Limelight on Dark Markets: Theory and Experimental Evidence on Liquidity and Information

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How informational asymmetries in over-the-counter markets affect an asset’s

1. role in exchange (as means of payment or collateral),
2. liquidity (velocity, market freezes),
3. price.
Why this is important
Private information in OTC markets

- Over-the-counter market: **bilateral** contacts and **bargaining**
- Many assets are traded over the counter
  - see OTC workshop at the beginning of the week
- Monetary exchange also involves pairwise meetings and bargaining
Why this is important
Private information in OTC markets

- OTC markets are *dark* markets
  - they are opaque, and little is known about how they function
- Bargaining is subject to private information frictions

"An OTC bargaining game can be complex because of private information ... The counterparties may have different information regarding the common-value aspects of the asset, current market conditions, and their individual motives for trade." (Darrell Duffie, *Dark Markets*, 2012)
Methodology

- A well-developed theoretical literature on information and liquidity in OTC markets.
  - The money/payment approach: Kiyotaki and Wright (1989), Williamson and Wright (1994) and others.
  - The finance approach: Duffie, Garleanu, and Pedersen (2005) and others.

- We provide a *simple* theoretical framework and test these theories in a laboratory setting.
Methodology: Why an experimental approach?

1. OTC markets are opaque: limited data.
2. Experimental approach provides different kind of data (e.g. rejected offers).
3. OTC bargaining games are complex and theory may have limited predictive power (refinements, behavioral aspects...).
4. Theory provides carefully designed environments that can be tested in the lab.
GENERAL SET-UP OF THE EXPERIMENT

Figure: Experimental Social Science Laboratory at UCI
Set up of the experiment

- Subjects divided into two categories:

1. **Proposers:**
   - Operate a technology that requires inputs $\omega$.
   - Don’t own inputs but are endowed with $\bar{n}$ divisible assets (e.g., a bond) with some $\$ \text{ terminal value}.$

2. **Responders:**
   - Cannot operate the technology.
   - But they are endowed with $\bar{\omega}$ units of input.

- Agents are matched bilaterally
  - The only two objects that can be traded are the asset and the input.
OTC bargaining

- A trade has two dimensions:
  - Quantity of input, $\omega$, purchased by Proposer and supplied by Responder.
  - Quantity of assets, $n$, transferred from Proposer to Responder.

- Payoff of Proposer:
  $$2\omega + \bar{n} - n$$

- Payoff of Responder:
  $$\hat{\omega} - \omega + n$$

- Assumption: subjects are risk-neutral.
  - justified under the expected utility paradigm when stakes are small
Gains from trade

\[ f(\omega) = 2\omega \]

technology of the Proposer

\[ c(\omega) = \omega \]

opportunity cost of Responder

Endowment of Responder

# widgets
OVERVIEW EXPERIMENTS

1. Symmetric Information, deterministic terminal value
2. Asymmetric information, adverse selection
3. Asymmetric Information, moral hazard
4. Liquidity choice
EXPERIMENT #1: SYMMETRIC INFORMATION, DETERMINISTIC VALUE

Key issues: Benchmark
Symmetric Information, deterministic value

- Proposer is endowed with 100 notes, where a note has deterministic terminal value $0.1$.

- Responder is endowed with 100 widgets. A widget has value $0.2$ to the Proposer and $0.1$ to the Responder.

- Proposer makes an offer $(\omega, n)$
  - Quantity of widgets, $\omega$, in exchange for quantity of notes, $n$.

- Responder chooses among \{Yes, No\}
You have been given 100 notes, and the Responder has been given 100 widgets.

What is your offer?

Number of notes to offer (0, ..., 100): 70
Number of widgets to receive (0, ..., 100): 1

Click "Confirm" to send your offer to the Responder.

<table>
<thead>
<tr>
<th>Period</th>
<th>Ticket Offer</th>
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<tr>
<td>1</td>
<td>96</td>
<td>70</td>
<td>Accept</td>
<td>$15.00</td>
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</table>
You have been given 100 widgets, and the Proposer has been given 130 notes.

The Proposer offered 70 notes for 40 widgets. Do you accept or reject this offer?  
- Accept
- Reject

Click "Confirm" to notify the Proposer of your decision.

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<tr>
<td>1</td>
<td>30</td>
<td>79</td>
<td>Accept</td>
<td>$12.60</td>
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</table>
Symmetric information, deterministic value

\[ n = 2\omega \]
\[ n = (1 + \theta)\omega \]
\[ n = \omega \]

\[ \frac{100}{1 + \theta} \]

IR\textsubscript{R}

IR\textsubscript{P}

Pareto frontier
Taking fairness into account

- The *motivation function* of the responder becomes

\[ \hat{U}_R = U_R - \frac{\theta}{1 - \theta} S_P, \]

where:

- \( S_P \equiv 2\omega - n \) is the Proposer’s surplus
- \( S_R \equiv n - \omega \) is the Responder’s surplus

- Responders only accept offers that satisfy \( S_R \geq \frac{\theta}{1 - \theta} S_P \)
- Equivalent to Kalai’s (1977) proportional bargaining solution
Motivation

Symmetric information, deterministic value

Hypothesis 1a \((Symmetric\ Information)\)

Under symmetric information with deterministic value, proposers will offer 100 notes for between 50 and 100 widgets.
Symmetric information, deterministic value

KEY STATISTICS

- 99% (100%) of all offers in the SI session meet IR of responder (proposer).
- Average number of notes offered 87.
- 63% of offers include 100 notes.
- Average widgets requested is 74.
- Three-quarters of offers are accepted.
- Average surplus of the responder is larger for accepted offers than rejected ones (fairness).
Symmetric information: Accepted offers

Accepted price: $n/\omega = 1.2$; Responder’s share: $\theta = 20\%$
Symmetric information: Rejected offers

Rejected price: \( n/\omega = 1.1 \)
Symmetric information: convergence

- $n$ converges to 100
EXPERIMENT #2: ADVERSE SELECTION

The market for lemons

Key issues: signaling, market freeze
Adverse selection

- Proposer receives blue or red notes
- As before, blue notes are worth $0.1 and red notes are worthless
  - AS1: probability of blue notes 50%
  - AS2: probability of blue notes 70%
  - AS3: probability of blue notes 90%
- Proposer is privately informed.
Bargaining under adverse selection

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Responder’s information set
Adverse selection: equilibria

Best pooling offer for the Proposer

\[ n = 2\omega \]
\[ \pi n = \omega \]

Incentive feasible trades if responders do not revise their beliefs.
**Hypothesis 2:** *(Adverse Selection)*

Trades satisfy one of the following patterns:

1. (Intuitive Criterion) Either proposer offers no trade or offers are rejected.
2. (Pooling) For any $\pi \geq 0.5$, proposers will offer $n$ notes and ask for between $0.5n$ and $\pi n$, and all these offers are accepted.
Adverse selection: key statistics

SU1 and AS1: 50%, SU2 and AS2: 70%, SU3 and AS3: 90%
Adverse selection: Accepted offers

\[ \pi n = (1 + \theta) \omega \]
\[ n = 2 \omega \]
\[ \pi n = \omega \]

Responder's share: \( \theta = -1\% \)
Adverse selection: Rejected offers

61% of offers were rejected
65% for blue notes and 49% for red notes
Offers with blue notes vs offers with red notes

SU1 and AS1: 50%, SU2 and AS2: 70%, SU3 and AS3: 90%
EXPERIMENT #3: MORAL HAZARD

Key issues: Fraud and liquidity, moral hazard
Experiment #4: Moral Hazard

- Proposer is endowed with $10.
- Can purchase either 100 red notes or 100 blue notes
  - blue notes worth $0.1, red notes are worthless
- Red notes can be acquired at cost $C \times 0.1$ per 100 notes
  - 6 treatments, MH1-MH6, where $C = \{0, 20, 40, 60, 80, 100\}$
- Blue notes can be acquired at cost $C_{b} = 100$
Moral Hazard: Screenshot Proposer

You have been given $10, and the Responder has been given 100 widgets.

You have two choices to make:

First, do you want to purchase 100 blue notes for $10 or do you want to purchase 100 red notes for $2?

Remember, the Responder will not know whether the notes you offer are blue or red.

- Blue notes
- Red notes

Second, what is your offer?

Number of notes to offer (0, 1, ..., 100): 
Number of widgets to receive (0, 1, ..., 100): 

Click "Confirm" to send your offer to the Responder.

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<tr>
<td>1</td>
<td>blue</td>
<td>100</td>
<td>75</td>
<td>Accept</td>
<td>$18.90</td>
</tr>
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Bargaining under the threat of fraud
Reverse-ordered game

You have been given $10, and the Responder has been given 100 widgets.

You have two choices to make:

First, what is your offer?
- Number of notes to offer (0, 1, ..., 100):
- Number of widgets to receive (0, 1, ..., 100):

Click "Confirm" to send your offer to the Responder.

Once your offer has been sent, you will be able to make your second choice: whether to purchase blue or red notes.

Money you will be paid for only one round chosen at random.

You just sent the following offer: 80 notes for 100 widgets.

Now do you want to purchase 100 blue notes for $10 or do you want to purchase 100 red notes for $0? Remember, the Responder will not observe this choice.

Click "Confirm" to continue.

Money you will be paid for only one round chosen at random.
Theory: Nash equilibria following an offer

- Reverse-ordered game: Proposer chooses \((\omega, n)\) first and the color of the notes next.
- A proper subgame following \((\omega, n)\)
- NE: \((\eta, p)\) where \(\eta = \Pr[\text{Blue}]\) and \(p = \Pr[\text{Accept}]\)
Theory: Optimal offer

\[ p : \text{acceptance probability} \]
HYPOTHESIS 3  *(Moral Hazard)*

1. If $C = 0$, fraud can occur but no offer should be accepted.
2. If $C > 0$, then no fraud takes place and 
   \[ n = (1 + \theta)\omega. \]
   
   2.1 Offers such that $n \leq C$ are accepted.
   2.2 Offers such that $n > C$ are accepted with probability $C/n$. 
Moral Hazard: all offers

![Graph showing the relationship between cost of fraud and percentage of notes offered, offers accepted, and fraudulent offers.](image)

- Notes offered: Blue line
- Offers accepted: Orange line
- Fraudulent offers: Gray line

The graph illustrates the impact of cost of fraud on the percentage of notes offered, offers accepted, and fraudulent offers.
Moral Hazard: Offers with blue notes

MH1, Blue Notes, Accepted

MH1, Blue Notes, Rejected

Optimal offers

$n = 2\omega$

$n = (1+\theta)\omega$

Optimal offers
Moral Hazard: Offers with red notes

Low cost of fraud: $C = 2$

37% of offers are fraudulent
Most offers are rejected (76%)
Moral Hazard: Acceptability

- Acceptability is lower than in theory
Moral Hazard: Fraud

Theory: $\theta = 0.2$

- Theory under-predicts fraud.
EXPERIMENT #4: LIQUIDITY CHOICE
Liquidity choices

- Proposers are endowed with some nonliquid wealth, $W$.
- The Proposer has the possibility to purchase notes at some price $\phi$ or to keep his wealth in the form of non-liquid capital.
  - Each note is redeemed for $0.1$ at the end of the session.
- 3 sessions:
  - L0: $\phi = \$0.10$ (Friedman rule)
  - L1: $\phi = \$0.11$
  - L2: $\phi = \$0.15$
- Question: Are subjects willing to hold an asset that is dominated in its rate of return?
Investment in liquidity under complete information

\[ n = 2\omega \]
\[ n = 2\omega / \phi \]
\[ n = (1 + \theta)\omega \]

\( IR_p \)
\( IR_R \)

Ex-ante individually rational

\[ \frac{100}{1 + \theta} \]
Screenshot Proposer

You have been given $15, and the Responder has been given 100 widgets.

You have two choices to make:
First, how many notes do you want to purchase at $0.15 per note? 100

Second, what is your offer?
Number of notes to offer (0, 1, ..., 100): 50
Number of widgets to receive (0, 1, ..., 100): 50

Click "Confirm" to send your offer to the Responder.

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<td>blue</td>
<td>100</td>
<td>30</td>
<td>Accept</td>
<td>$18.00</td>
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Liquidity choice: key statistics

L0: $\phi = 0.1$; L1: $\phi = 0.11$; L2: $\phi = 0.15$
Liquidity choice: rounds of trading
Liquidity choice under private information

- Three types of notes: blue, orange, and red
- Prices of notes: $\phi^b > \phi^o = 1 > \phi^r = 0$
- Red notes can be acquired for free but they are worthless.
- Responder cannot distinguish orange notes from red ones.
- We restrict $n = 100$.
- In equilibrium Proposers should accumulate blue notes despite their lower rate of return.
Liquidity choice under private information
Findings

- Acceptance rate for blue notes: 76% (when first 5 rounds are removed).
- Acceptance rate of red/orange notes: 14%

37% blue, 46% red, and 17% orange
Conclusion: informational cascade

- No uncertainty. Gains from trade are well exploited, high velocity and acceptance rates.

- Symmetric uncertainty. Affects trade more than expected: low velocity, high rejection rates.

- Private information. Makes matters even worse.

- Liquidity adversely affected if private info arises from hidden actions (fraud) instead of Nature.

- Rate of return dominance
THE LABORATORY

Experimental Social Science Laboratory at UCI
The Experimental Social Science Laboratory at UCI

- Fully equipped with custom lab furniture.
- 40 subject stations, 3 administrative computers.
- Approval for economics-style experiments (no deception, money payments) using own subject pool.
- Has already been used for about 50 experiments
- Director of the lab: Michael McBride
The UCI lab: subjects

- Subjects into subject pool: approx 1000 subjects.
  - Emails are sent around the campus, and interested students register to be in subject pool.
- All subjects in the subject pool are sent an email stating date and time of an upcoming experiment session.
- Subjects come from all majors on campus.
- Subjects always paid for participation (not course credit as in psychology experiments) in order to incentive actions.
- Subjects usually get $7 payment to show-up and then earn additional salient payments.
LITERATURE
Liquidity in OTC markets

- Money and payments: Lagos and Wright (2005), Williamson and Wright (2010), Nosal and Rocheteau (2011)
Liquidity and private information

- **Adverse selection**: Hopenhayn and Werner (1996) and Golosov, Lorenzoni, and Tsyvinski (2008)
Experimental work

- Bank runs: Garratt and Keister (2005)
- Macroeconomics in the lab: Duffy (2008)
- Bubbles: Smith, Suchanek, and Williams (1988)
Why this is important
Liquidity, information, and the 2008 financial crisis

- Robert Lucas WSJ 2011:

"the shock came because complex mortgage-related securities minted by Wall street and certified as safe by rating agencies had become part of the effective liquidity supply of the system. All of a sudden, a whole bunch of this stuff turns out to be crap"
Interpretations

1. **Corporate finance**
   An company (1) purchases inputs from an investor (2) and uses its assets as means of payment or collateral.

2. **Risk-sharing in OTC markets**
   A company (1) purchases risk-sharing services from a bank (2) and uses its assets as collateral.

3. **Repos market**
   A dealer (1) borrows funds from cash-investors (2) in exchange for collateral.
Figure S2: Comparison of MH and Reverse MH Sessions

(a) Median Notes Offered

(b) Median Price

(c) % Accepted