Shades of Darkness:
A Pecking Order of Trading Venues

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Motivation

Dark (off-exchange) venues account for a large fraction of volume.

U.S. (Dow 30)  European Indices

![Graph showing dark market share (%) over time for U.S. (Dow 30) and European Indices from 2006 to 2014.](image)

- FTSE100 stocks
- CAC40 stocks
- DAX30 stocks

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Menkveld-Yueshen-Zhu  Shades of Darkness: A Pecking Order of Trading Venues
Dark fragmentation

- U.S. has 18 stock exchanges, ~50 dark pools, >200 broker-dealers
- Theory: “liquidity begets liquidity” versus “investor self-selection”
  “Fragmentation can inhibit the interaction of investor orders and thereby impair certain efficiencies and the best execution of investors orders. . . .On the other hand, mandating the consolidation of order flow in a single venue would create a monopoly and thereby lose the important benefits of competition among markets. The benefits of such competition include incentives for trading centers to create new products, provide high quality trading services that meet the needs of investors, and keep trading fees low.” —SEC (2010)

- We analyze the dynamic fragmentation of U.S. equity markets
How do we think about fragmentation

- Dark Venue Fragmentation
- Do venues behave differently?
  - NO: Consolidation is better
  - YES:
    - Can we explain this difference?
      - NO: Back to drawing board
      - YES:
        - Rationale for fragmentation
        - Additional implications
What we find

Unique data: disaggregated U.S. dark volume

Volume share under urgency shocks (VIX and earnings)

Do venues behave differently?

Can we explain this difference?

A “pecking order” of trading venues

Dark venues help reduce investor costs (with calibration)

Consolidation is better

Back to drawing board

Rationale for fragmentation

Additional implications
## Literature on dark venues

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<th>Country</th>
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<td><strong>Aggregate dark</strong></td>
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<tr>
<td>O’Hara-Ye (2011)</td>
<td>U.S.</td>
<td>All TRF</td>
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<td>Hatheway-Kwan-Zheng (2014)</td>
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<td>Degryse-de Jong-van Kervel (2014)</td>
<td>Netherlands</td>
<td>All off-exchange</td>
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<tr>
<td><strong>Selected dark venues</strong></td>
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<tr>
<td>Hendershott-Jones (2005)</td>
<td>U.S.</td>
<td>Island ECN</td>
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<td>Ready (2014)</td>
<td>U.S.</td>
<td>Liquidnet, POSIT</td>
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<td>Buti-Rindi-Werner (2011)</td>
<td>U.S.</td>
<td>11 anonymous dark pool</td>
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<td>Boni-Brown-Leach (2012)</td>
<td>U.S.</td>
<td>Liquidnet</td>
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<td>Nimalendran-Ray (2014)</td>
<td>U.S.</td>
<td>One anonymous dark pool</td>
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<td>Foley-Malinova-Park (2013)</td>
<td>Canada</td>
<td>Dark order on TSX</td>
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<td><strong>Dark heterogeneity</strong></td>
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<td>Comerton-Forde-Putnins (2015)</td>
<td>Australia</td>
<td>“block” and “non-block dark” on ASX</td>
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<td>Foley-Putnins (2014)</td>
<td>Canada</td>
<td>“dark midpoint” and “dark limit orders”</td>
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<td>Kwan-Masulis-McInish (2014)</td>
<td>U.S.</td>
<td>5 categories that differ from ours</td>
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<td>Tuttle (2014)</td>
<td>U.S.</td>
<td>ATS and non-ATS</td>
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<td>Degryse-Tombeur-Wuyts (2015)</td>
<td>Netherlands</td>
<td>“hidden order” and “dark venues”</td>
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</tbody>
</table>

Theory: Hendershott-Mendelson (2000); Degryse-Van Achter-Wuyts (2009); Ye (2011); Boulatov-George (2013); Buti-Rindi-Werner (2014); Zhu (2014)

Experimental: Bloomfield-O’Hara-Saar (2013)
1 Pecking Order Hypothesis

2 Data and Econometric Model

3 Venue Pecking Order in the Data

4 A Suggestive Model and Welfare Implications
Pecking order hypothesis: generic form

- We conjecture that investors “sort” venues by cost and immediacy, along a “pecking order”
- Trading activity moves down if demand for immediacy goes up
Pecking order hypothesis: specific form

- Given the recent advance in theories of dark pools, we conjecture the specific sorting:

```
High Cost
High Immediacy
Low Cost
Low Immediacy
Investor
Order
Flow
DarkMid
DarkNMid
Lit
```

```
Low Cost
Low Immediacy

  DarkMid

Investor
Order
Flow

High Cost
High Immediacy

  DarkNMid

  Lit
```
1. Pecking Order Hypothesis

2. Data and Econometric Model

3. Venue Pecking Order in the Data

4. A Suggestive Model and Welfare Implications
Data

- 21 trading days in October 2010
- A stratified sample of 117 stocks (the same stocks as the 120 stocks in the “Nasdaq HFT data”)
- Five types of dark venues, disaggregated from Nasdaq TRF
  - Nasdaq TRF has about 92% of all TRF volume for our sample
  - FINRA recently starts to publish weekly ATS volumes by venue with a delay; our data are trade by trade
- Limit order book and HFT activity on Nasdaq
- Intraday VIX
- 67 earnings announcements

→ Stock-day-minute panel (117 × 21 × 390)
Dark volume shares

- **DarkMid (2.1%)**: dark pools focusing on trading at midpoint
- **DarkNMid (7.7%)**: dark pools with flexible prices
- **DarkRetail (10.8%)**: retail internalization
- **DarkPrintB (0.9%)**: average-price trade
- **DarkOther (5.8%)**: remainder

[Diagram showing the distribution of dark volume shares with Lit (72.8%) at the bottom, followed by DarkMid (2.1%), DarkNMid (7.7%), DarkRetail (10.8%), DarkPrintB (0.9%), and DarkOther (5.8%).]
## Alcoa on Oct 1, 2010

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## VARX model

### Endogenous variables $Y$:

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<tr>
<th>Type</th>
<th>Variable Name</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td><strong>Panel A: Dark venue trading volumes</strong></td>
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<tr>
<td>$Y$</td>
<td>$VDarkMid_{jt}$</td>
<td>Volume of midpoint-cross dark pools</td>
</tr>
<tr>
<td></td>
<td>$VDarkNMid_{jt}$</td>
<td>Volume of non-midpoint dark pools</td>
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<td></td>
<td>$VDarkRetail_{jt}$</td>
<td>Volume of retail flow internalization</td>
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<td>$VDarkPrintB_{jt}$</td>
<td>Volume of average-price trades (“print back”)</td>
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<td></td>
<td>$VDarkOther_{jt}$</td>
<td>Volume of other dark venues</td>
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<td></td>
<td>$VLit_{jt}$</td>
<td>Total volume minus all dark volume</td>
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<tr>
<td><strong>Panel B: NASDAQ lit market characterization</strong></td>
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<tr>
<td>$BASpread_{jt}$</td>
<td>NASDAQ lit market bid-ask spread divided by the NBBO midpoint</td>
<td></td>
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<tr>
<td>$TopDepth_{jt}$</td>
<td>Sum of NASDAQ visible best bid depth and best ask depth</td>
<td></td>
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<tr>
<td>$HFTinTopDepth_{jt}$</td>
<td>$Depth_{jt}$ based on only HFT limit orders divided by $Depth_{jt}$</td>
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<tr>
<td>$HFTinVolume_{jt}$</td>
<td>NASDAQ lit volume in which HFT participates divided by total NASDAQ lit volume</td>
<td></td>
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<td><strong>Panel C: Overall market conditions</strong></td>
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<tr>
<td>$TAQVolume_{jt}$</td>
<td>TAQ volume</td>
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<tr>
<td>$RealVar_{jt}$</td>
<td>Realized variance, i.e., sum of one-second squared NBBO midquote returns</td>
<td></td>
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<tr>
<td>$VarRat10S_{jt}$</td>
<td>Variance ratio, i.e., ratio of realized variance based on ten-second returns relative to realized variance based on one-second returns (defined to be one for a minute with only one-second returns that equal zero)</td>
<td></td>
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</tbody>
</table>
Exogenous variables

- VIX shocks are innovations from an AR(1) model of $\Delta \ln(VIX_t)$ at minute frequency:

$$\Delta \ln(VIX_t) = \alpha + \beta \Delta \ln(VIX_{t-1}) + Innov_t.$$  

(In the current paper we use VIX level, and results are very similar.)

- EPS surprise is calculated as

$$\left| \frac{\text{Announced EPS} - \text{Forecast EPS}}{\text{Closing price on the day before}} \right|.$$
VARX model:

\[ y_{j,t} = \alpha_j + \Phi_1 y_{j,t-1} + \cdots + \Phi_p y_{j,t-p} + \Psi_1 z_{j,t-1} + \cdots + \Psi_r z_{j,t-r} + \varepsilon_{jt}. \]

- dark volumes, market conditions (spread, depth, volatility, HFT,...)
- urgency: VIX shocks and EPS surprise

Optimal lags \( p = 2 \) and \( r = 1 \) chosen according to BIC

The estimation gives the dynamic interrelation between dark volumes and market conditions. We focus on the implications on dark venue market shares.
1. Pecking Order Hypothesis

2. Data and Econometric Model

3. Venue Pecking Order in the Data

4. A Suggestive Model and Welfare Implications
Volume share response to VIX shocks

Impulse-response of volume shares to $+1\%$ shock to $\Delta \ln(VIX)$

Pecking order predicts: SDarkMid $\downarrow \downarrow$, SDarkNMid $\downarrow$, SLit $\uparrow$
Volume share response to VIX shocks

Impulse-response of volume shares to $+1\%$ shock to $\Delta \ln(VIX)$

Pecking order predicts: SDarkMid $\downarrow\downarrow$, SDarkNMid $\downarrow$, SLit $\uparrow$
Volume share response to VIX shocks

Impulse-response of volume shares to \(+1\%\) shock to \(\Delta \ln(VIX)\)

Pecking order predicts: SDarkMid ↓↓, SDarkNMid ↓, SLit ↑

Pecking order hypothesis is confirmed:

\[
\text{Reject null: } \frac{\Delta SDarkMid}{SDarkMid} = \frac{\Delta SDarkNMid}{SDarkNMid}
\]

\[
\text{Reject null: } \frac{\Delta SDarkNMid}{SDarkNMid} = \frac{\Delta SLit}{SLit}.
\]
Other dark venues’ response to VIX shocks

Impulse-response of volume shares to $+1\%$ shock to $\Delta \ln(VIX)$
Volume share response to earnings surprises

Consider a 1% shock to earnings surprises

Pecking order predicts: SDarkMid ↓↓, SDarkNMid ↓, SLit ↑

<table>
<thead>
<tr>
<th>Venue</th>
<th>No shock</th>
<th>1% EpsSurprise</th>
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<tbody>
<tr>
<td>SDarkMid</td>
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<tr>
<td>SDarkNMid</td>
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<td>SLight</td>
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<td>SDarkRetail</td>
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<td>SDarkPrintB</td>
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<tr>
<td>SDarkOther</td>
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</table>

Volume share relative to stead state

1% EpsSurprise: 1.82% → 2.27%
No shock: 1.82%

1% EpsSurprise: 6.3% → 7.06%
No shock: 6.3%

1% EpsSurprise: 80.04% → 77.52%
No shock: 80.04%
Volume share response to earnings surprises

Consider a 1% shock to earnings surprises

Pecking order predicts: SDarkMid ↓↓, SDarkNMid ↓, SLit ↑

SDarkMid shares

1.82% 2.27%

SDarkNMid shares

6.3% 7.06%

SLit shares

80.04% 77.52%

SDarkRetail shares

8.83% 9.53%

SDarkPrintB shares

0.33% 0.41%

SDarkOther shares

2.64% 3.17%
1 Pecking Order Hypothesis

2 Data and Econometric Model

3 Venue Pecking Order in the Data

4 A Suggestive Model and Welfare Implications
Model setup

- One traded asset with normalized value $E(v) = 0$
- Two representative investors: a buyer and a seller
- Three venues: Lit, DarkNMid, DarkMid

Timing
- Buyer and seller observe private trading needs $Z^+$ and $Z^-$. Size of each is either $Q > 0$, with probability $\phi$, or 0, with probability $1 - \phi$.
- They simultaneously choose trading venues, possibly splitting orders
- Trade happens in three venues
- Unexecuted orders incur inventory cost of

$$\frac{\gamma}{2} \times \text{Inventory}^2,$$

where $\gamma > 0$ is a proxy for urgency.
Venues

- Lit: Buyer pays the ask $\beta > 0$; seller gets the bid $-\beta$; infinite depth
- DarkNMid is run by a competitive liquidity provider with inventory cost: $(\eta/2) \cdot \text{Inventory}^2$. Restrict to linear prices:
  
  Buyer’s price is $p^+ = \delta x_N^+$
  Seller’s price is $p^- = -\delta x_N^-$

- DarkMid crosses orders at midpoint price 0. Volume is
  
  $v_M = \min(x_M^+, x_M^-)$.
Buyer’s problem is to maximize

\[
\pi^+(z) = \left( -E \left[ 0 \cdot V_M^+(z) \right] - \frac{\delta}{2} x_N^+(z)^2 - \beta \cdot x_L^+(z) \right) + E \left[ 0 \cdot (z - V_M^+(z) - x_N^+(z) - x_L^+(z)) \right] - \frac{\gamma}{2} E (z - V_M^+(z) - x_N^+(z) - x_L^+(z))^2.
\]

Similar for the seller.
Equilibrium

Proposition. If

\[ Q \leq \Delta \equiv \beta \left( \frac{1}{(1 - \phi)\gamma} + \frac{1}{(1 - \phi)\eta} \right), \]

then there exists an equilibrium with the following strategies:

\[ x_M(0) = 0; \quad x_M(Q) = \frac{\delta}{\delta + (1 - \phi)\gamma} Q, \]
\[ x_N(0) = 0; \quad x_N(Q) = \frac{(1 - \phi)\gamma}{\delta + (1 - \phi)\gamma} Q, \]
\[ x_L(0) = 0; \quad x_L(Q) = 0. \]

If \( Q > \Delta \), then there exists an equilibrium with the following strategies:

\[ x_M(0) = 0; \quad x_M(Q) = \frac{\beta}{(1 - \phi)\gamma}, \]
\[ x_N(0) = 0; \quad x_N(Q) = \frac{\beta}{\delta}, \]
\[ x_L(0) = 0; \quad x_L(Q) = Q - \Delta. \]

In both cases, the DarkNMid liquidity provider sets the slope of price schedules \( \delta = (1 - \phi)\eta \).
Venue pecking order as an equilibrium implication

**Proposition.** As investor urgency $\gamma$ increases, lit volume share increases and dark volume share decreases. Furthermore, DarkMid is more sensitive to urgency than DarkNMid:

$$\frac{\partial s_M}{s_M} \varphi < \frac{\partial s_N}{s_N} \varphi < 0 < \frac{\partial s_L}{s_L} \varphi.$$
**Proposition.** As investor urgency $\gamma$ increases, lit volume share increases and dark volume share decreases. Furthermore, DarkMid is more sensitive to urgency than DarkNMid:

$$\frac{\partial s_M}{s_M} \frac{\partial \gamma}{\gamma} < \frac{\partial s_N}{s_N} \frac{\partial \gamma}{\gamma} < 0 < \frac{\partial s_L}{s_L} \frac{\partial \gamma}{\gamma}.$$ 

Recall the empirical test:

$$\frac{\Delta S_{\text{DarkMid}}}{S_{\text{DarkMid}}} < \frac{\Delta S_{\text{DarkNMid}}}{S_{\text{DarkNMid}}} < 0 < \frac{\Delta S_{\text{Lit}}}{S_{\text{Lit}}} ,$$

after VIX shock or earnings surprises.
Welfare cost of shutting down dark venues

- Two sources of investors’ cost $C_{MNL}$: spread paid to liquidity providers and inventory cost
- Shut down DarkMid and DarkNMid, recalculate the equilibrium and the associated $C_L$

\[
C_L - C_{MNL} = \frac{\beta}{2} (Volume_M + Volume_N)
\]

\[\approx \$1.43 \text{ billion/year}\]

Calibrated result
Conclusion

- We characterize dynamic fragmentation of U.S. equity markets
- A unique dataset on disaggregated U.S. dark trading
- A pecking order of trading venues, characterized by heterogeneous responses to urgency shocks
- Evidence supports investor self-selection
- Suggestive model with welfare implications