\delta}{r + \gamma + \lambda(1 - \theta)} + \left[\frac{\lambda\theta(1 - \theta)}{r + \lambda(1 - \theta)} + (1 - \theta) \right] \frac{1}{r} \frac{r + \lambda(1 - \theta)}{r + \gamma + \lambda(1 - \theta)} \delta^* \quad \text{if } \delta < \delta^*$$
$$A(\delta) = \frac{\theta\delta}{r + \gamma + \lambda(1 - \theta)} + \left[\frac{\lambda\theta(1 - \theta)}{r + \lambda(1 - \theta)} + (1 - \theta) \right] \frac{1}{r} \frac{r + \lambda(1 - \theta)}{r + \gamma + \lambda(1 - \theta)} \delta^* \quad \text{if } \delta > \delta^*$$

- Limiting case (no search and bargaining friction):

$$\lim_{\lambda(1-\theta) \rightarrow \infty} P = \frac{\delta^*}{r}$$

- ▶ Discounted value of utility flow of the marginal investor.

- Comparative statics:

- ▶ When $\lambda \uparrow$ (search friction decreases):

- ★ $P \uparrow, B \uparrow, A \uparrow$
 - ★ Check by taking derivative with respect to λ
 - ★ Asset prices are increasing in search intensity λ . That is, asset prices are higher when search friction is lower (since trade is less costly).

- ▶ When $1 - \theta \uparrow$ (investor bargaining power increases):

- ★ $P \uparrow, B \uparrow, A ?$
 - ★ Check by taking derivative with respect to $(1 - \theta)$
 - ★ Higher bargaining power to investors makes trade less costly, which tends to boost prices. Due to higher bargaining power, investors can extract more of the surplus, thus selling investors get better price (higher bid price). The two effects work in opposite directions for buying investors (ask price).

Part c

“What kind of agents become dealers? What factors about tastes and technology determine the answer? This question asks whether the dealer (intermediary) sector can endogenously emerge.”

Part c

- Consider our setup but trading is fully decentralized. That is, investors meet with each other at random.
 - ▶ Since investors have different utility δ , they also have different reservation values $\Delta V(\delta)$.
 - ▶ If $\Delta V(\delta)$ is high, investor is more likely to be a buyer; if $\Delta V(\delta)$ is low, investor is more likely to be a seller.
 - ▶ For investors whose $\Delta V(\delta)$ is close to economy-wide median, it is approximately equally likely to meet with investors with higher or lower reservation values. These investors both buy and sell. If these investors' reservation values are also consistent, they become dealers.
- Other potential factors:
 - ▶ Differences in trading speed (e.g., Farboodi et al. (2018a)); differences in rent-extracting abilities (e.g., Farboodi et al. (2018b)). Still active area of research...

Part d

"Dealers quote bid and ask prices for each bond. Bid price is the price the dealer is willing to purchase the bonds at; ask price is the price the dealer is willing to sell the bonds at. The bid-ask spread is the difference between bid and ask quotes, and is revenue generated by the dealer. If dealers act competitively (the dealer sector is competitive), do you expect the bid-ask spread to be zero?"

Part d

- Suppose dealer buys from type $\delta^* - \epsilon$ and sells to type $\delta + \epsilon'$.
- Use our expressions for bid and ask prices, bid-ask spread:

$$\text{B-A Spread} = A(\delta^* + \epsilon') - B(\delta^* - \epsilon) = \frac{\theta(\epsilon + \epsilon')}{r + \gamma + \lambda(1 - \theta)} > 0$$

- ▶ This is what we would observe in data.
- ▶ With search and bargaining friction, even if the dealer sector is competitive and information is symmetric, bid-ask spread is still positive.
- ▶ Intuition is from part a and b. With search friction, dealers cannot instantaneously find the marginal types to transact.
- Other potential reasons for positive bid-ask spreads:
 - ▶ E.g., information asymmetry (uninformed dealers trading against informed investors), order processing costs etc.

Part e

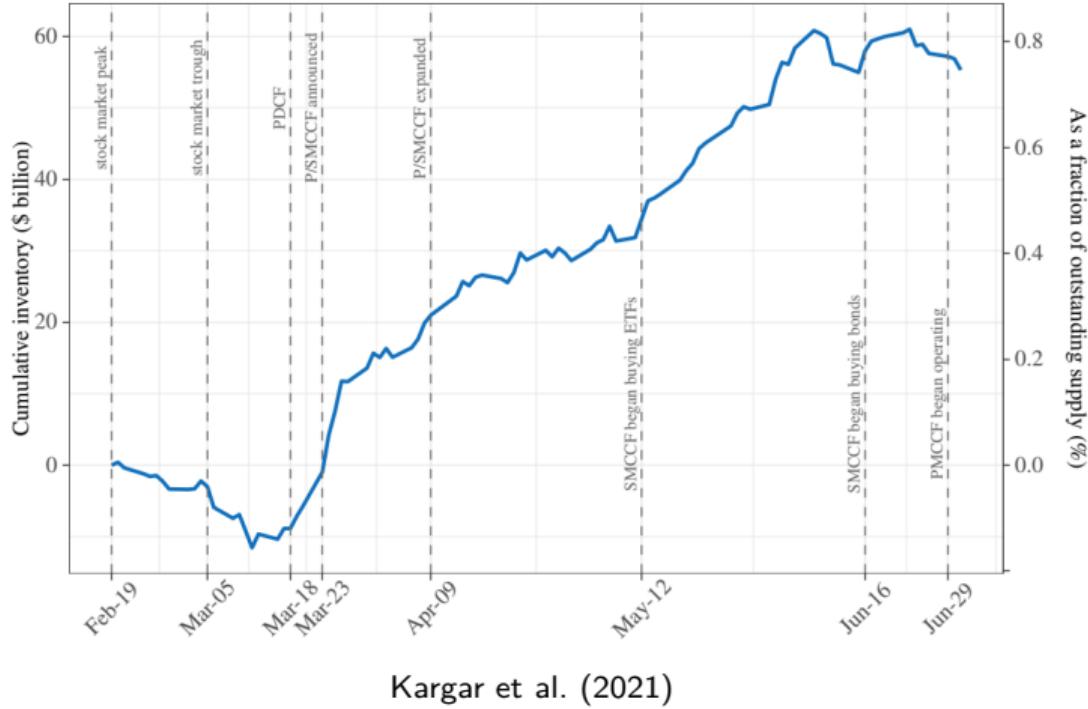
"During crises (such as the COVID-19 crisis) when investors must sell bonds to meet fund redemptions, do you expect dealers to "lean against the wind" by absorbing these bonds into their inventories?"

Part e

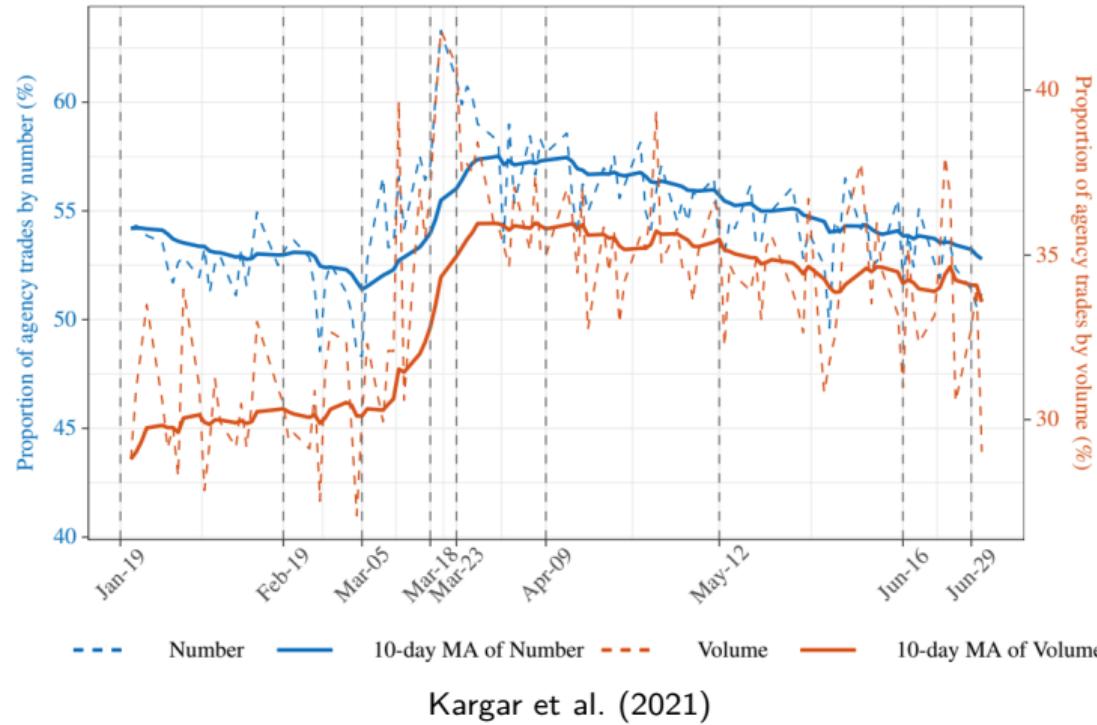
A: Insurance Companies									
	Downgrade (IG)			Fallen Angels			No Rating Change		
	Obs	Amount	% Holding	Obs	Amount	% Holding	Obs	Amount	% Holding
$\Delta Holding_t$	9673	-0.916	-1.249	3261	-1.353	-1.904	416254	-0.390	-0.448
$\Delta Holding_{t+1}$	9604	-1.008	-1.374	3185	-1.274	-1.793	416965	-0.404	-0.464
$Holding_{t-1}$		73.359			71.075			87.087	
B: Mutual Funds									
	Downgrade (IG)			Fallen Angel			No Rating Change		
	Obs	Amount	% Holding	Obs	Amount	% Holding	Obs	Amount	% Holding
$\Delta Holding_t$	5265	0.376	0.489	1760	0.116	0.153	345154	-0.423	-0.649
$\Delta Holding_{t+1}$	5204	-0.161	-0.209	1701	-0.237	-0.312	345385	-0.390	-0.599
$Holding_{t-1}$		76.882			75.998			65.153	
C: Pension Funds									
	Downgrade (IG)			Fallen Angel			No Rating Change		
	Obs	Amount	% Holding	Obs	Amount	% Holding	Obs	Amount	% Holding
$\Delta Holding_t$	4566	0.285	1.453	1484	0.204	1.126	304541	-0.321	-2.682
$\Delta Holding_{t+1}$	4508	-0.246	-1.254	1443	-0.474	-2.617	304883	-0.309	-2.581
$Holding_{t-1}$		19.621			18.110			11.971	
D: Dealers									
	Downgrade (IG)			Fallen Angel			No Rating Change		
	Obs	Amount	% Holding	Obs	Amount	% Holding	Obs	Amount	% Holding
$\Delta Inventory_t$	20254	0.343	17.599	6792	1.311	76.756	687927	0.254	21.381
$\Delta Inventory_{t+1}$	18949	0.022	1.129	6449	-0.275	-16.101	614380	0.028	2.357
$Inventory_{t-1}$		1.949			1.708			1.188	

He et al. (2021)

Part e



Part e



Part e

- To simplify, assume there are only two preference types - high and low.
 - ▶ High-type investor derives utility flow δ_h and low-type investor derives utility flow δ_l .
 - ▶ Conditional on preference change, investor draws δ_h with probability p and δ_l with probability $1 - p$.
- Abstract the dealer sector into a representative dealer, who can now hold inventory $I \geq 0$.
 - ▶ Dealer can hold any positive units of asset.
 - ▶ Dealer has access to capital W .
- Suppose asset supply is small $s < p$.
- Suppose at time 0, investors experience an aggregate (negative) preference shock, such that all investors are low-type.

Part e

- If dealer does not take in inventory at $t = 0$, no trading takes place.
 - ▶ At $t = 0$, there are s low-type owner (lo) and $1 - s$ low-type non-owner (ln).
 - ▶ After re-drawing preferences, there are ps high-type owner (ho), $(1 - p)s$ low-type owner (lo), $p(1 - s)$ high-type non-owner (hn), and $(1 - p)(1 - s)$ low-type non-owner (ln).
 - ▶ lo will wish to sell and hn will wish to buy. Thus, we have $(1 - p)s$ sellers and $p(1 - s)$ buyers. Notice that $(1 - p)s < p(1 - s)$.
 - ▶ If dealer does not hold inventory, at least $p(1 - s) - (1 - p)s = p - s$ hn investors cannot purchase asset.
- If dealers takes in inventory H at $t = 0$,
 - ▶ At $t = 0$, there are $s - H$ lo and $1 - s$ ln .
 - ▶ After re-drawing preferences, there are $p(s - H)$ ho , $(1 - p)(s - H)$ lo , $p(1 - s)$ hn , and $(1 - p)(1 - s)$ ho .
 - ▶ If dealers sell from inventory, $(1 - p)(s - H) + H = (1 - p)s + pH$ are sellers.

Part e

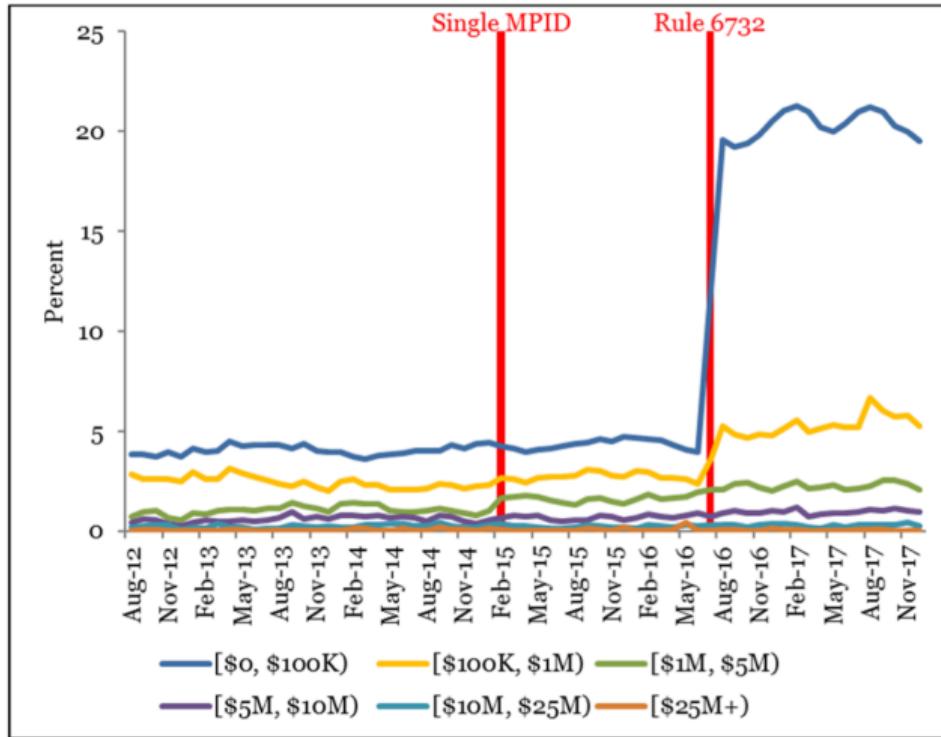
- Key prediction is that if dealer sector is not exposed to the same shock, intertemporal re-allocation of inventories by absorbing selling pressure during crises and releasing assets from inventories during recovery period increases dealer trading volumes and profits.
- Immediate that liquidity provision during crises is efficient.
- What could go wrong?
 - ▶ Dealers do not have access to enough capital, leading to socially sub-optimal liquidity provision during crises.
 - ▶ Dealer (intermediary) sector is subject to the same shock.
 - ★ Dealers may rush to offload inventories instead of "leaning against the wind".
 - ▶ Regulatory constraints.
 - ★ E.g., balance sheet constraint makes it costly to hold inventories, particularly during crises.
- See Weill (2007) if you are interested.

Part f

"In the past few years, electronic platforms have emerged in the corporate bond market. A type of electronic trading, "all-to-all" trading, aggregates and matches orders of buyers and sellers directly, like how stocks are traded on exchanges. Proponents of electronic trading argue that such all-to-all trading offers immediacy of execution and cuts out the middleman (dealers). Do you agree? Do you think all-to-all trading will dominate traditional trading for all investors?"

Part f

Figure 3.3 Percent Monthly Trading Volume by Trade Size



Kozora et al. (2020)

Part f

- All-to-all trading in principle would lower search and bargaining friction, improving transaction cost.
- But, in all-to-all trading, trading intention is revealed to all participants on the platform.
 - ▶ In bilateral voice trading, investor and dealer meet and negotiate price and quantity. Other investors and dealers do not observe this.
- This question considers endogenous venue choice. Investors trade off search and bargaining friction against information leakage.
- Follow Hendershott and Madhavan (2015) closely.

Part f

- Consider a buy order.
 - ▶ Let p_0 denote investor's expected purchase price through traditional voice trading.
 - ▶ Let p_a denote investor's expected purchase price through all-to-all trading.
 - ▶ Investor selects traditional trading if $p_0 < p_a$.
- Expected purchase price in bilateral trading is expected value of the asset v plus dealer markup d . Thus, $p_0 = v + d$.
- In all-to-all trading:
 - ▶ Investor fails to find a counterparty with probability q , and must transact bilaterally.
 - ▶ Because dealers observe investor's failure in all-to-all market, investor is subject to an information leakage cost s .
 - ▶ Investor finds at least a counterparty with probability $1 - q$. Each counterparty offers at the fair value v plus an adjustment term π (which reflects expected value of counterparty preferences/beliefs and can be positive or negative).

Part f

- Expected all-to-all price:

$$\begin{aligned} p_a &= q(p_0 + s) + (1 - q)(v + \pi) \\ \iff p_a - p_0 &= (q - 1)(v + d) + qs + (1 - q)(v + \pi) \end{aligned}$$

- Investor chooses to trade bilaterally iff

$$p_a - p_0 > 0 \iff qs + (1 - q)(\pi - d) > 0$$

- ▶ More likely to trade in all-to-all market if s is small, π is low and d is high.
- ▶ Thus, less information-sensitive securities (e.g., high-quality bonds) and small sizes are good candidates for all-to-all trading.

Part f

- All-to-all trading volume is tiny. Corporate bond electronic trades are primarily request-for-quotes (RFQ) which are akin to first price sealed bid auctions.
 - ▶ Same analysis carries over for RFQ.
 - ▶ All-to-all trading imposes even more information leakage compared to RFQ.
 - ▶ All-to-all trading also faces participation constraint. Only very large institutions can participate.
 - ▶ This analysis also applicable to equity market (e.g., dark pools).
- An open question is why some assets are traded OTC instead of in centralized markets.
 - ▶ E.g., corporate bonds were in fact traded on exchanges before 1940s (Biais and Green (2018)).
 - ▶ Information frictions, technological advance, sorting of heterogeneous investors across markets, regulations, etc.

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Appendix - Part a

- Second inequality follows from law of total expectation:

$$\begin{aligned} LHS &= -k\lambda w + k\lambda \mathbb{E}[\max\{w, w'\}] \\ &= k\lambda \left\{ \Pr(w' < w)w + \Pr(w' \geq w)\mathbb{E}[w'|w' \geq w] - w \right\} \\ &= k\lambda(1 - F(w))[\mathbb{E}[w'|w' \geq w] - w] \\ &= k\lambda(1 - F(w)) \left[\frac{1}{1 - F(w)} \int_w^{\bar{w}} w' dF(w') - w \right] \\ &= k\lambda \left[\int_w^{\bar{w}} w' dF(w') - (1 - F(w))w \right] \end{aligned}$$

- Take derivative with respect to w :

$$\frac{\partial LHS}{\partial w} = k\lambda \left[-wf'(w) - 1 + wf'(w) + F(w) \right] = k\lambda(F(w) - 1) < 0$$

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Appendix - Nash Bargaining

- Consider a type- δ owner (holding one unit of tree).
 - If investor sells, their net payoff: $B(\delta) + V_0(\delta) - V_1(\delta) = B(\delta) - \Delta V(\delta)$
 - If investor sells, dealer net payoff: $P - B(\delta)$
 - Gain from trend iff $B(\delta) - \Delta V(\delta) + P - B(\delta) \geq 0$, that is, $P \geq \Delta V(\delta)$.
 - Nash bargaining determines $B(\delta)$:

$$B(\delta) = \arg \max_B (B - \Delta V(\delta))^{1-\theta} (P - B)^\theta$$

FOCs yield:

$$B(\delta) = \theta \Delta V(\delta) + (1 - \theta) P$$

- For type- δ non-owner, $A(\delta)$ can be determined analogously.

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Appendix - Investor HJB Equations

- Since investors are risk neutral:

$$\dot{V}_0(\delta) + \gamma \int [V_0(\delta') - V_0(\delta)] dF(\delta') + \lambda \max\{\Delta V(\delta) - A(\delta), 0\} = rV_0(\delta)$$

$$\dot{V}_1(\delta) + \delta + \gamma \int [V_1(\delta') - V_1(\delta)] dF(\delta') + \lambda \max\{B(\delta) - \Delta V(\delta), 0\} = rV_1(\delta)$$

- In steady state, $\dot{V}_q(\delta) = 0$ for $q \in \{0, 1\}$.
- Then subtract the first equation from the second equation, and use the expressions for $B(\delta)$ and $A(\delta)$.

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