

Dealer Participation

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- ▶ Relative to OTC markets, trading volume on exchanges is large – so how should we think about **exchange-traded liquidity**?
 - ▶ **Market depth** and the number of **active dealers** matters more than you perhaps would expect!

Times series of market depth

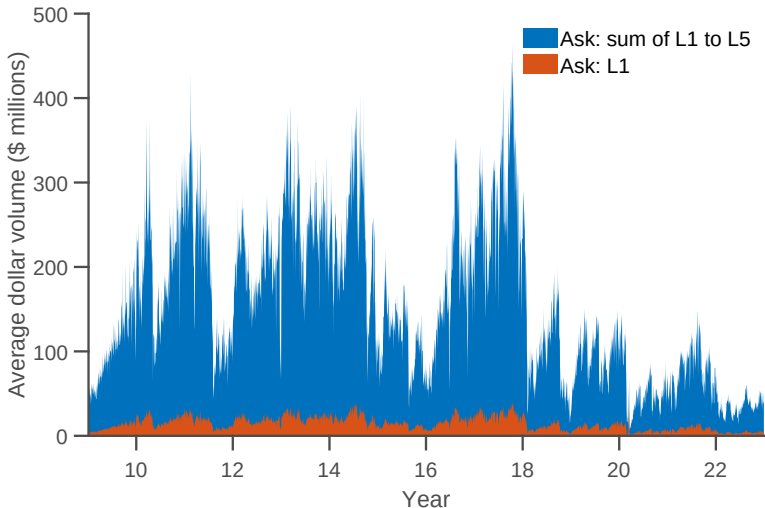


Figure: The figure plots the time series of market depth measured as dollar volume available at level 1 and at level 1 to 5 of the limit order book for the S&P 500 E-mini futures contract. The daily dollar volume is measured as averages of 5-minute samples throughout the trading day.

$$\text{Depth} \equiv \text{DVol} = \# \text{Contracts} \cdot \text{Price}$$

Time series of dealer number and depth per dealer

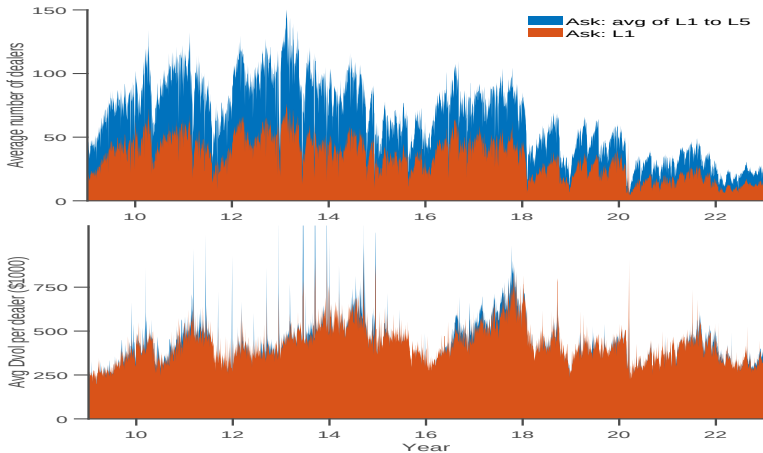


Figure: Top figure plots the time series for the number of dealers at level 1 of the order book and for the average number of dealers at level 1 to 5. Bottom figure plots the time series of the average daily liquidity offered per dealer.

$$\text{DVol} = \frac{\# \text{Contracts}}{\# \text{Dealers}} \cdot \# \text{Dealers} \cdot \text{Price}$$

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Dealers' choice of providing liquidity

- ▶ **Empirics:** document the liquidity (depth and dealer number) in the E-mini contract – has dropped by $\sim 80\%$
- ▶ **Theory:** develop a simple model where the dealer number, N , is endogenized by exposing dealers to participation costs and a balance sheet constraint

Model predictions

► Dealers and returns:

- Contemporaneous absolute returns and the dealer number are negatively correlated
- Expected future absolute returns are negatively correlated with the dealer number → our model captures liquidity risk/price reversals

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► Dealers and volatility:

- There is a negative relationship between volatility and the dealer number. Mechanism: dealer balance sheet capacity drives both
- Increasing the cost of dealer participation lowers the dealer number but does not affect volatility

Model – Setting

- ▶ Three dates, $t = 0, 1$, and 2
- ▶ Two assets:
 - ▶ a riskless asset in elastic supply
 - ▶ a risky asset: $S = 0$; payoff $D \sim N(\bar{D}, \sigma^2)$ at $t = 2$; price p at $t = 1$
- ▶ Agents:
 - ▶ risk averse **end users**: fixed mass n ; receive endowment/liquidity shock $z(D - \bar{D})$ at $t = 2$ with $z \sim N(0, \sigma_z^2)$ learned at $t = 1$
 - ▶ **dealers**: risk neutral, subject to the **margin constraint**

$$\kappa |x_1^d| \leq W^d \Leftrightarrow |x_1^d| \leq w_\kappa^d \equiv \frac{W^d}{\kappa}, \quad (1)$$

with W^d starting wealth, x_1^d the position in the risky asset, $\kappa \geq 0$ capital requirement associated with trading the risky asset, and w_κ^d the **balance sheet capacity**

- ▶ need to pay a **cost $c > 0$** to enter the market, e.g. cost of monitoring the market or information acquisition
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Model – Equilibrium

- ▶ Plugging the optimal demand for dealers and end users into the market clearing condition yields

$$p = \begin{cases} \bar{D} - \alpha\sigma^2 \left(z + \frac{N}{n} w_{\kappa}^d \right) & \text{if } z < -\frac{N}{n} w_{\kappa}^d \\ \bar{D} & \text{if } |z| \leq \frac{N}{n} w_{\kappa}^d \\ \bar{D} - \alpha\sigma^2 \left(z - \frac{N}{n} w_{\kappa}^d \right) & \text{if } z > \frac{N}{n} w_{\kappa}^d. \end{cases} \quad (2)$$

- ▶ Dealer **participation decision**: enter market as long as ex ante expected wealth is higher

$$\mathcal{U}_0^d = W^d - c + 2\alpha\sigma^2\sigma_z w_{\kappa}^d \Psi\left(-\frac{1}{\sigma_z} \frac{N}{n} w_{\kappa}^d\right) \geq W^d, \quad (3)$$

with $\Psi(x)$ strictly increasing convex function.

- ▶ $d\mathcal{U}_0^d/dw_{\kappa}^d > 0$ as long as $0 < w_{\kappa}^d < \bar{w}$

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Model – Dealer numbers

Proposition 1

(Balance sheet capacity and dealer number) If $c \geq \bar{c}$, we have $N = 0$. If $0 < c < \bar{c}$, dealers enter the market as long as the equilibrium mass reaches

$$N = -n\sigma_z \frac{1}{w_\kappa^d} \Psi^{-1} \left(\frac{c}{2\alpha\sigma^2\sigma_z} \frac{1}{w_\kappa^d} \right) > 0. \quad (4)$$

If $0 < w_\kappa^d < \bar{w}$, N increases in dealers' wealth and decreasing in margin, $\partial N / \partial w_\kappa^d > 0$.

- ▶ We can now derive testable implications on the relationships between
 - ▶ balance sheet capacity (exogenous),
 - ▶ the equilibrium number of liquidity providers (endogenous),
 - ▶ and return moments (endogenous)

Data

- ▶ Tick data (millions of observations per day)
- ▶ We focus on the S&P 500 E-mini futures contract – the most traded equity contract in the world
- ▶ We are working on adding more asset classes!
- ▶ Quotes are firm not indicative

Returns regressed on the dealer number

- **Model prediction:** absolute returns – both contemporaneous and future returns – are decreasing in the dealer number

	R_t^{CTC}	R_t^{CTC}	R_{t+1}^{CTC}	R_{t+1}^{CTC}	R_{t+1}^{CTC}	R_{t+1}^{CTO}	R_{t+1}^{CTO}	R_{t+1}^{CTO}
SV_t	1.9 (0.10)	4.1 (0.25)						
$N_t \times SV_t$		-0.028 (0.0027)						
R_t^{CTC}			-0.090 (0.043)	-0.19 (0.10)	0.056 (0.054)	-0.054 (0.026)	-0.12 (0.64)	0.061 (0.040)
$N_t \times R_t^{\text{CTC}}$				0.0023 (0.0015)			0.0015 (0.00097)	
R_t^{CTC}/N_t					-4.1 (2.0)			-3.2 (1.41)
$R^2(\%)$	38	42	0.78	1.1	2.1	0.74	1.1	2.9

Table: This table shows the coefficients for regressions of the types

$$R_t^{\text{period}} = \alpha + \beta_1 f(N_t, SV_t) + \epsilon_t \text{ and } R_{t+1}^{\text{period}} = \alpha + \beta_2 f(N_t, R_t^{\text{CTC}}) + \epsilon_{t+1},$$

where R_t^{period} is the daily (or overnight) return in basis points, N_t is the number of dealers, and SV_t is the signed trading volume measured in contracts/1000.

CTC, OTC and CTO returns

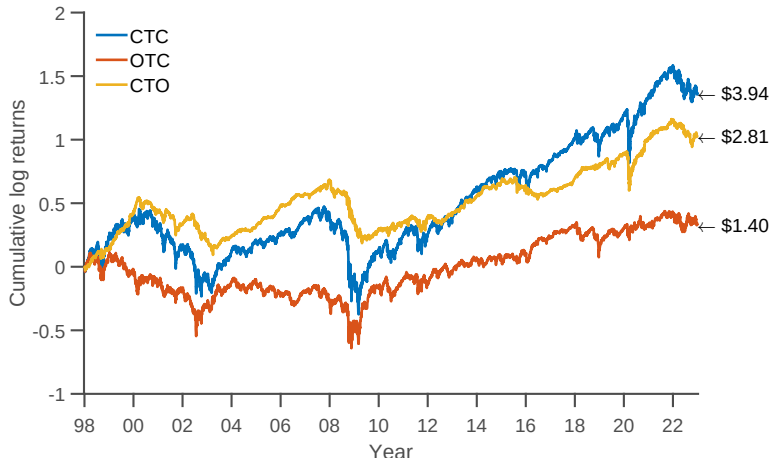
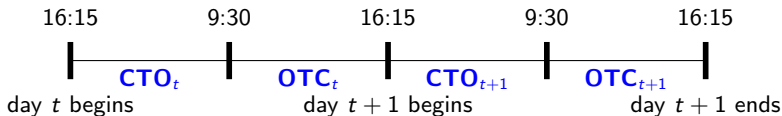


Figure: The figure plots the time series of close-to-close, open-to-close and close-to-open log returns for the S&P 500 futures contract. Opening prices are sampled at 9:30 ET and closing prices are sampled at 16:15 ET.



Time series of dealer number and volatility

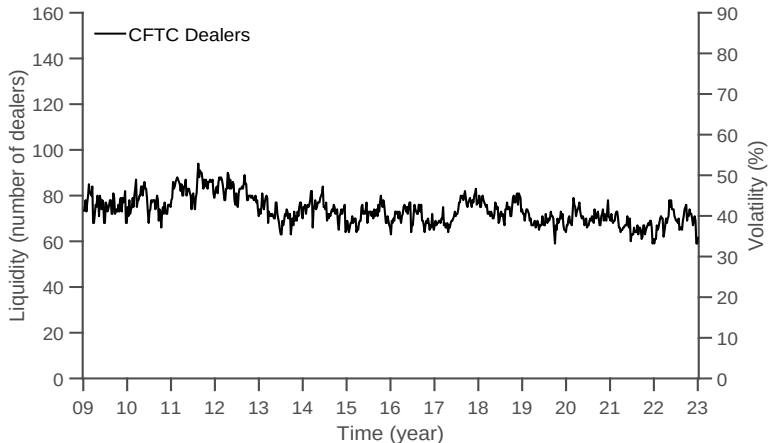


Figure: The figure plots the time series of 1) the average daily number of active dealers (i.e. dealers that are posting limit orders) across level 1 to 5 of the LOB for the S&P 500 E-mini futures contract, 2) the number of registered CFTC dealers (computed as long plus short positions), and 3) the (annualized) daily realized volatility computed from 5-minute log returns.

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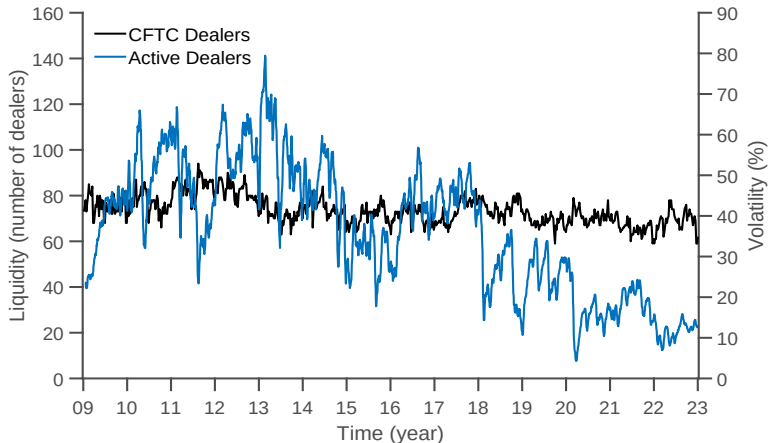


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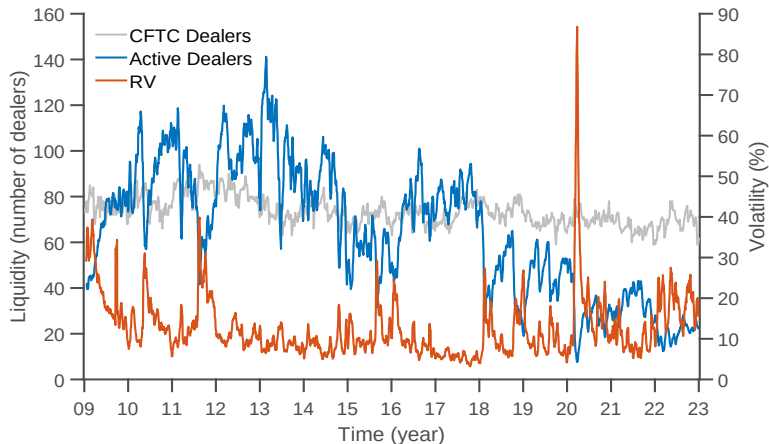


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► **Model prediction:** the dealer number and volatility have a negative relationship

regression

Time series of dealer number and volatility

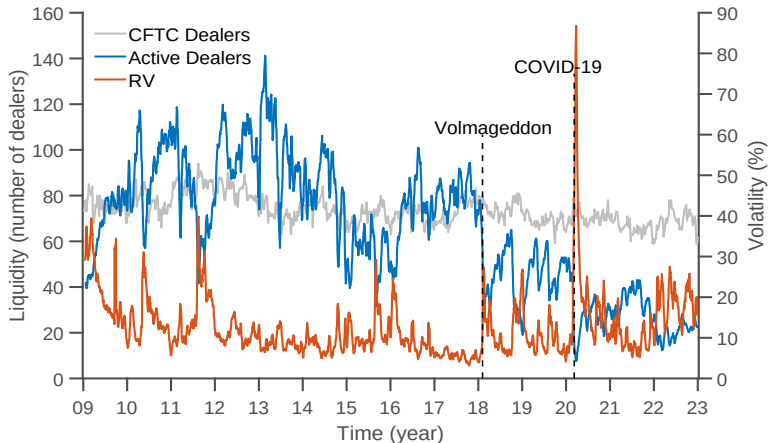


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Scatter plot of volatility and number of dealers

- ▶ Given the volatility level, the dealer number today (2022) is lower compared to previously

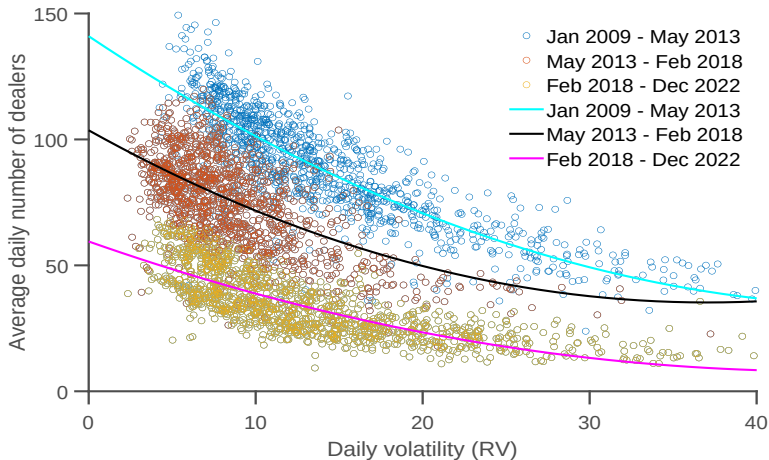


Figure: The figure plots the average daily number of dealers (computed as the average across level 1 to 5 of the LOB) against volatility (computed as the annualized daily realized volatility from 5-minute log returns) for the S&P 500 E-mini futures contract. The lines plot a quadratic regression of dealer number on the volatility.

Additional Results

- ▶ Do dealer constraints explain the dealer number as predicted by the model?
 - ▶ Yes ! regression: N on dealer constraints
- ▶ Is the dealer number explained by the traditional liquidity measures?
 - ▶ No ! regression: N on liq measures
- ▶ Does the dealer number provide additional information to market fundamentals like volatility and returns?
 - ▶ Yes ! regression: vola on liq measures
- ▶ correlation matrix

Conclusion

This paper

- ▶ argues that the number of **active dealers** is important when discussing liquidity in exchange-traded markets
- ▶ provides a model which endogenizes the dealer number by making dealers subject to participation costs and a balance sheet constraint
- ▶ documents that there is significantly fewer dealers and lower market depth in the S&P 500 E-mini futures market ($\sim 80\%$ lower)

Related literature

- ▶ Our analysis of participation decisions and equilibrium prices is closely related to those in Grossman and Miller (1988), Huang and Wang (2009, 2010), and the analysis on participation costs of Vayanos and Wang (2012, 2013).

References

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- HUANG, J., AND J. WANG (2009): "Liquidity and Market Crashes," *Review of Financial Studies*, 22, 2607–2643.
- (2010): "Market Liquidity, Asset Prices and Welfare," *Journal of Financial Economics*, 95, 107–127.
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- (2013): "Market Liquidity: Theory and Empirical Evidence," in *Handbook of the Economics of Finance*, eds.: George Constantinides, Milton Harris, and Rene Stulz, pp. 778–878.

Appendix: depth

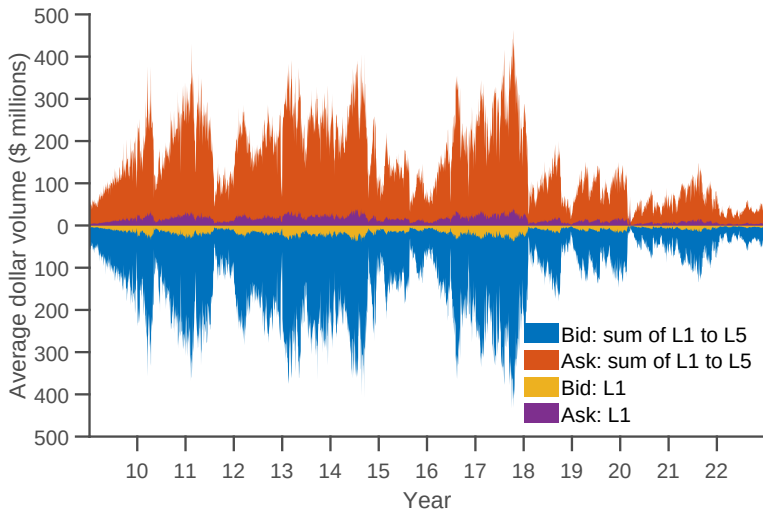


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Appendix: dealers and depth per dealer

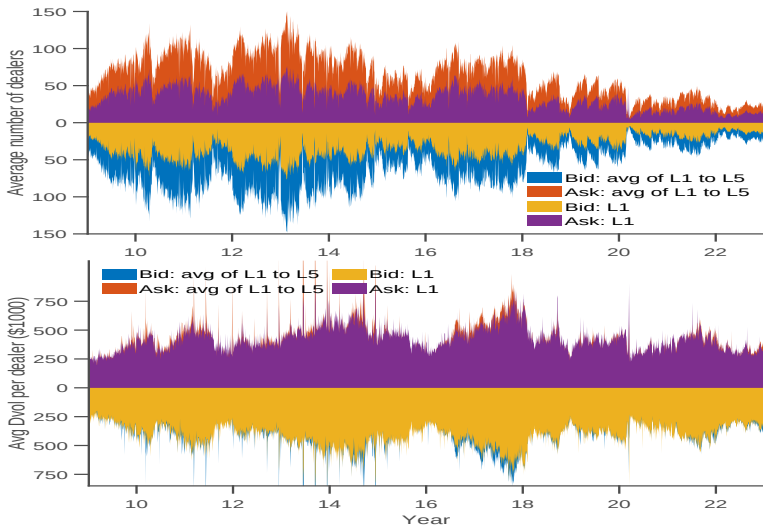


Figure: Top figure plots the time series for the number of dealers at level 1 of the order book and for the average number of dealers at level 1 to 5. Bottom figure plots the time series of the average daily liquidity offered per dealer.

Appendix: additional results on liquidity – Intraday depth

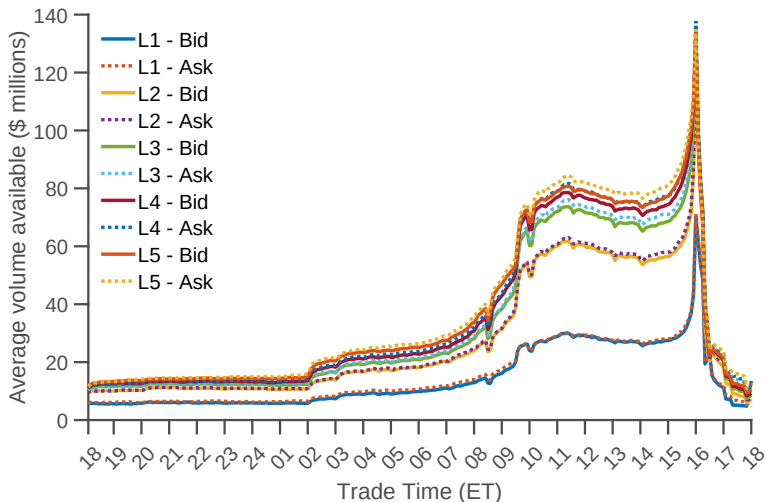


Figure: The figure plots the intraday average market depth measured as dollar volume available for level 1 to 5 of the order book for the S&P 500 E-mini futures contract. The dollar volume is measured at a 5 minute frequency throughout the trading day.

Appendix: additional results on liquidity – Intraday dealer number

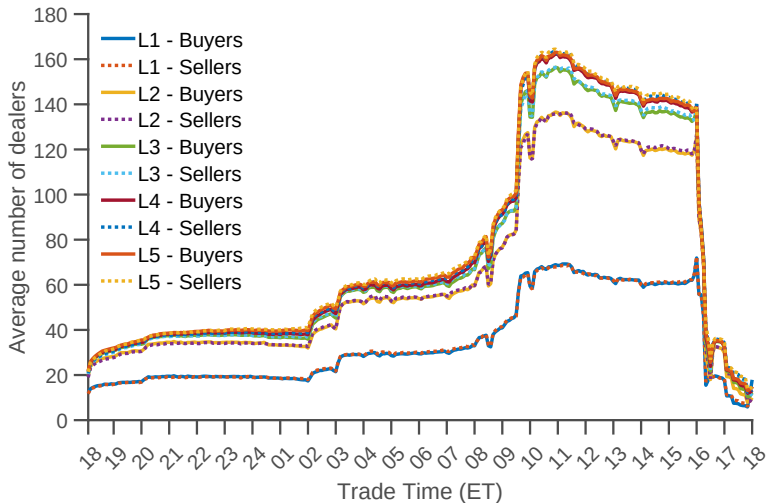


Figure: The figure plots the intraday average number of dealers for level 1 to 5 of the order book. The dealer number is measured at a 5 minute frequency throughout the trading day.

Appendix: traditional liquidity measures – bid/ask spread

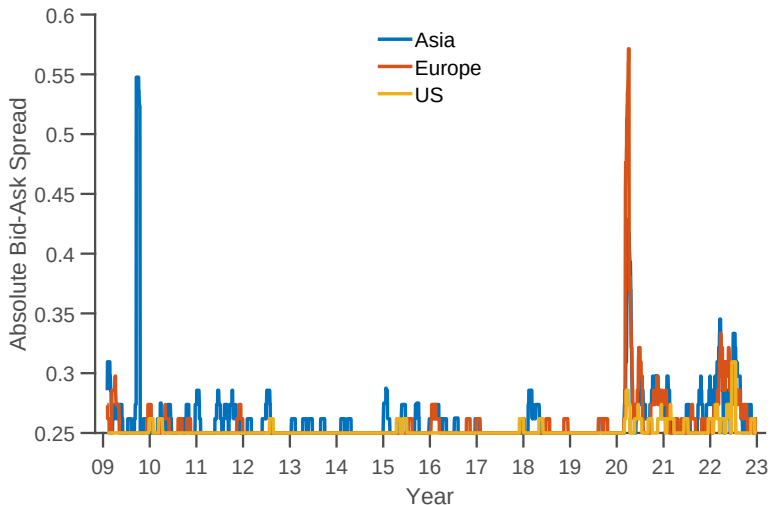


Figure: The figure plots the time series of the bid–ask spread for the S&P 500 E-mini futures contract. The spread is measured in index point and the minimum tick size is 0.25 index points.

Appendix: traditional liquidity measures – Kyle's lambda

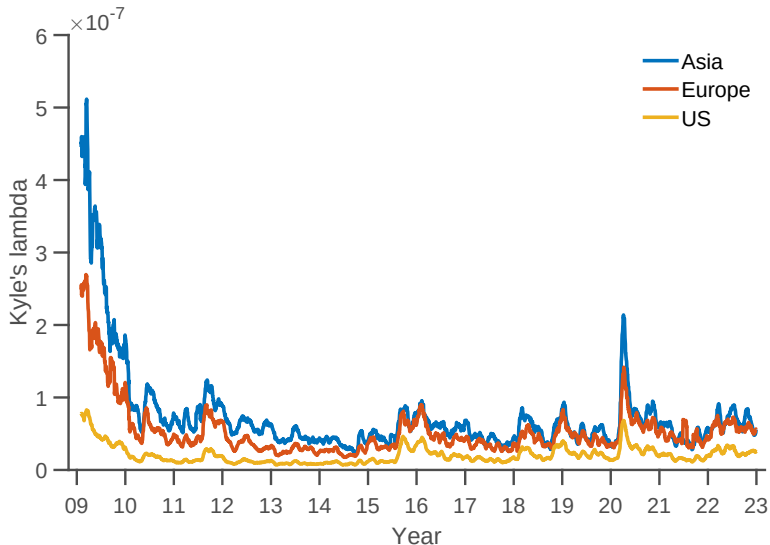


Figure: The figure plots the time series of Kyle's lambda for the S&P 500 E-mini futures contract.

Appendix: traditional liquidity measures – Amihud illiquidity measure

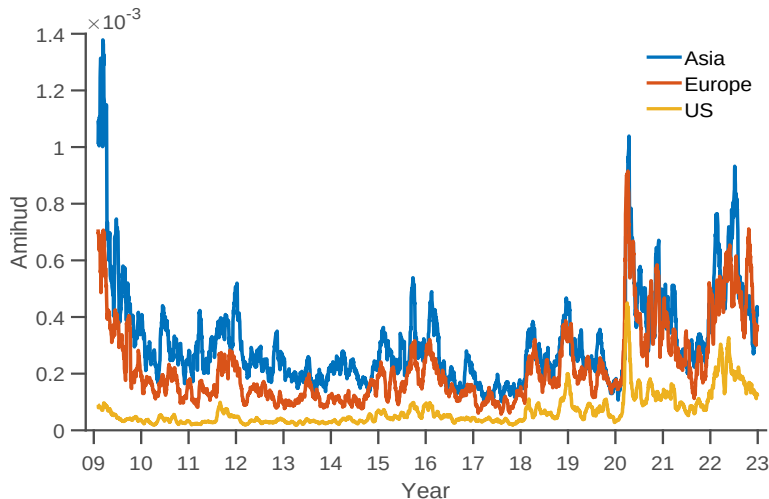


Figure: The figure plots the time series of Amihud's illiquidity measure for the S&P 500 E-mini futures contract. Amihud's illiquidity measure is defined as $1/N \sum_{i=1}^N |r_i| / \$V_i$, where N is the number of observations, r_i is the return and $\$V$ is the dollar trading volume.

Appendix: the dealer number regressed on volatility and margins

- **Model prediction:** liquidity (the dealer number) and volatility have a negative relationship

	(i)	(ii)	(iii)	(iv)	(v)
$\Delta\sigma_t$	-0.53 (0.09)		-1.19 (0.14)		-1.16 (0.14)
$\Delta\sigma_t^2$		-0.31 (0.10)	0.93 (0.16)		0.93 (0.16)
$\Delta\kappa_t$				-14.37 (5.05)	-6.66 (2.72)
α	-0.01 (0.03)	-0.00 (0.04)	-0.01 (0.03)	-0.02 (0.04)	-0.02 (0.03)
$R^2(\%)$	10.29	2.44	15.84	2.11	16.27

Table: This table considers the contemporaneous relationship between the dealer number, volatility and margins for the S&P 500 E-mini futures contract. The dependent variable is the change in dealer number on day t which is measured as the change in the average daily number of dealers, N_t , at level 1 to 5 of the LOB. The explanatory variables are changes to volatility (and/or variance) on day t which is measured using daily realized variance computed from 5-minute log returns, and the change in the margin percent, $\Delta\kappa_t$, which is the USD margin requirement in percent of the E-mini contract value.

Appendix: scatter plot of volatility and number of dealers - by year

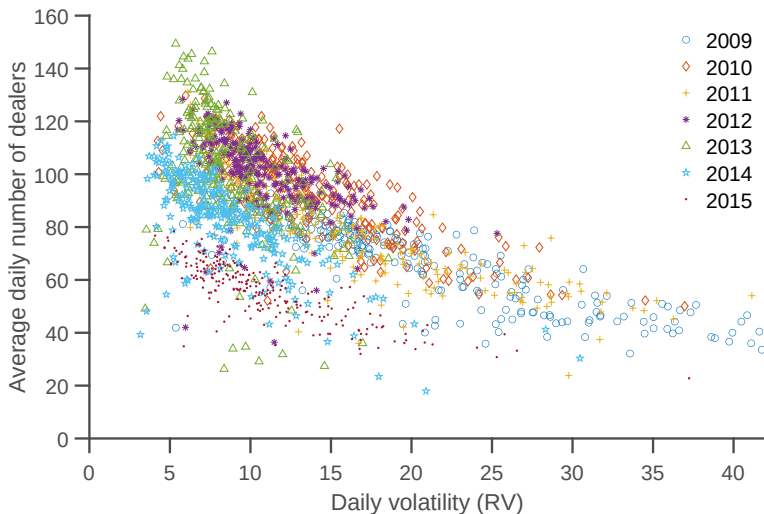


Figure: For the years 2009 to 2015, the figure plots the average daily number of dealers (computed as the average across level 1 to 5 of the LOB) against volatility (computed as the annualized daily realized volatility from 5-minute log returns) for the S&P 500 E-mini futures contract.

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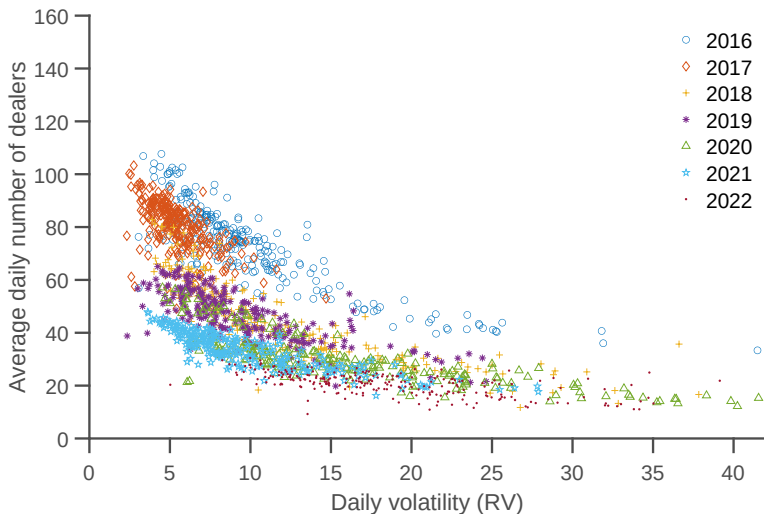


Figure: For the years 2016 to 2022, the figure plots the average daily number of dealers (computed as the average across level 1 to 5 of the LOB) against volatility (computed as the annualized daily realized volatility from 5-minute log returns) for the S&P 500 E-mini futures contract.

Appendix: E-mini margins (USD)

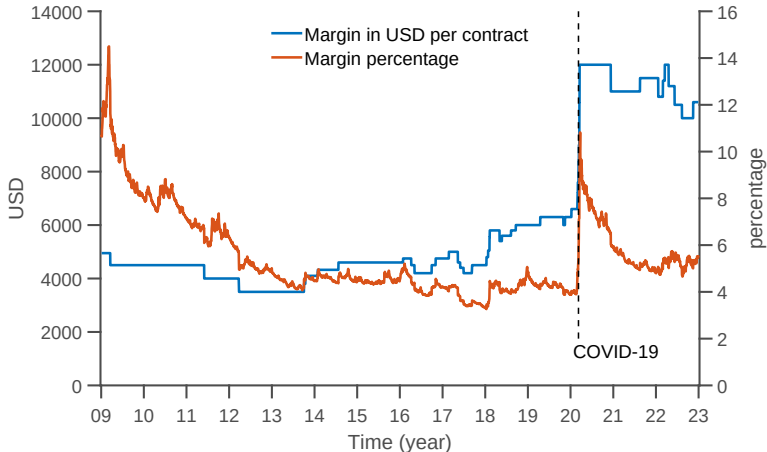


Figure: The figure plots the time series of the margin in USD and in percentages of the contract value for the S&P 500 E-mini futures contract.

Appendix: the dealer number regressed on dealer constraints

	(i)	(ii)	(iii)	(iv)	(v)
$\Delta\kappa_t$	-0.16 (0.028)				-0.088 (0.021)
ΔCR_t		0.20 (0.021)			0.12 (0.022)
ΔSV_t			-0.086 (0.021)		-0.053 (0.022)
ΔCDS_t				-0.18 (0.021)	-0.073 (0.023)
$R^2(\%)$	2.59	3.85	0.74	3.28	5.45

Table: This table shows regression coefficients for the daily number of dealers, N_t regressed on daily dealer constraints, D_t^i , for the S&P 500 E-mini futures contract. The regressions are in differences.

$$\Delta N_t = \alpha + \beta \Delta D_t^i + \epsilon_t.$$

We proxy for the dealer constraints with (i) the E-mini margin percentage, κ_t , (ii) the capital ratio of dealers, CR_t , (iii) absolute signed trading volume relative to the dealer number, SV_t , and (iv) the average credit default swap rate of G14 dealers, CDS_t .

Appendix: volatility regressed on dealer constraints

	(i)	(ii)	(iii)	(iv)	(v)
$\Delta\kappa_t$	0.19 (0.032)				0.12 (0.031)
ΔCR_t		-0.19 (0.025)			-0.11 (0.024)
ΔSV_t			0.21 (0.057)		0.18 (0.057)
ΔCDS_t				0.17 (0.026)	0.037 (0.030)
$R^2(\%)$	3.43	3.78	4.52	2.76	8.86

Table: This table shows regression coefficients for volatility, σ_t , regressed on daily dealer constraints, D_t^i , for the S&P 500 E-mini futures contract. The regressions are in differences.

$$\Delta\sigma_t = \alpha + \beta\Delta D_t^i + \epsilon_t.$$

We proxy for the dealer constraints with (i) the E-mini margin percentage, κ_t , (ii) the capital ratio of dealers, CR_t , (iii) absolute signed trading volume relative to the dealer number, SV_t , and (iv) the average credit default swap rate of G14 dealers, CDS_t .

Appendix: the dealer number-to-volatility ratio regressed on dealer constraints

	(i)	(ii)	(iii)	(iv)
margin %	-0.30 (0.11)			-0.24 (0.15)
capital ratio		0.21 (0.13)		-0.01 (0.18)
signed volume			-0.35 (0.06)	-0.29 (0.05)
$R^2(\%)$	9.00	4.45	11.94	17.09

Table: This table considers the daily dealer number-to-volatility ratio regressed on daily dealer constraints for the S&P 500 E-mini futures contract. Dealer constraints are measured using the margin percentage, capital ratio, and signed trading volume. All variables are z-scored.

Appendix: the dealer number regressed on other liquidity measures

- Is the dealer number explained by the traditional liquidity measures?

	(i)	(ii)	(iii)	(iv)	(v)
depth	0.87 (0.09)				0.87 (0.08)
Kyle's λ		-0.16 (0.36)			0.22 (0.08)
Amihud illiq			-0.19 (0.13)		-0.04 (0.03)
BA spread				-0.32 (0.20)	-0.19 (0.04)
$R^2(\%)$	76.49	2.70	3.54	10.39	79.72

Table: This table considers the daily number of dealers regressed on traditional liquidity measures for the S&P 500 E-mini futures contract. Liquidity is measured using (i) the market depth (measured as the available dollar volume), (ii) Kyle's λ , (iii) Amihud's (2002) illiquidity measure, and (iv) the bid-ask spread. All variables are z-scored.

Appendix: volatility regressed on other liquidity measures

- Does the dealer number provide additional information to market fundamentals like volatility?

	(i)	(ii)	(iii)	(iv)	(v)	(vi)
N_t	-0.41 (0.09)					-0.26 (0.08)
Kyle's λ		0.64 (0.36)			0.44 (0.31)	0.46 (0.28)
Amihud illiq			0.41 (0.12)		-0.03 (0.07)	-0.04 (0.06)
BA spread				0.61 (0.10)	0.35 (0.14)	0.27 (0.14)
$R^2(\%)$	16.74	41.20	17.13	37.28	48.51	54.38

Table: This table considers daily volatility regressed on daily liquidity for the S&P 500 E-mini futures contract. Liquidity is measured using (i) the number of dealers N , (ii) Kyle's λ , (iii) Amihud's (2002) illiquidity measure, and (iv) the bid-ask spread. All variables are z-scored.

Appendix: open interest

- ▶ Robustness check: has the demand for liquidity decreased?

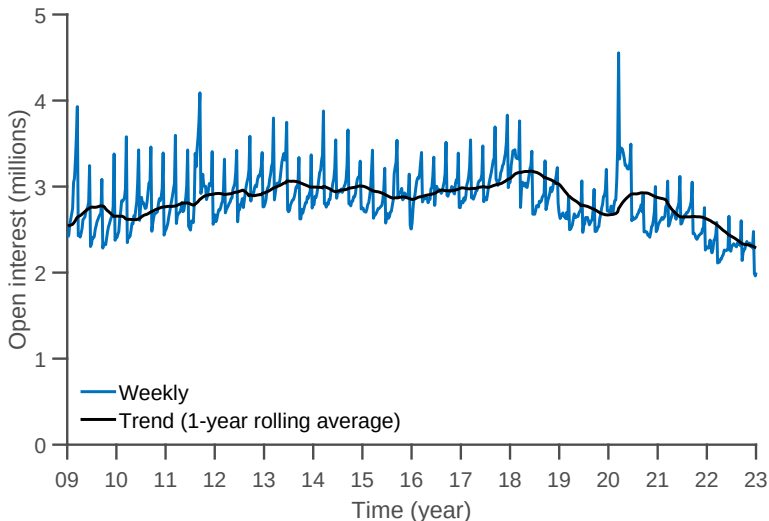


Figure: The figure plots the time series of the open interest for the S&P 500 E-mini futures contract. Open interest is the total number of futures contracts held by market participants at the end of the trading day.

Appendix: volatility and margins

- Volatility affects future margins:

	(i)	(ii)
$\Delta\sigma_{t-1}$	0.00 (4.07)	0.00 (5.53)
$\Delta\sigma_{t-1}^2$		-0.00 (-3.08)
α	-0.00 (-0.75)	-0.00 (-0.75)
$R^2(\%)$	0.98	1.51

Table: This table shows that changes in volatility on day $t - 1$ predict changes in margins on day t for the S&P 500 E-mini futures contract. The dependent variable is the change in margin percentage on day t measured as the USD margin requirement in percent of the E-mini contract value, and the predictor variable is the change in volatility from day $t - 2$ to $t - 1$ measured using daily realized volatility computed from 5-minute log returns. The sample period is January 2009 to December 2022. The regression specifications are

$$(i) \Delta\kappa_t = \alpha + \beta\Delta\sigma_{t-1} + \epsilon_t,$$

$$(ii) \Delta\kappa_t = \alpha + \beta_1\Delta\sigma_{t-1} + \beta_2\Delta\sigma_{t-1}^2 + \epsilon_t,$$

Appendix: correlation matrix

	2	3	4	5	6	7	8
1: ΔN	62	-14	-7	-12	-30	-19	21
2: Δ Depth		-10	-6	-10	-22	-18	11
3: Δ Kyle's λ			66	76	69	-5	-1
4: Δ Amihud illq				50	49	-3	-6
5: Δ B/A spread					60	-1	-1
6: $\Delta\sigma$						41	-21
7: Δ trading vol							-27
8: Return							

Table: This table shows the pairwise correlations (in %) using daily changes of variables of interest (except for the return which is computed as the daily change of log prices).

back

Appendix: model – end users

- ▶ End users have exogenously given mass n and exponential utility with the with ARA α , i.e., their certainty-equivalent wealth is

$$-\frac{1}{\alpha} \log E [\exp \{-\alpha W_2^e\}] \quad (5)$$

- ▶ Terminal wealth consists of starting wealth W^e , capital gains from trading the risky asset, and an endowment $z (D - \bar{D})$ of the consumption good at date 2 that covaries with the payoff of the risky asset

$$W_2^e = W^e + x_1^e (D - p) + z (D - \bar{D}) , \quad (6)$$

where x_1^e is the position in the risky asset and $z \sim N(0, \sigma_z^2)$ and is independent of D

- ▶ The endowment is received at date 2, but agents learn z at date 1
- ▶ When $z > 0$, the endowment exposes agents to the risk that D will be low, and they hedge against that risk by selling the risky asset

Appendix: model – dealers

- ▶ Dealers are risk neutral and do not receive any endowment shocks
- ▶ Dealers maximize their expected date-2 wealth

$$\mathbb{E} \left[W_2^d \right], \quad (7)$$

subject to the budget constraint

$$W_2^d = W^d + x_1^d (D - p), \quad (8)$$

and the margin constraint

$$\kappa \left| x_1^d \right| \leq W^d, \quad (9)$$

where W^d is the starting wealth, x_1^d is the position in the risky asset, and $\kappa \geq 0$ is the capital requirement associated with trading the risky asset.

- ▶ The margin constraint (9) states that to trade a size of $|x_1^d|$, dealers must commit $\kappa |x_1^d|$ of their scarce capital. Equivalently, the *balance sheet capacity* must satisfy

$$w_\kappa^d \equiv \frac{W^d}{\kappa} \geq x_1^d \quad (10)$$

Appendix: model – equilibrium

- ▶ We first compute the equilibrium price and quantities at date 1 given the mass of market participants, and then we study the entry decision of dealers at date 0
- ▶ At date 1, end-users choose holding x_1^e of the risky asset to maximize the expectation of (5)
- ▶ Substituting (6) into (5), we obtain that the optimization problem of end-users is equivalent to

$$\max_{x_1^e} W^e + x_1^e (\bar{D} - p) - \frac{1}{2} \alpha \sigma^2 (x_1^e + z)^2. \quad (11)$$

- ▶ Optimal demand of liquidity demanders is given by

$$x_1^e = \frac{\bar{D} - p}{\alpha \sigma^2} - z. \quad (12)$$

Appendix: model – equilibrium

- Dealers choose holdings x_1^d of the risky asset to maximize (7).
Substituting in (8) and taking the constraint (1) into account, we obtain

$$x_1^d = \begin{cases} -w_\kappa^d & \text{if } p > \bar{D} \\ \in [-w_\kappa^d, w_\kappa^d] & \text{if } p = \bar{D} \\ w_\kappa^d & \text{if } p < \bar{D}. \end{cases} \quad (13)$$

- Market clearing requires that aggregate demand equals supply, i.e.,

$$N \cdot \operatorname{sgn}(\bar{D} - p) w_\kappa^d + n \cdot \left(\frac{\bar{D} - p}{\alpha \sigma^2} - z \right) = 0,$$

which implies

$$p = \begin{cases} \bar{D} - \alpha \sigma^2 \left(z + \frac{N}{n} w_\kappa^d \right) & \text{if } z < -\frac{N}{n} w_\kappa^d \\ \bar{D} & \text{if } |z| \leq \frac{N}{n} w_\kappa^d \\ \bar{D} - \alpha \sigma^2 \left(z - \frac{N}{n} w_\kappa^d \right) & \text{if } z > \frac{N}{n} w_\kappa^d. \end{cases} \quad (14)$$

Appendix: model – dealers' liquidity supply decision

- Dealers' aggregate position is either $\frac{N}{n} w_{\kappa}^d$ or $-\frac{N}{n} w_{\kappa}^d$ (due to risk neutrality), and, if they decide to enter the market, expected interim utility (after the liquidity shock realization but before the asset payoff) is

$$\mathcal{U}_1^d(z) = \begin{cases} W^d - c - w_{\kappa}^d \alpha \sigma^2 \left(z + \frac{N}{n} w_{\kappa}^d \right) & \text{if } z < -\frac{N}{n} w_{\kappa}^d \\ W^d - c & \text{if } |z| \leq \frac{N}{n} w_{\kappa}^d \\ W^d - c + w_{\kappa}^d \alpha \sigma^2 \left(z - \frac{N}{n} w_{\kappa}^d \right) & \text{if } z > \frac{N}{n} w_{\kappa}^d, \end{cases} \quad (15)$$

- The ex ante expected utility of dealers who enter the market is

$$\mathcal{U}_0^d = W^d - c + 2\alpha\sigma^2\sigma_z w_{\kappa}^d \Psi\left(-\frac{1}{\sigma_z} \frac{N}{n} w_{\kappa}^d\right), \quad (16)$$

where

$$\Psi(x) \equiv \phi(x) + x \cdot \Phi(x) \quad (17)$$

is a strictly increasing convex function, and ϕ and Φ denote the pdf and cdf of the standard normal distribution.

Appendix: model – dealers' liquidity supply decision

- ▶ Higher wealth or lower margins allow risk neutral dealers to take larger positions, bringing the price closer to the expected asset payoff and thereby lowering the realized and expected dollar return. Thus, the expected profit is a hump-shaped function of w_{κ}^d
- ▶ Using (16), shows that higher balance sheet capacity allows for higher expected profits as long as

$$0 \leq w_{\kappa}^d \leq \bar{w}_{\kappa}^d \equiv \frac{n}{N} \sigma_z \bar{w} \quad (18)$$

and $\bar{w} > 0$ the only root of $0 = \phi(-\bar{w}) + 2(-\bar{w})\Phi(-\bar{w})$.

- ▶ From now on we make the assumption that we are in this intuitive range
- ▶ Dealers enter the market as long as their expected utility is at least as high as the utility from staying out:

$$u_0^d \geq \bar{u}_0^d \equiv W^d. \quad (19)$$

- ▶ Since we require $N \geq 0$, (16) and (19) imply the following results:

Appendix: model results – balance sheet capacity effects

Proposition 1

(Balance sheet capacity and dealer number) Let $\bar{c}(w_{\kappa}^d) \equiv \sqrt{2/\pi} \alpha \sigma^2 \sigma_z w_{\kappa}^d$. If $c \geq \bar{c}(w_{\kappa}^d)$, we have $N = 0$. If $0 < c < \bar{c}(w_{\kappa}^d)$, dealers enter the market as long as their equilibrium mass reaches

$$N = -n\sigma_z \frac{1}{w_{\kappa}^d} \Psi^{-1} \left(\frac{c}{2\alpha\sigma^2\sigma_z} \frac{1}{w_{\kappa}^d} \right) > 0. \quad (20)$$

If (18) also holds, the equilibrium dealer number N is increasing in dealers' wealth and decreasing in the margin, $\partial N / \partial w_{\kappa}^d > 0$.

Proposition 2

(Balance sheet capacity and volatility) When $c \geq \bar{c}(w_{\kappa}^d)$, price volatility is $\text{Var}[p] = (\alpha\sigma^2)^2 \sigma_z^2$. When $0 < c < \bar{c}(w_{\kappa}^d)$,

$$\text{Var}[p] = 2 \left(\alpha\sigma^2 \right)^2 \sigma_z^2 \Gamma \left(\Psi^{-1} \left(\frac{c}{2\alpha\sigma^2\sigma_z} \frac{1}{w_{\kappa}^d} \right) \right), \quad (21)$$

where $\Gamma(x) \equiv \Phi(x) + x \cdot \Psi(x)$ is a strictly increasing function. As a result, $\partial \text{Var}[p] / \partial w_{\kappa}^d < 0$.

Appendix: model results – dealer number and volatility

- ▶ Combining Propositions 1 and 2 gives

Corollary 1

(Dealer number and volatility) Assume that $0 < c < \bar{c}(w_{\kappa}^d)$. Then we have $\frac{dN}{d\text{Var}[p]} < 0$.

- ▶ Suppose we allow w_{κ}^d to be time varying while keeping other model parameters constant. As a result, Corollary 1 implies a negative relationship between return volatility and the equilibrium number of liquidity providers, and the mechanism is through the impact of margin constraints dealers are subject to: more balance sheet capacity (lower dealer wealth and/or higher margins) lead to a lower number of liquidity providers and higher volatility.

Appendix: model results – dealer number and volatility

Proposition 3

Assume that $0 < c < \bar{c}(w_{\kappa}^d)$ so that $N > 0$. An increase in c while keeping c/w_{κ}^d constant lowers N but does not affect $\text{Var}[p]$.

- ▶ A straightforward implication of Proposition 3 is the following:

Corollary 2

($N - \text{Var}[p]$ curve shifts) When participation gets more costly and c increases, the $N - \text{Var}[p]$ curve shifts “inwards”, and the same level of $\text{Var}[p]$ corresponds to a lower equilibrium dealer number N .

Appendix: model results – dealer number and returns

- ▶ From (14), realized returns between dates 0 and 1 are given by $R_1 = p - \bar{D}$ and expected returns between dates 1 and 2, conditional on the liquidity shock, are $E[R_2|z] = E[R_2|p] = \bar{D} - p = -R_1$
- ▶ Since dealers are risk neutral and subject to the balance sheet constraint (10), the expected dollar return must compensate them for paying the cost of liquidity provision, c . Together with Proposition 1, we get:

Proposition 4

(Balance sheet capacity and returns) Ex ante expected returns, both contemporaneous and future, satisfy $E[R_2] = -E[R_1] = c \frac{1}{w_{rc}^d}$. Therefore, higher balance sheet space lowers absolute realized returns and lowers absolute expected future returns.

Corollary 3

(Dealer number and returns) Assuming the variation in the equilibrium dealer number is driven by variation in balance sheet space, fewer dealers leads to larger price reversals. Specifically, there is a positive relationship between contemporaneous returns and dealer number multiplied by the sign of the dealers' positions, and a negative relationship between expected future returns and dealer number multiplied by the sign of dealers' positions: $dE[R_1]/d(N \cdot \text{sgn}(z)) > 0$ and $dE[R_2]/d(N \cdot \text{sgn}(z)) < 0$.