Contagion, Cascades and Disruptions to the Interbank Payment System

NEW DIRECTIONS FOR UNDERSTANDING SYSTEMIC RISK
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The National Infrastructure Simulation and Analysis Center (NISAC) is a program under the Department of Homeland Security’s (DHS) Preparedness Directorate.
financial markets

clearing and settlement

markets for goods and services
Primer on Interbank Payment System

Federal Reserve - bank of banks

Fedwire
- Large-value, time-critical payments
- Real Time Gross Settlement (RTGS) system
- Fed provides intraday credit for a fee

other infrastructures

bank i
- market
- bank j

Max day = 800,000 payments worth $2.9 trillion

Turnover = US GDP every six business days

7600 participants
A Break Down in Coordination

\[
\text{Payments Sent}_t = \alpha + \beta \cdot \text{Payments Received}_t + \epsilon_t
\]

Slope of Reaction Function of Payments Sent to Payments Received: Fixed-Effects Tobit Model

McAndrews and Potter (2002)
The Intraday Liquidity Management Game

Fee $F$ charged by central bank for overdrafts

<table>
<thead>
<tr>
<th></th>
<th>Bank B (Morning)</th>
<th>Bank B (Afternoon)</th>
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</thead>
<tbody>
<tr>
<td>Morning</td>
<td>0, 0</td>
<td>3, 4</td>
</tr>
<tr>
<td>Afternoon</td>
<td>D, F</td>
<td>D, D</td>
</tr>
</tbody>
</table>

Total cost = 0 (FIRST BEST)

Time is money (also intraday) so delay is costly. The cost is $D > 0$ per dollar

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Total cost = 0 or (6)

Rational players are pulled in one direction by considerations of mutual benefit and in the other by considerations of personal risk.
Adjustment following Wide-Scale Disruption

Liquidity cheap relative to delaying

Liquidity expensive relative to delaying

\[ F = D \]

\[ F < D \]

\[ F > 2D \]

\[ D < F < 2D \]

Share of banks hit by disruption / holding back payments
Heterogeneous Banking Sector

Share of banks hit by disruption / holding back payments

Potential

Large bank not affected

Large bank affected
Network Topology of Payment Flow

Potential

Large bank affected
Large bank not affected
Research Goals

1. Evaluate the actual network topology of interbank payment flows through analysis of Fedwire transaction data
2. Build a parsimonious agent based model for payment systems that honors network topology
3. Evaluate response of payment systems to shocks and the possibility of cascading failure
All Commercial Banks
>6600 nodes, 70,000 links
Network Components

Giant Strongly Connected

Tendril

GIN

12%

78% nodes

Giant Weakly Connected

Tube

Disconnected

GSSC Dominates

• 78% nodes
• 90% edges
• 92% transfers
• 90% value

GOUT

8%
Out-Degree Distribution

\[ P(k) \sim k^{-\gamma} \]

- Fedwire network
- Poisson random network (\( p=0.30\% \))

slope = 2.111
Scale-free Networks

Albert, Jeong, Barabasi, Nature 2000

Preferential attachment
“rich get richer”
tolerant to random failure…
vulnerable to informed attack
But, not all scale free networks are created Equal

LaViollette, Beyeler, Glass, Physica A, 2006

Fedwire network

Poisson random network (p=0.30%)

BA slope = 3

sill

slope = 2.111
Fedwire’s Core
Congestive failure of the WECC

Western Power Grid (WECC), 69 kev lines and above

Highest degree

Highest load
Number of Nodes in GSCC

Non-9/11 Mean +/- St. Dev
Average Path Length

- Sept 11th
- Good Friday
- Thanksgiving
- Christmas Eve

2.55
2.60
2.65
2.70
2.75
2.80

Apr 2001
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan 2002
Feb
Mar
Apr

Averge Path Length
Non-9/11 Mean +/- St. Dev
Note: 100 = September 10th, 2001.
A Break Down in Coordination

Payments Sent\(t\) = \(\alpha + \beta \cdot\) Payments Received\(t\) + \(\varepsilon_t\)

Slope Reaction Function

Slope of Reaction Function of Payments Sent to Payments Received: Fixed-Effects Tobit Model

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Payment Physics Model

1. Agent instructs bank to send a payment

2. Depositor account is debited

3. Payment is settled or queued

4. Payment account is debited

5. Payment account is credited

6. Depositor account is credited

7. Queued payment, if any, is released

Productive Agent

Central bank

Payment system

Liquidity Market
Influence of Liquidity

Summed over the network, instructions arrive at a steady rate.

When liquidity is high, payments are submitted promptly, and banks process payments independently of each other.
Reducing liquidity leads to episodes of congestion when queues build, and cascades of settlement activity when incoming payments allow banks to work off queues. Payment processing becomes coupled across the network.
At very low liquidity payments are controlled by internal dynamics. Settlement cascades are larger and can pass through the same bank numerous times.
A liquidity market substantially reduces congestion using only a small fraction (e.g. 2%) of payment-driven flow.
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Ongoing Disruption Analyses

Disruption of a bank creates a liquidity sink in the system.

Disruptions to liquidity market represented as decreased conductance.

System throughput can be rapidly degraded.

Queues build; system becomes increasingly congested; recovery quickly follows restoration.
What we’re learned

• Payment system participants have learned to coordinate their activities, and this coordination can be re-established after massive disruption
• Payment flows, like many other networks, follow a scale-free distribution
• Performance is a function of both topology and behavior – neither factor alone is enough to evaluate robustness
• Liquidity limits can lead to congestion and a deterioration of throughput, but a shift in behavior is evidently needed to understand responses to disruption
• System performance can be greatly improved by moving small amounts of liquidity to the places where it’s needed
• Collaboration among researches with different backgrounds helps bring new theoretical perspectives to real problems, and helps shape theoretical development to practical ends
Next steps

- **Intraday analysis of network topology** –
  - How does it get built?
  - Over what time scales do banks manage liquidity?
  - Are there discernable behavioral modes (e.g. early/late settlement) or triggers (e.g. settlement of market transactions)?

- **Long-term network dynamics** (e.g. changes in TARGET topology with integration)

- **Disruption/recovery behavior of simple model**, including a central bank

- **Adaptation of decision process**, including market participation, to minimize cost (ongoing).
  - How is cooperative behavior established and maintained?
  - How might it be disrupted, restored, through institutions’ policies and reactions?

- **Modeling the processes that drive payment flows** (banks’ and customer investments, market movements, etc.) to:
  - Introduce plausible correlations and other structure on the payment instruction stream
  - Explore the feedbacks between payment system disruptions and the economy