OTC Market Theory
Part Deux

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Review (I): What are over-the-counter (OTC) markets?

- OTC (or decentralized) usually refers to market in which
  - agents trade in small groups (e.g., pairs)
  - terms of trade determined inside the group (e.g., bargaining)
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  - law of one price
  - typically transparent prices and histories
- Examples of OTC markets
  - Treasuries, corp and muni bonds, derivatives, FX swaps, fed funds...
  - Also: used capital, ideas (VCs and entrepreneurs), ...

Review (II): Why study OTC markets?

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  - trading arrangements differ dramatically across asset classes
  - open question: what features of asset/participants determine market structure?
- Important (and timely!) policy questions
  - Do trading frictions exacerbate information frictions? Or ameliorate them?
  - Market disruptions from "bad" *distribution* of assets?
  - Should regulators force OTC markets onto centralized exchanges?
  - What are welfare effects of more competition? More transparency?

Review (III): The Search-Theoretic Approach

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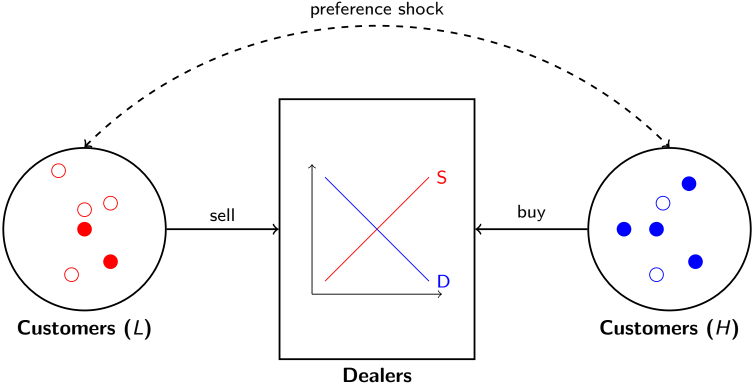
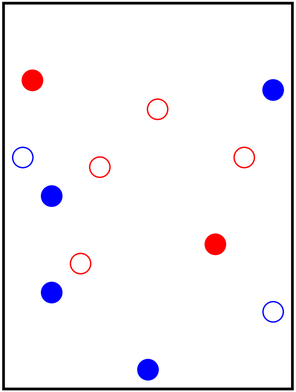
- **Model 1:** trade organized through **semi-centralized market** (last week)



Review (III): The Search-Theoretic Approach

- Two benchmark models (with many extensions, discussed later)
- Basics: investors with $\{0, 1\}$ asset holdings & stochastic preferences
- **Model 2:** trade organized through **pure decentralized market** (this week)



Investors

the economic environment

The Basics

- **Investors, goods, & assets**
  - continuous time, ∞ horizon, measure 1 of risk-neutral investors with $r > 0$
  - numéraire good produced and consumed by all investors (transferable utility)
  - measure $s \in (0, 1)$ of indivisible assets: investors hold $\{0, 1\}$
- **Preferences**
  - investors' flow utility from asset: $\delta \in [0, 1]$
  - at rate γ, new δ' i.i.d. draw from $F(\delta)$
  - for today: initial types drawn from $F(\delta)$ at $t = 0$

  $\Rightarrow$ valuations across all investors always given by $F(\delta)$
- **Search and trade**
  - investors randomly matched at rate λ, bargain over price
  - investor with $q \in \{0, 1\}$ assets has bargaining power θ_q
  - $P(\delta, \delta') =$ price between owner (δ) and non-owner (δ')

Joint Distribution of Asset Holdings and Types

- $\Phi_{q,t}(\delta) \equiv$ measure of investors...
  - holding $q \in \{0, 1\}$ assets,
  - with type $\delta' \leq \delta$,
  - at time $t \geq 0$.

- $\Phi_{0,t}(\delta)$ and $\Phi_{1,t}(\delta)$ have to satisfy accounting identities:
  - $\Phi_{0,t}(\delta) + \Phi_{1,t}(\delta) = F(\delta)$
  - $\Phi_{0,t}(1) = 1 - s$ and $\Phi_{1,t}(1) = s$.

  for all $\delta \in [0, 1]$ and $t \geq 0$.

quick reminder: frictionless benchmark

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- When investors can trade instantly in competitive, centralized market

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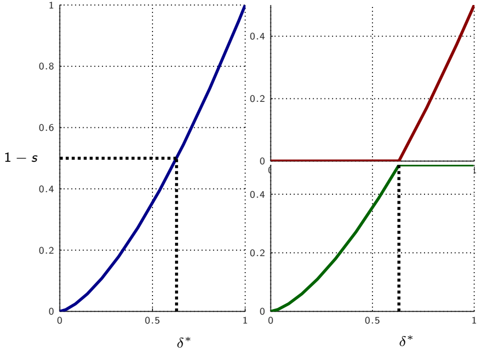

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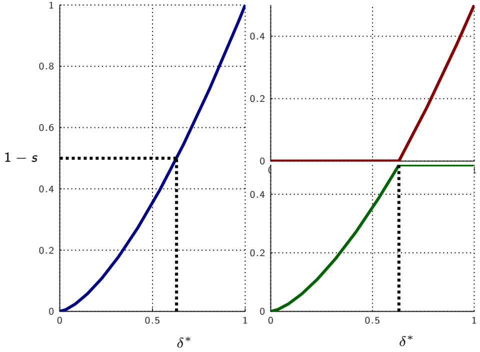

- Price is: $p_t = p^\star \equiv \frac{\delta^\star}{r}$ for all t.

equilibrium with search frictions

Derivation in Two Steps (Steady-State)

1. Derive "reservation values" given $\{\Phi_0(\delta), \Phi_1(\delta)\}$.

   - Reservation value defined as:

     $$\Delta V(\delta) = V_1(\delta) - V_0(\delta).$$

     where $V_q(\delta)$ = value of holding q assets with utility type δ

   - Price satisfies Nash bargaining solution

     $$\max_p \; [p + V_0(\delta) - V_1(\delta)]^{\theta_1} \left[-p + V_1(\delta') - V_0(\delta')\right]^{\theta_0}$$

     $$\Rightarrow P(\delta, \delta') = \theta_0 \Delta V(\delta) + \theta_1 \Delta V(\delta')$$

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Combine 1 + 2 $\Rightarrow$ characterize unique equilibrium.

Step 1: Bellman equation for Reservation Value

- (Flow) value of owning a unit of asset when type is δ:

$$rV_1(\delta) = \delta + \gamma \int \left[V_1(\delta') - V_1(\delta) \right] dF(\delta') + \lambda \int \max\{0, P(\delta, \delta') + V_0(\delta) - V_1(\delta)\} d\Phi_0(\delta')$$

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- Reservation value of type δ is:

$$\begin{aligned} r\Delta V(\delta) =& \delta + \underbrace{\gamma \int_0^1 \left[\Delta V(\delta') - \Delta V(\delta)\right] dF(\delta')}_{\text{preference shock}} \\ & + \underbrace{\lambda \int_\delta^1 \theta_1 \left[\Delta V(\delta') - \Delta V(\delta)\right] d\Phi_0(\delta')}_{\text{option to sell asset}} - \underbrace{\lambda \int_0^\delta \theta_0 \left[\Delta V(\delta) - \Delta V(\delta')\right] d\Phi_1(\delta')}_{\text{foregone option to buy}} \end{aligned}$$

more

Comparison

- Pure Decentralized vs Semi-centralized:

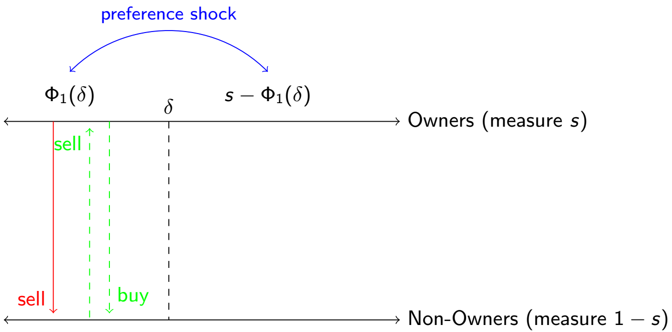
$$
\begin{aligned}
r\Delta V(\delta) =& \delta + \gamma \int_0^1 \left[\Delta V(\delta') - \Delta V(\delta)\right] dF(\delta') \\
& + \lambda \int_\delta^1 \theta_1 \left[\Delta V(\delta') - \Delta V(\delta)\right] d\Phi_0(\delta') - \lambda \int_0^\delta \theta_0 \left[\Delta V(\delta) - \Delta V(\delta')\right] d\Phi_1(\delta') \\
r\Delta V(\delta) =& \delta + \gamma \int_0^1 \left[\Delta V(\delta') - \Delta V(\delta)\right] dF(\delta') \\
& + \lambda\theta_d \left[P - \Delta V(\delta)\right].
\end{aligned}
$$

- Note key differences:
  - There are *two* option values in first equation:
    1. option to resell at higher price
    2. foregone option value of buying at (potentially) lower price
  - Option values depend on *distributions* of other investors' holdings, preferences

Step 2: Joint Distribution of Asset Holdings and Types

- Given monotonicity of ΔV, trading decision is trivial $\Rightarrow$

$$\dot{\Phi}_1(\delta) = \underbrace{\gamma[s - \Phi_1(\delta)]F(\delta)}_{\text{inflow from type-switching}} - \underbrace{\gamma\Phi_1(\delta)[1 - F(\delta)]}_{\text{outflow from type-switching}} - \underbrace{\lambda\Phi_1(\delta)[1 - s - \Phi_0(\delta)].}_{\text{outflow from trade}}$$



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- Since $\Phi_0(\delta) = F(\delta) - \Phi_1(\delta)$, in steady-state we have:

$$\dot{\Phi}_1(\delta) = -\lambda\Phi_1(\delta)^2 - \Phi_1(\delta)[\gamma + \lambda(1 - s - F(\delta))] + \gamma s F(\delta) = 0.$$

- This ODE is a Riccatti equation and has a unique solution:

$$\Phi_1(\delta) = \frac{1}{2}\left\{\sqrt{\left[1 - s + \frac{\gamma}{\lambda} - F(\delta)\right]^2 + 4s\frac{\gamma}{\lambda}F(\delta)} - \left[1 - s + \frac{\gamma}{\lambda} - F(\delta)\right]\right\}.$$

Equilibrium

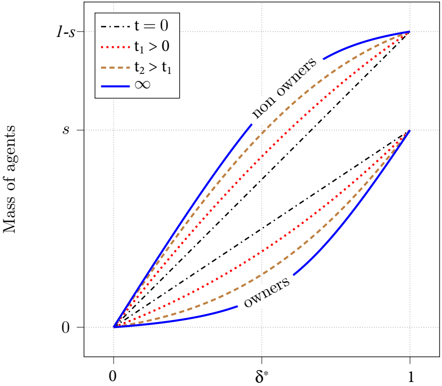
- Equilibrium is prices, reservation values, and allocations s.t.:
    1. Prices solve $P(\delta, \delta') = \theta_0 \Delta V(\delta) + \theta_1 \Delta V(\delta')$,
    2. Reservation values, $\Delta V(\delta)$, solves the HJB equation.
    3. Allocation $\Phi_1(\delta)$ solves ODE, $\Phi_0(\delta) = F(\delta) - \Phi_{1,t}(\delta)$.

Theorem

There exists a unique equilibrium.

Non-stationary Dynamics and Aggregate Shocks

- Note: can derive closed-form solutions for $\Delta_t(\delta)$ and $\Phi_{q,t}(\delta)$, too![1]
  - Study convergence to frictionless benchmark
  - Also study effects of aggregate "liquidity shock"



[1] See forthcoming paper in *Theoretical Economics*

Taking Stock

- Pure decentralized trade w arbitrary heterogeneity in preferences
  - Closed-form solutions, in and out of steady state
  - Essentially no loss in tractability from 2-type case of DGP (07)

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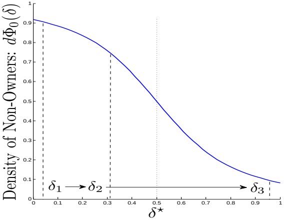
  - Essentially no loss in tractability from 2-type case of DGP (07)
- Rest of lecture
  1. What do we learn from this benchmark model?
  2. Extensions/applications to confront important issues, data

implications of benchmark model

A Day in the Life of an Asset



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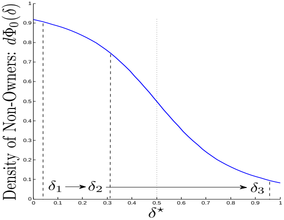

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  quickly at first, more slowly later, with prices rising.

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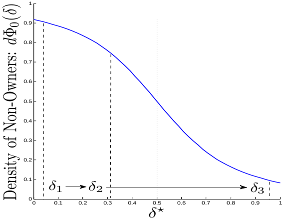

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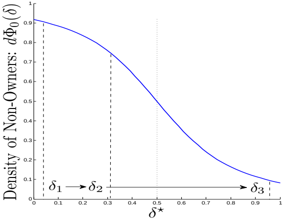

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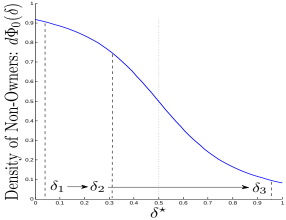

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- These trading patters have important implications...

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- Expected time to trade is:

  $\uparrow$ in δ for owners.

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  (i) Investors with high δ have high reservation values.

  (ii) Investors with high δ trade with *others* with high δ, res value.

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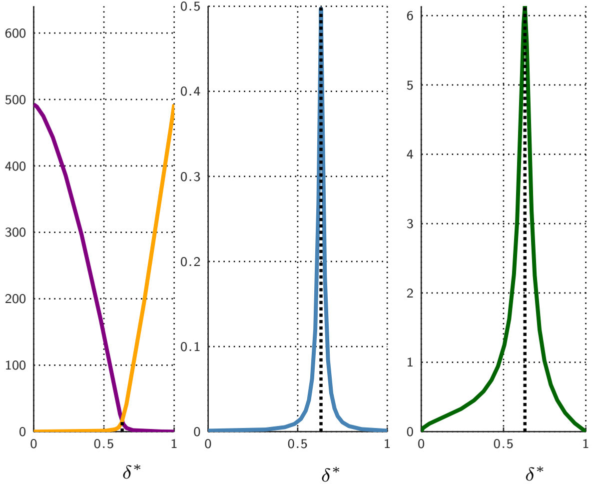
- $1 + 2 \Rightarrow$ expected time before *next* trade

  $\uparrow$ in purchase price for current owners.

  $\downarrow$ in sale price for current non-owners.

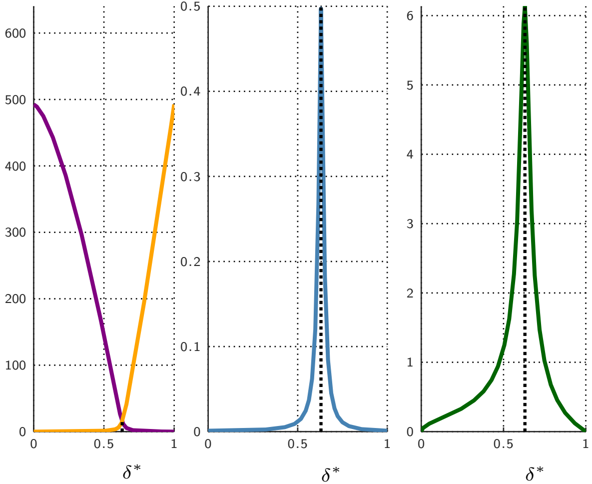
Implications for Aggregate Outcomes



Expected time to trade S-shaped, with inflection near $\delta^\star$.

asset gets into cluster around $\delta^\star$ fast, slow to exit.

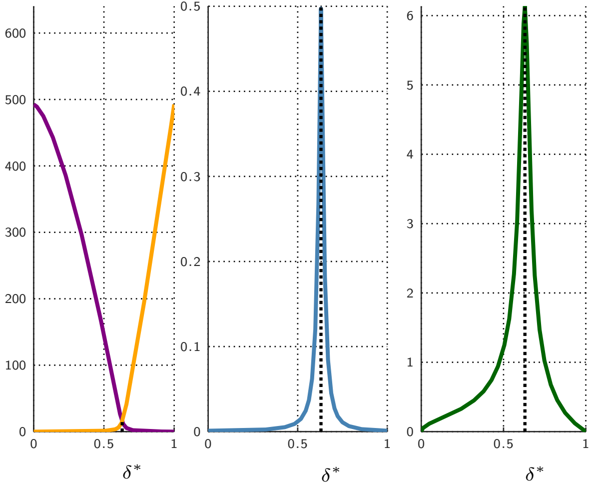
Implications for Aggregate Outcomes



Misallocation concentrated in this cluster, vanishing elsewhere.

$$\text{Misallocation} = \left| d\Phi_1(\delta) - d\Phi_1^\star(\delta) \right| / dF(\delta).$$

Implications for Aggregate Outcomes

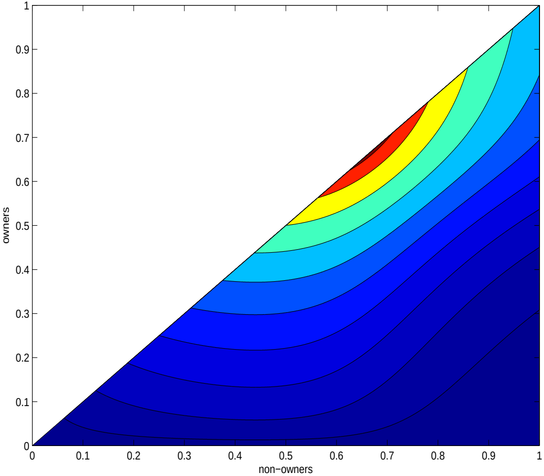


This cluster around $\delta^\star$ accounts for lots of trading volume.

even though *search* is **random**, *patterns of trade* **are not...**

Structure of Trading Network: Core-Periphery

- A core who trades heavily and intermediates.
- A periphery who trades less and mostly in the same direction.



Summary of Aggregate Implications

- Assets re-allocated through chains of inframarginal trades.

  Ashcraft-Duffie (07), Afonso-Lagos (13), Li-Schurhoff (12), Viswanathan-Wang (04)

- Investors with the most to gain tend to trade fastest at worse terms.

  Ashcraft-Duffie (07)

- Desperate investors get worse terms of trade $\Rightarrow$ price dispersion.

  Ashcraft-Duffie (07) find direct evidence in fed funds market

  Price dispersion in OTC markets: Gavazza (11), Jankowitsch et al (11), Feldhutter (12) ...

- These patterns endogenously generate a core-periphery network.

  Atalay-Bech(10), Afonso-Lagos (13), Craig-Peter (14), Boss et al (04)

  Chang et al (08), Li-Schurhoff (12), Soromaki et al (07), Peltonen et al (14)

extensions and applications

(Just a few) Extensions and Applications

- Variations of the model, taken to the data:

  Vayanos-Weill (08) study the on-the-run phenomena

  Gavazza (11) studies the market for commercial aircraft

  Afonso-Lagos (15) study fed funds market, allowing investors to hold non-trivial inventories

  Hugonnier-Lester-Weill (20) introduce OTC inter-dealer market to study muni bonds ▸ more

- More/other dimensions of heterogeneity

  Neklyudov (19), Üslü (19), Farboodi-Jarosch-Shimer (21): heterogeneous meeting rates

  Yang-Zeng (21), Tse-Xu (21): heterogeneous capacity

  Farboodi-Jarosch-Menzio-Wiriadinata (19): heterogeneous bargaining power

- Incorporating private information

  Camargo-Lester (14), Chiu-Koeppl (16), ..., Zou (20), Bethune-Sultanum-Trachter (21)

Conclusion

- A young, growing literature studying markets that were historically opaque
- Data and models leap-frogging each other
- These two lectures: benchmark models covering two market structures
  1. Semi-centralized markets
  2. Pure decentralized markets
- Lots more to be done!

Closed-Form Characterization

- Let $= \sigma(\delta) = \frac{\partial \Delta V(\delta)}{\partial \delta} \approx$ "local surplus":

$$\sigma(\delta) = \frac{1}{r + \gamma + \lambda\left[1 - s - \Phi_{0,v}(\delta)\right]\theta_1 + \lambda \Phi_{1,v}(\delta)\theta_0}$$

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$$r\Delta V(\delta) = \delta - \int_0^{\delta} \sigma(\delta')\left\{\gamma F(\delta') + \lambda\theta_0 \Phi_1(\delta')\right\} d\delta' + \int_{\delta}^{1} \sigma(\delta')\left\{\gamma[1 - F(\delta')] + \lambda\theta_1[1 - s - \Phi_0(\delta')]\right\} d\delta'$$

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- Comparative statics taking $\Phi_{0,t}(\delta)$ and $\Phi_{1,t}(\delta)$ as given
  1. Reservation values go up with θ_1, down with θ_0
  2. Reservation values go up with FOSD shift in $F(\delta)$
  3. Reservation values go up with FOSD shift in $\Phi_{0,t}(\delta)$ and $\Phi_{1,t}(\delta)$
  4. Effect of frictions, captured by λ, is ambiguous.

back

The Muni Bond Market

- An attractive candidate for search-based models
  - Large, important OTC market, remains largely telephone-based
  - Highly fragmented: many different bonds, many dealers

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- An attractive candidate for search-based models
  - Large, important OTC market, remains largely telephone-based
  - Highly fragmented: many different bonds, many dealers
- Transaction-level data (from MSRB) reveals
  - Assets move from customer to customer through "intermediation chains"
  - Some dealers account for lots of volume $\Rightarrow$ "Core-periphery" network
  - Large "markups," grow (steeply) with chain length

Intermediation Chains and Markups

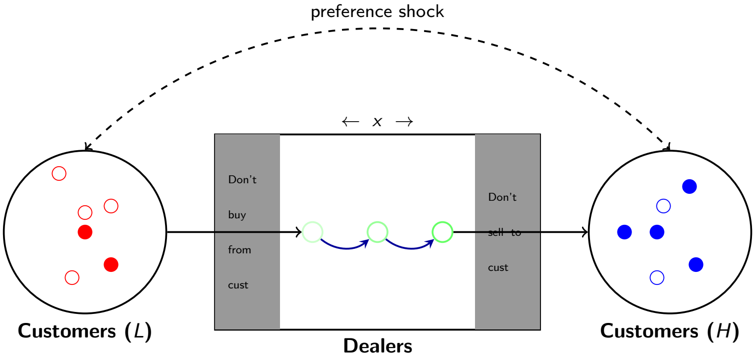
Table 7: How do dealers split markups?

The table reports average markups per dealer on round-trip transactions with varying degree of dealer involvement. Total dealer markups are broken down by the number of dealers (across rows) and by each dealer (across columns) in the sequence of dealers intermediating the round-trip transaction. We restrict the sample to non-splits. Markups are measured in percentage of the first dealer's purchase price from customer. No additional data filters are applied.

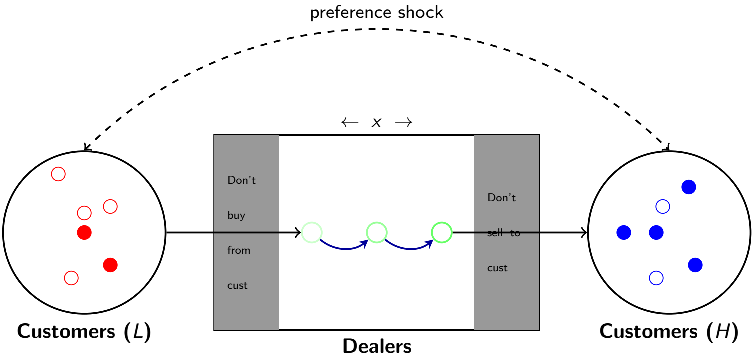
Trade type	Total markup	Markup of each dealer in round-trip chain						
		#1	#2	#3	#4	#5	#6	#7
CDC	1.85	1.85	.	.	.	.	.	.
		(100%)	.	.	.	.	.	.
CDDC	1.94	0.84	1.10	.	.	.	.	.
		(43%)	(57%)	.	.	.	.	.
CDDDC	2.26	0.66	0.52	1.08	.	.	.	.
		(29%)	(23%)	(48%)	.	.	.	.
CDDDDC	2.92	0.64	0.60	0.55	1.13	.	.	.
		(22%)	(21%)	(19%)	(39%)	.	.	.
CDDDDDC	3.26	0.63	0.30	0.82	0.40	1.11	.	.
		(19%)	(9%)	(25%)	(12%)	(34%)	.	.
CDDDDDDC	3.57	0.60	0.27	0.45	0.85	0.27	1.14	.
		(17%)	(8%)	(13%)	(24%)	(8%)	(32%)	.
CDDDDDDDC	3.71	0.62	0.23	0.43	0.53	0.47	0.29	1.15
		(17%)	(6%)	(12%)	(14%)	(13%)	(8%)	(31%)

Figure: Li and Schurhoff (2014)

Extending the Benchmark Model



Extending the Benchmark Model



- Calibration ⇒ back out estimates of:
  - trading frictions between customer-dealer, dealer-dealer
  - dealer bargaining power
  - share of surplus expropriated by dealers
  - welfare cost of trading frictions Back