Opening the Book: Price Information's Impact on Market Efficiency in the Lab

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Motivation

A market contains, aggregates, and disseminates information to and for its actors.

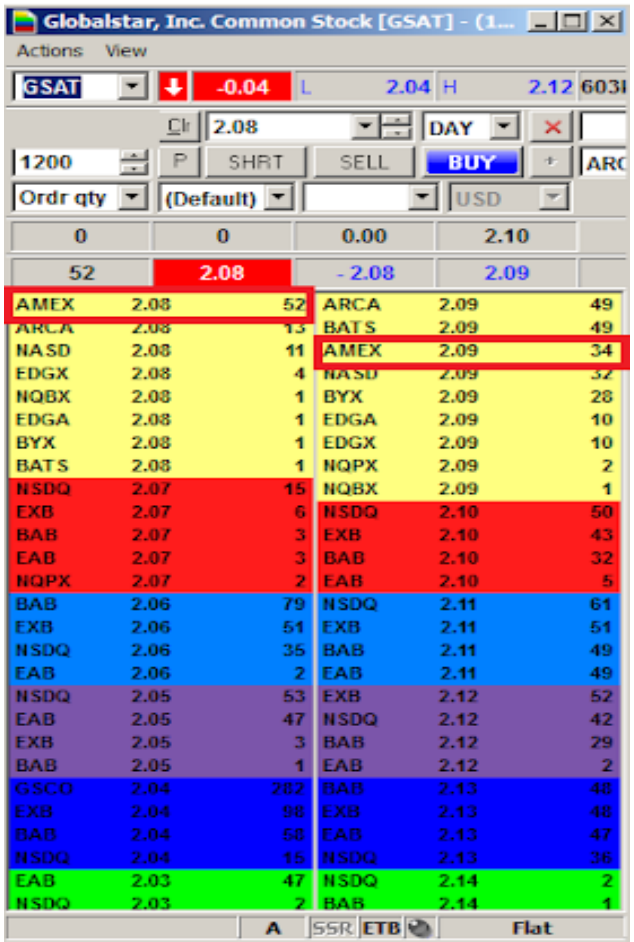
- There exists a minimum and a maximum amount of price information to be held and shown by a market. If we consider information linearly, there is a set of information bundles mapping the gap between the min and max.

A natural question then arises: *Which bundle is best?*
To which a natural response may be: *As much as can be given. Why not just give full information in any market?*

Increasing information is not necessarily costless: behaviorally and/or financially

Markets Revealing Info

NYSE OpenBook



In financial markets:

- In January 2002, NYSE released a subscription-based platform giving traders access to the full limit order book of NYSE despite being away from NYSE itself.
- Boehmer et al. (2005) assesses the new transparancy's impact on market outcomes, finding significant effects on cancel rate (↑) and order size (↓).
- A similar study (Madhavan, Porter, and Weaver (2000)) of TSE's increase in transparency (depth and BBO) shows increases in spread and volatility. NYSE's transparency shows the opposite effect.

Markets Revealing Info

Kerala Fisherman Market

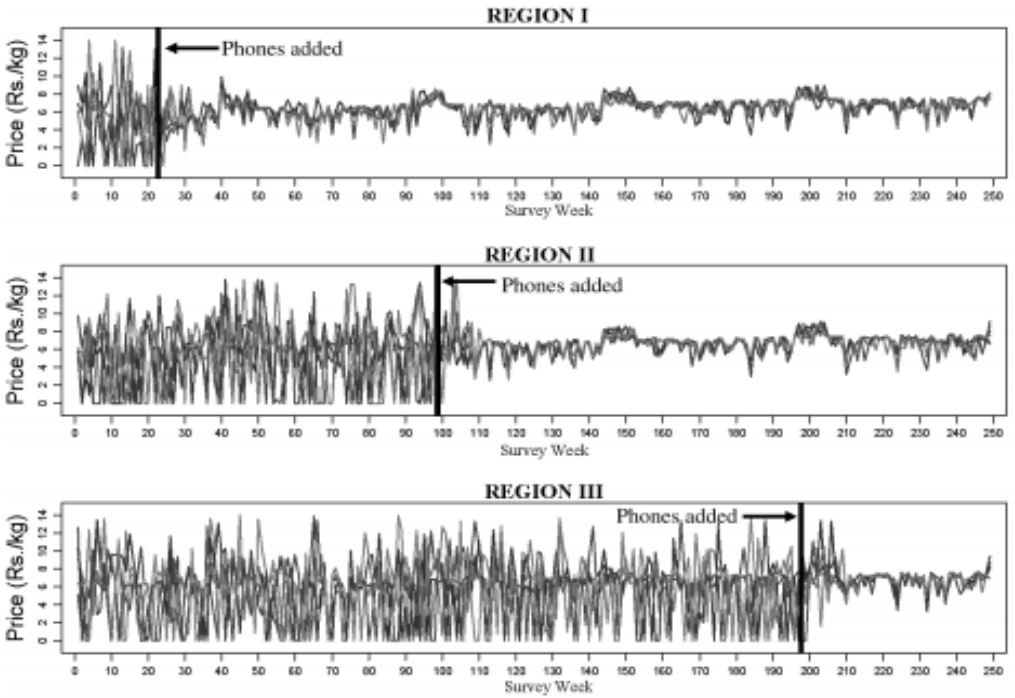


FIGURE IV
Prices and Mobile Phone Service in Kerala

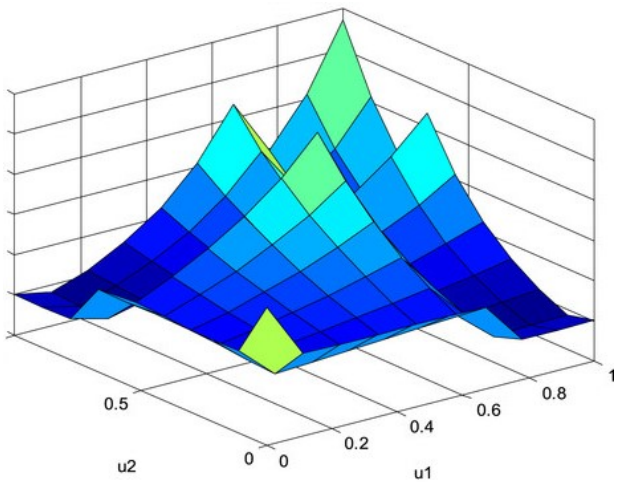
In goods markets:

- Robert Jensen (2007) studied the Kerala fisherman market, situated across a set of lakes. Price volatility was massive due to a lack of transparency in the prices and avail abilities amongst the fisherman and market vendors.
- A field experiment in which phones were distributed and connected to make prices and demand/supply more transparent, massively decreasing the volatility of trade prices.

Motivation

What does this tell us?
Clearly, traders respond to changes in information availability in a market. Of the changes in these empirical case studies, the largest may be the sudden availability of prices.

What this project does?
Test bundles of price information availability to help map market efficiency across the landscape of feasible bundles



Questions

1. Are market outcomes and trader behavior impacted by changes in the availability/accessibility of individual offers and transactions available in a CDA?
2. Which bundles of orderbook and transaction history accessibility are most efficient? From a given bundle, what is the best direction of improvement?
3. How do trader's incorporate this information into their bidding and timing/placement strategies?

Literature

Tests of efficiency/behavior in simple CDA:

- **In Partial eq.:** Chamberlin (1948), Smith (1962), Friedman (1987), Friedman and Cason (1997, 1999, 2000), Ledyard and Arifovic (2007), Asparouhova et al. (2013, 2017)
- **In General eq.:** Smith, Gjerstad, and Ledyard (2000); Anderson et al. (2004), Crockett (2008); Gjerstad (2013); Goeree and Lindsay (2016), Crockett, Friedman, and Oprea (2017, working), Crockett, Friedman, and Oprea (2021)

Tests of book adjustments in the lab/field:
Bloomfield and O'Hara (1999), Madhavan et al. (2000), Boehmer et al. (2005), Kirchsteiger et al. (2005), Ikica et al. (2018)

PE/GE CDA Models for trader behavior:
Wilson (1986), Friedman (1991), Easley and Ledyard (1993), Gode and Sunder (1993), Gjerstad and Dickhaut (1998), Crockett et al. (2008), Anufriev et al.(2013), Crockett and Oprea (2012), Ladley and Pellizari (2014), van de Leur and Anufriev (2018)

Setting: CDA

Traders:

- Two goods, commodity X and numeraire Y; traders are endowed with varying amounts of each at the beginning of each trading period
- May buy or sell X for Y at any point within a period; though predisposed to prefer one side of the market
- Traders have access to an orderbook showing bids and asks, as well as the period's transaction history

Orders:

1. 3-tuples with price, quantity and time fields
2. Price and quantity chosen by trader, time preset to trading-period length
3. Multiple unit orders/trades are allowable
4. Units are divisible
5. Gains (losses) in both goods simultaneously is not allowed
6. A trader can have at most one bid and one ask at a time
7. Orders may be cancelled or replaced at any time

Setting: General Equilibrium

Payoff/Utility: Trader's are incentivized via constant elasticity of substitution (CES) preferences:

$$u_i(x,y) = c_i((a_i x)^{r_i} + (b_i y)^{r_i})^{\frac{1}{r_i}}$$

Given a budget constraint, $px_i + y_i = m$, where p is written as the ratio of prices to allow y to serve as numeraire, each trader solves

$$\max_{(x,y)} u_i(x_i,y_i) = c_i((a_i x_i)^{r_i} + (b_i y_i)^{r_i})^{\frac{1}{r_i}} \quad s.t. \quad px_i + y = m$$

Equilibrium: To solve for the equilibrium p and allocation adjustment, we examine each trader's excess demand

$$Z_i^X(p|(x_{i,o},y_{i,o})) = \frac{a^{\gamma_i}(y_{i,o} + px_{i,o})}{p(a^{\gamma_i} + p^{\gamma_i} b_i^{\gamma_i})} - x_{i,o}$$

where $(x_{i,o}, y_{i,o})$ is the initial bundle of trader i and $\gamma_i = \frac{r_i}{1-r_i}$.
Solving

$$Z^X(p|(x_o,y_o) = \sum_{i=1}^{N} Z_i^X(p|(x_{i,o},y_{i,o})) = 0$$

yields p^*, and plugging this back into each trader's Z_i^X gives their desired change in x.

Belief-Driven (Gjerstad and Dickaut (1998))

I propose a general-equilibrium adjusted version of Gjerstad and Dickhaut (1998), which models CDA trader behavior through market history driven beliefs.

Setting: *I natural* sellers and *J natural* buyers participate in continuous double market, where traders have *CES preferences* over two goods. Traders attempt to maximize *utility* by placing orders under a set of beliefs developed from past market history. Traders are *not* limited to single unit quantities. Traders have some potentially limited memory of the history of the market.

Algorithm:

- At each time increment t_k in T, where t_k is the most recent action in the market, each trader draws an expected wait/elapse time to post an order.
- When a trader's wait time expires, they develop beliefs on how acceptable each price is on their side of the market (that is at least as good as the current best price), with those beliefs being dependent of their remembered history of orders and transactions.
- Using these beliefs, the trader selects their message randomly (uniform) around their expected surplus maximizing price
- If the order crosses another order in the market then a transaction occurs, otherwise order becomes the new best order on that side of the market.

Beliefs, Orders and Timing

Beliefs

- Define $TA(\rho)$ to be the weighted number of asks at price ρ in the remembered history of trader i. Each order o_k in this history takes the form $\{p_k, q_k\}$. *The weight for order* o_k *is* $\sqrt{q_{k,traded}} \cdot \frac{q_{k,traded}}{q_k}$. Define $TB(\rho)$ analogously for bids in the history.
- Rejected asks are defined as $RA(\rho)$ are similarly weighted. Let $RB(d)$ be defined similarly for bids.
- For $a \epsilon P$, the seller's belief about a potential ask is

$$p(a) = \frac{\sum_{\rho \geq a} TA(\rho) + \sum_{\rho \geq a} TB(\rho)}{\sum_{\rho \geq a} TA(\rho) + \sum_{\rho \geq a} TB(\rho) + \sum_{\rho \leq a} RA(\rho)}$$

Order Choice

The entrant attempts to maximize their expected utlity gain

$$S_i^k = \max\{\max_{\rho \in P}(u_i(x_{i,k}, y_{i,k}) - u_i(x_{i,k-1}, y_{i,k-1})) \cdot p(\rho), 0\}$$

- Traders create a piecewise linear function for their $p(a)$ and $q(b)$, choose price between two highest surplus prices from P which yields highest expected surplus.
- Choose quantity by checking utility gains along price vector, using vector of weighted gains as the probability vector for choice of q.

Timing

Traders draw their optimal time of re-entry as both a buyer and a seller after each new market event. These draws are from an exponential distribution with parameter

$$\alpha_{s,i} = S_{s,i}^k \cdot \frac{T}{T - t_k} \quad or \quad \alpha_{b,j} = S_{b,j}^k \cdot \frac{T}{T - t_k}$$

Zero Intelligence

In its original partial equilibrium form (Gode and Sunder, 1993)...

The zero intelligence (constrained) framework has the following market rules:

- Spread reduction rule
- Single unit orders
- One way traders

As well as trader behavior defined by:

- Traders enter randomly
- Traders draw prices under a budget constraint (acts as a no-loss constraint in partial eq. and a utility floor in general eq.)
  - Buyers make a draw from a uniform distribution over [0,redemption value], while sellers make a draw from a uniform distribution over [unit cost, M] where M is some maximum allowable price

ZI in GE

Changes made to bring ZI to a general equilibrium setting (influenced by Gode et al. (2004) and Crockett et al. (2008)):

Rules:

- Units are divisible; orders may have multiple units or partial units
- Two-way traders
- Two goods, x and y, are traded for one another
- Retrade is allowed

Behavior:

- Traders enter randomly; choice of side is made with a weighted coin flip
- Order (p,q) is chosen randomly from a uniform distribution over a lattice on the side of entry
  - Buyers make a uniform draw from 0 to the highest price that still yields at least as much utility as the current bundle, and sellers make a uniform draw from their lowest non-utility-losing price to M
- Traders have utility functions over x and y, as opposed to redemption value or cost schedules

Design: Treatments & Sessions

Transaction History

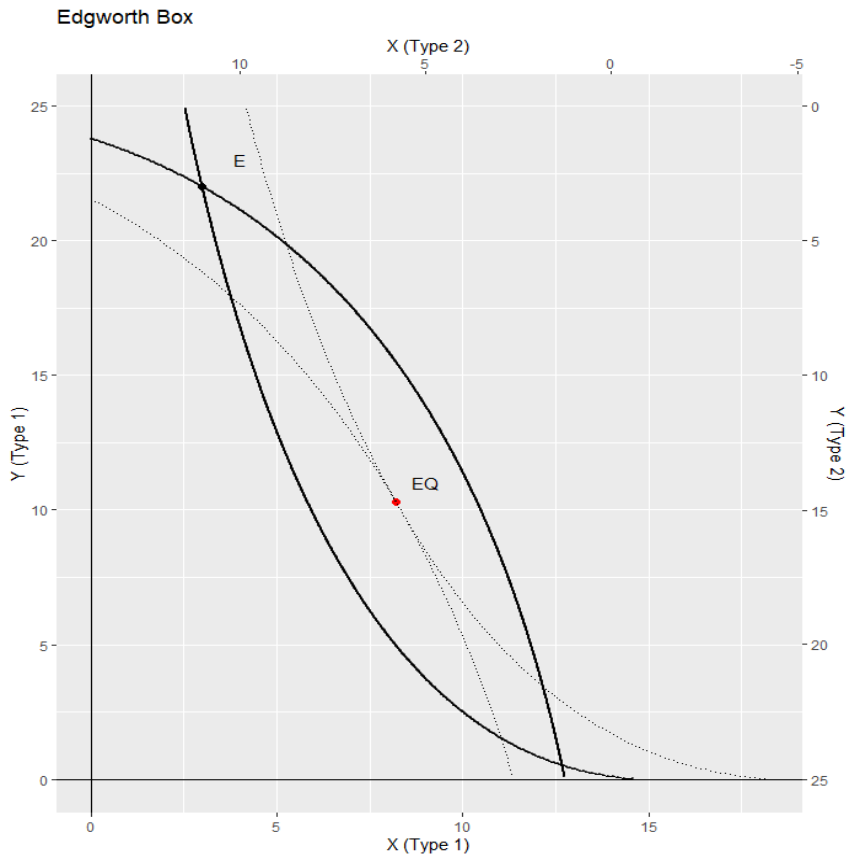
- Full: all trades within a round are visible to everyone for the entirety of the round
- Ticker Tape (TT): all own trades within the round, as well as the most recent trade in the market

Order Book

- Full: All bids and asks in the market are visible to all traders
- BBO: Traders can see their own active orders as well as the current best bid and ask in the market

Setup:

- 8 players per session, 4 each are given natural buyer and seller parameters
- Natural buyer parameters: (c=0.113,a=0.825,b=0.175,r=0.5)
- Natural seller parameters: (c=0.099,a=0.6875,b=0.3125,r=0.5)
- 12 three-minute trading periods with 30 second interim screens
- Type, parameter set and treatment were constant across all rounds within session (between subject design)



Design: Procedure

Procedure:

- Subjects were recruited through ORSEE (Greiner, 2015)
- Subjects were given the instructions an hour before the session to glance over
- The sessions were held virtually; subjects were required to stay in a zoom call with cameras on for the duration of the session
- The first ten minutes of the session is devoted to instruction-reading, followed by a five minute instructional video on the UI, and then a ten minute slide-show on frequently asked questions.
- Subjects played two practice rounds, each 3.5 minutes; questions were welcome between and during all of the instructional phases
- Payments include a \$4 show-up fee, and average at \$20 per subject (for an 80 minute session including 42 minutes of paid rounds).

User Interface

Time Remaining: 0:40

Bids

0.42 @ $3.45
0.49 @ $1.79
1.43 @ $1.08

Price: 1.08
Qty: 1.43
BID

Trades

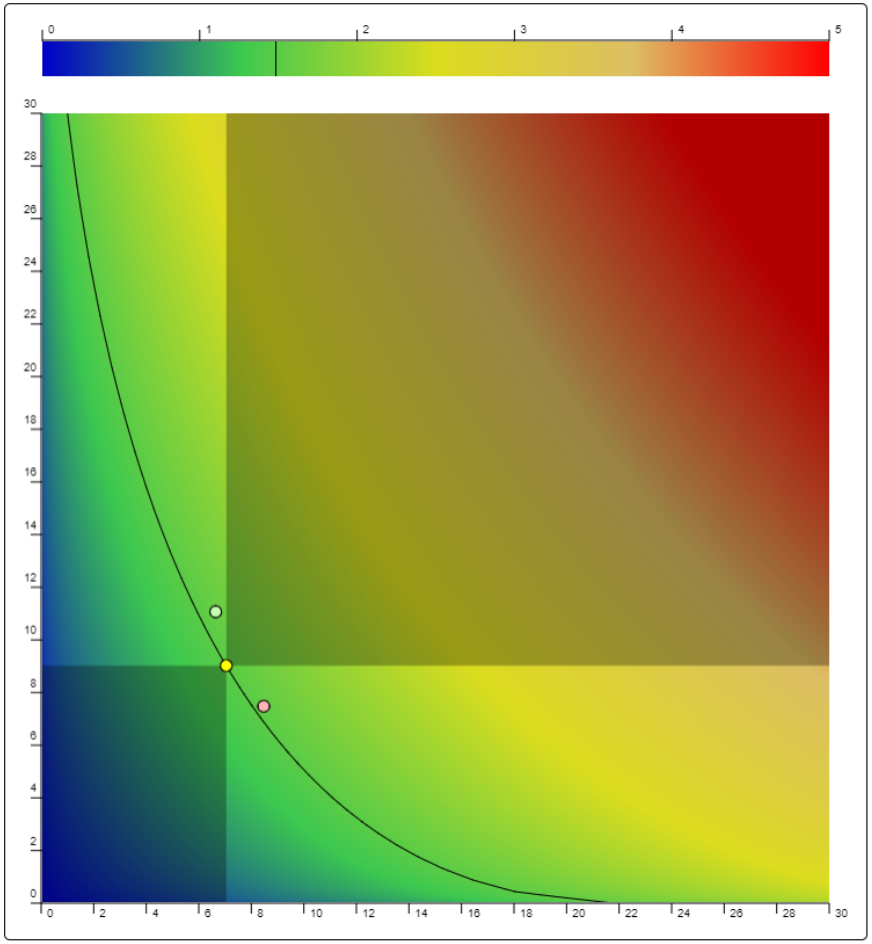
0.69 @ $4.07
0.79 @ $3.45
0.93 @ $2.76
1.96 @ $1.79

Asks

0.4 @ $5.12

Price:
Qty:
ASK

Your Allocation	
X:	7.01
Y:	8.9924
Utility:	1.48



Hypotheses

(1) Convergence is expected to be stronger in full accessibility sessions compared to intermediate sessions in both domains

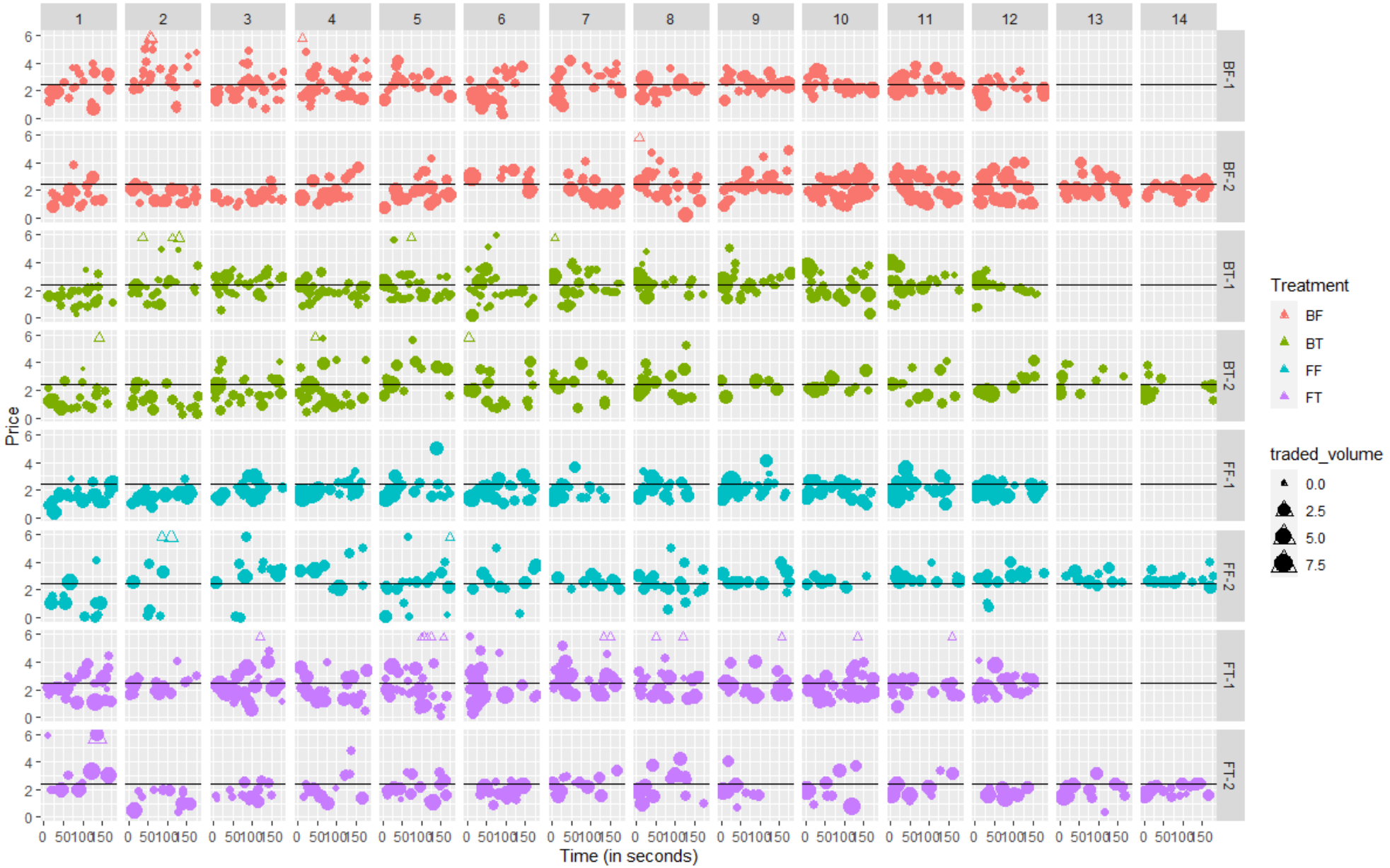
- Related to adjustments in TA or RA (as traders may be missing trades or cancels)

(2) Order size will be smaller in higher accessibility sessions, and order frequency will increase (as risk is made more obvious to traders)

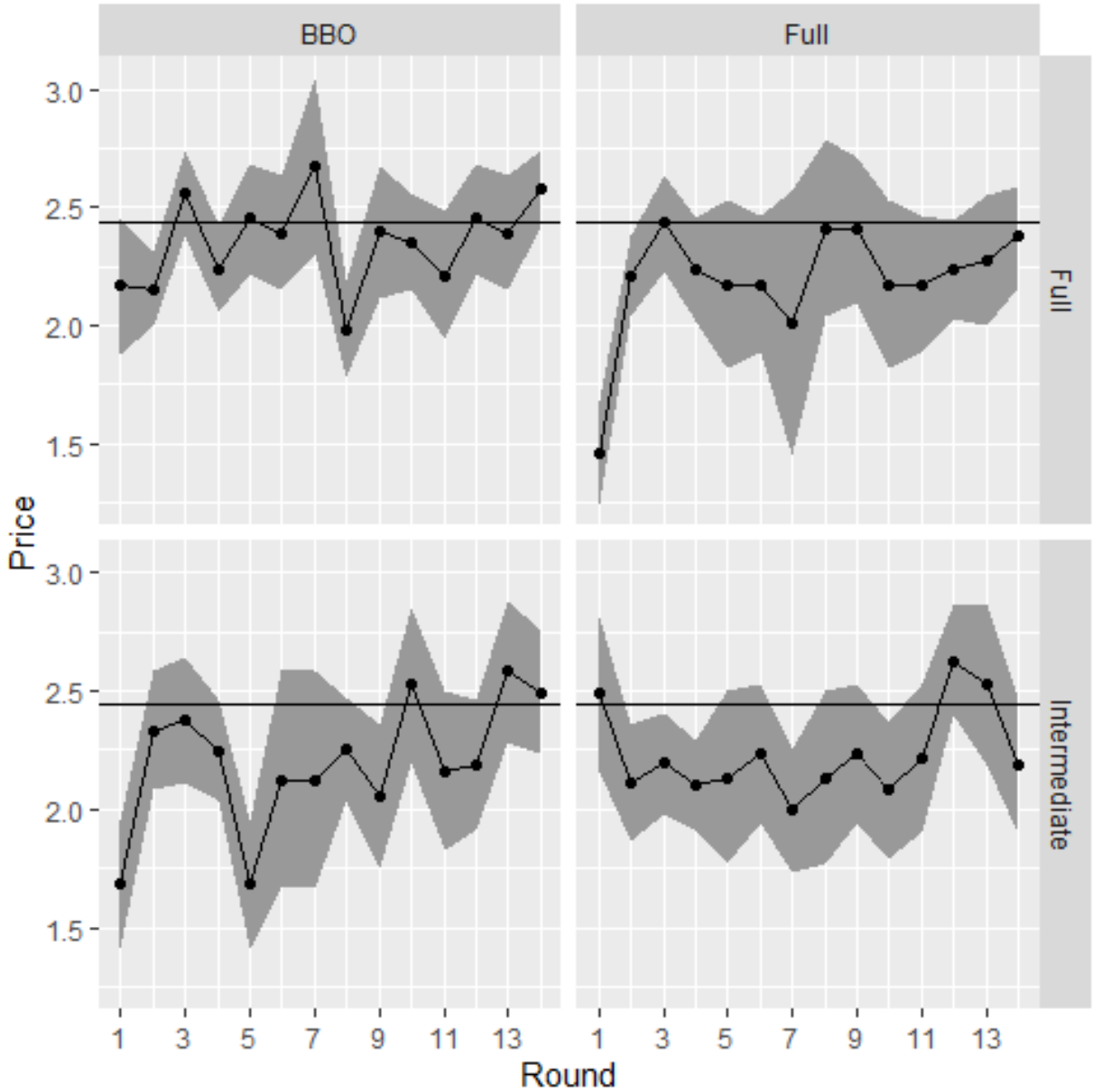
- Related to adjustments in α

(3) The pricing strategies of players will be increasingly reliant on transaction prices in less accessible sessions, leading to slower convergence and higher price variation when decreasing transaction history visibility.

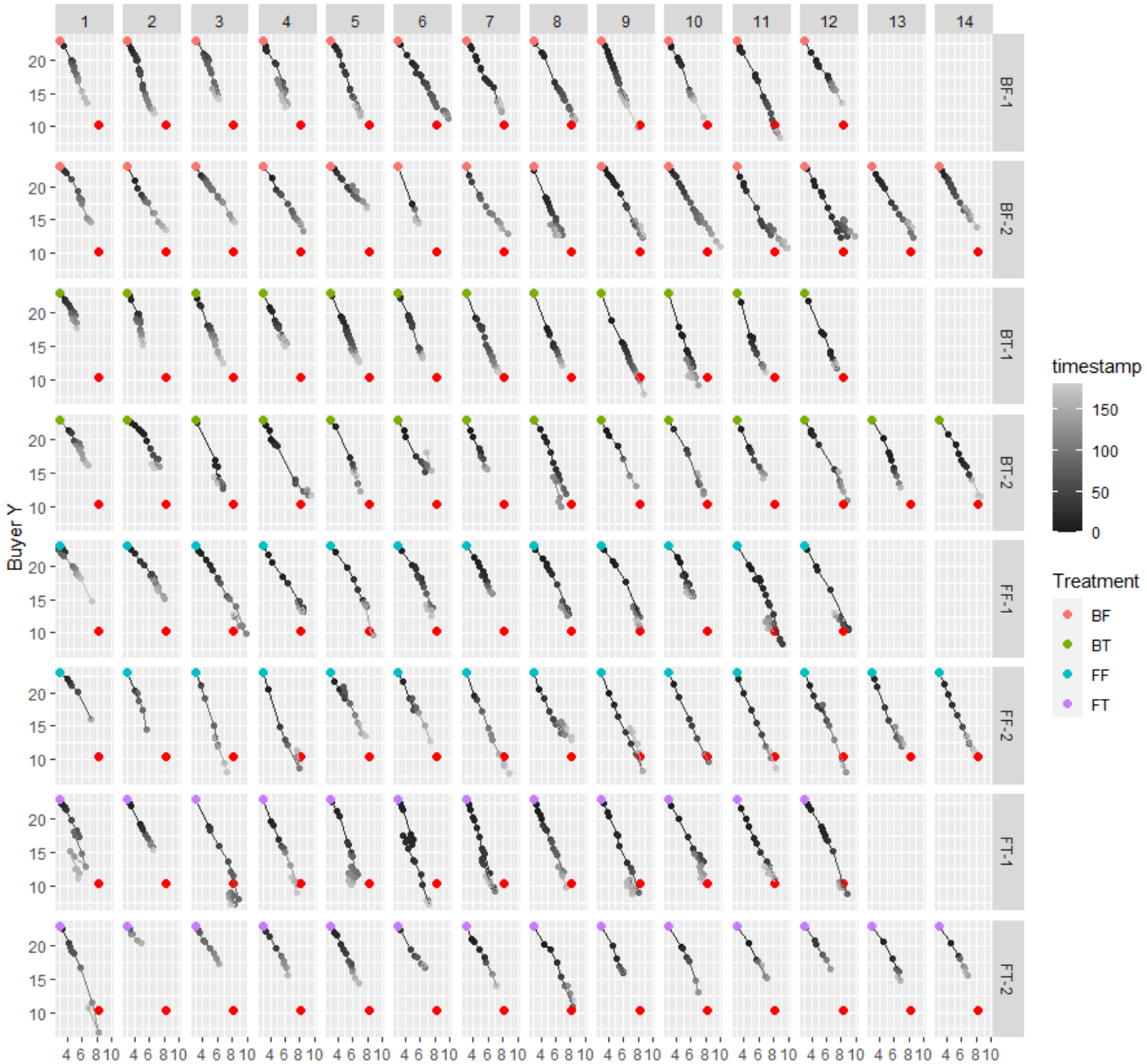
Prices: Individual Trades



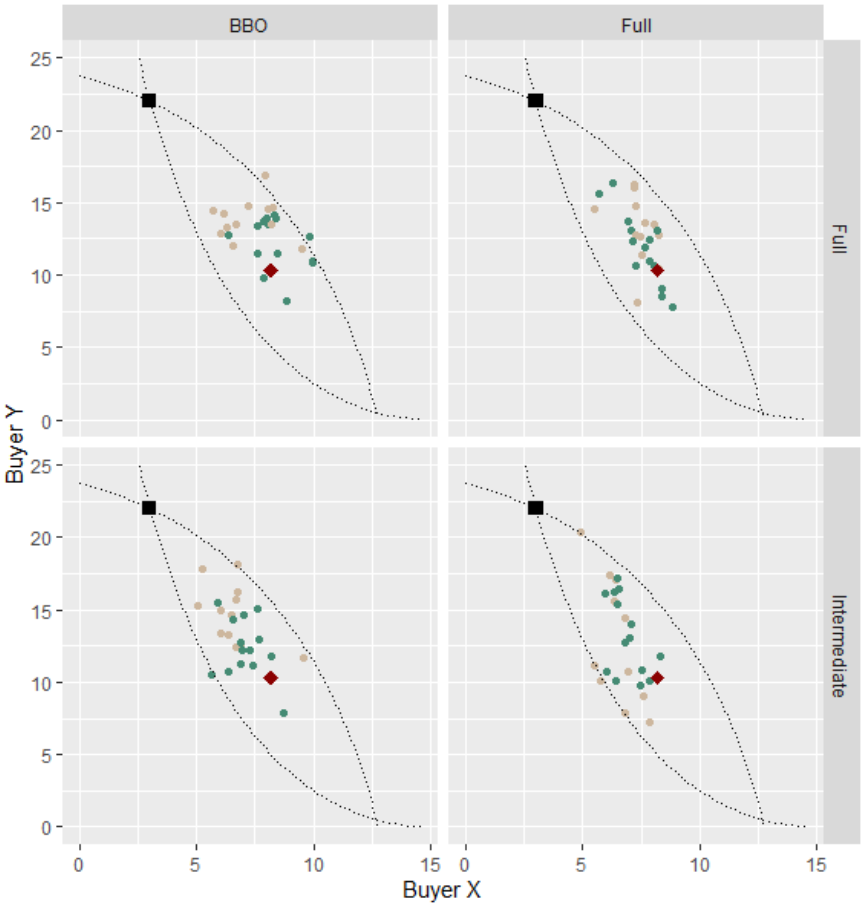
Prices: Round Average

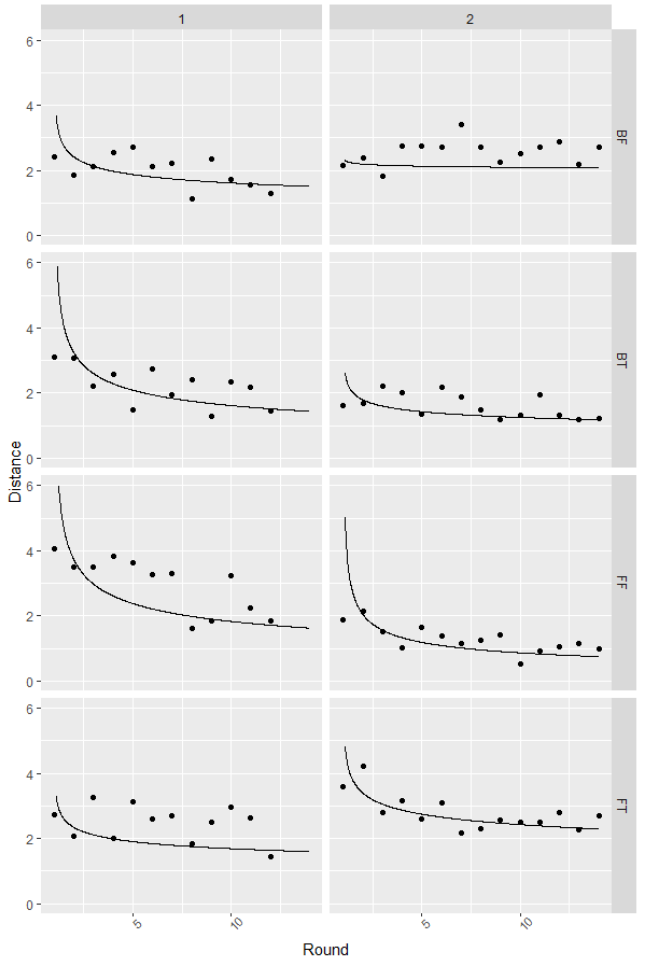


Allocations: Edgeworth Boxes

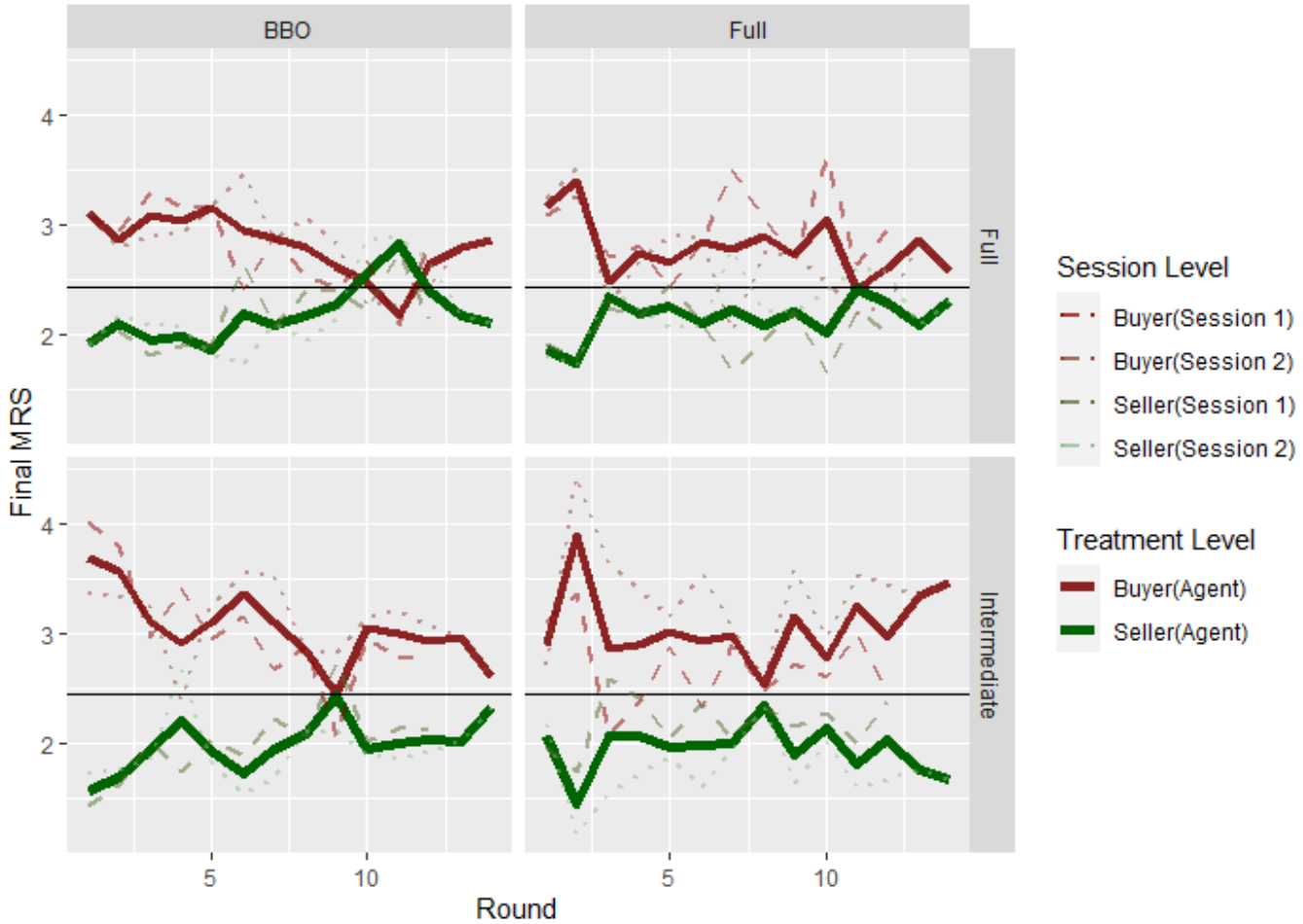


Allocations: End-of-Round





Marginal Rates of Substitution



Descriptive: Outcomes

		BBO		Full	
		All Rounds	Second Half	All Rounds	Second Half
Full	Price	2.29(0.39)	2.35(0.24)	2.35(0.51)	2.44(0.33)
	$\lvert Price - CE \rvert$	0.71(0.56)	0.69(0.55)	0.72(0.95)	0.71(0.72)
	SD	0.77(0.28)	0.71(0.25)	0.79(0.56)	0.56(0.20)
	RMSE	0.86(0.34)	0.75(0.12)	0.91(0.13)	0.64(0.05)
	# Orders	139.12(29.60)	141.71(21.32)	108.27(14.41)	113.21(12.87)
	Order Size	2.10(0.50)	2.20(0.38)	2.11(0.37)	1.94(0.34)
	# Trades	35.33(6.68)	35.17(6.11)	23.58(3.90)	22.83(4.17)
	Trade Size	1.28(0.41)	1.39(0.41)	1.78(0.23)	1.79(0.22)
	Seller MRS	2.19(0.33)	2.35(0.32)	2.15(0.29)	2.21(0.33)
	Buyer MRS	2.82(0.34)	2.63(0.29)	2.81(0.40)	2.74(0.45)
TT	Price	2.29(0.37)	2.39(0.19)	2.19(0.34)	2.19(0.28)
	$\lvert Price - CE \rvert$	0.87(0.96)	0.92(1.00)	1.04(2.40)	1.12(2.72)
	SD	0.97(0.37)	0.80(0.16)	0.82(0.30)	0.74(0.25)
	RMSE	1.02(0.36)	0.79(0.16)	0.91(0.25)	0.82(0.19)
	# Orders	88.77(20.57)	88.07(19.34)	107.35(47.54)	122.43(53.44)
	Order Size	1.62(0.43)	1.81(0.40)	2.25(0.36)	2.24(0.29)
	# Trades	22.42(10.96)	17.36(8.33)	19.35(8.35)	18.29(9.22)
	Trade Size	1.23(0.48)	1.46(0.44)	1.92(0.53)	2.13(0.53)
	Seller MRS	1.98(0.30)	2.09(0.25)	1.97(0.34)	1.99(0.28)
	Buyer MRS	3.07(6.68)	2.88(0.33)	3.04(0.53)	3.01(0.40)

Table: Descriptive Statistics at the round-level. Estimates are shown for all rounds and the rounds in the second half of sessions. The four quadrants relate to data from the four treatments, with the vertical panels denoting levels in the orderbook factor and horizontal panels representing levels of the transaction history factor. Seller MRS and Buyer MRS are using round-end estimates, while the rest of the outcomes are in round averages or averaged round totals.

Descriptive: Efficiencies

		BBO		Full	
		All Rounds	Second Half	All Rounds	Second Half
Full	Alloc Eff	0.77(0.12)	0.79(0.14)	0.74(0.24)	0.83(0.16)
	Distance Eff	0.56(0.10)	0.57(0.12)	0.60(0.21)	0.69(0.16)
TT	Alloc Eff	0.80(0.09)	0.84(0.07)	0.71(0.15)	0.73(0.10)
	Distance Eff	0.63(0.11)	0.68(0.09)	0.49(0.11)	0.53(0.08)
ZI	Alloc Eff	0.83	0.83	0.83	0.83
	Distance Eff	0.65	0.65	0.65	0.65

- Allocative Efficiency is a GE take on the standard version used in PE experiments; utility gains are used instead of surplus
- Distance Efficiency is calculated using the metric used in Gjerstad (2013), essentially average euclidean distance in 2-space
- 100 ZI simulations were run; 10 "minutes" per period; no spread reduction rule enforced

Treatment Effects

	Dependent variable:						
	$\lvert Price - CE \rvert$	Price	Variance	Orders	Trades	RMSE	Alloc Eff
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
FullOB	0.053	−0.101	−0.310	18.577**	−3.077	−0.109	−0.090**
	(0.065)	(0.112)	(0.265)	(9.173)	(2.401)	(0.086)	(0.042)
FullT	0.046	0.005	−0.402	50.346***	7.423***	−0.160*	−0.032
	(0.065)	(0.112)	(0.265)	(9.173)	(2.401)	(0.086)	(0.042)
Round	−0.029***	0.018*	−0.089***	1.794**	−0.341	−0.051***	0.014***
	(0.006)	(0.010)	(0.025)	(0.852)	(0.223)	(0.008)	(0.004)
FullOB:FullT	0.043	0.160	0.577	−49.423***	−9.538***	0.165	0.058
	(0.091)	(0.158)	(0.375)	(12.973)	(3.395)	(0.121)	(0.059)
Constant	0.491***	2.161***	1.688***	76.140***	24.822***	1.380***	0.701***
	(0.062)	(0.107)	(0.255)	(8.833)	(2.312)	(0.083)	(0.040)
Observations	104	104	104	104	104	104	103
R^2	0.221	0.051	0.137	0.264	0.256	0.314	0.159
Adjusted R^2	0.190	0.012	0.102	0.234	0.226	0.286	0.124

Note: *p<0.1; **p<0.05; ***p<0.01

Conclusions

Intent: Study impact of accessibility of transaction history and orderbook depth on market efficiency and trader behavior in a simple two good pure exchange using CDA

Findings:

- Human levels of efficiency in both "profit" and "allocation" space are near ZI estimates, though markets with asymmetry in accessibility between orderbook and transaction history see reductions.
- Order of improvement shows differing impacts on price discovery behavior.
- Volatility seems to be negatively correlated with accessibility.
- Treatment effect signs are unsurprising, though noisily estimated.

Next: Finish running sessions, as well as a batch of experienced trader sessions.