

# 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.*



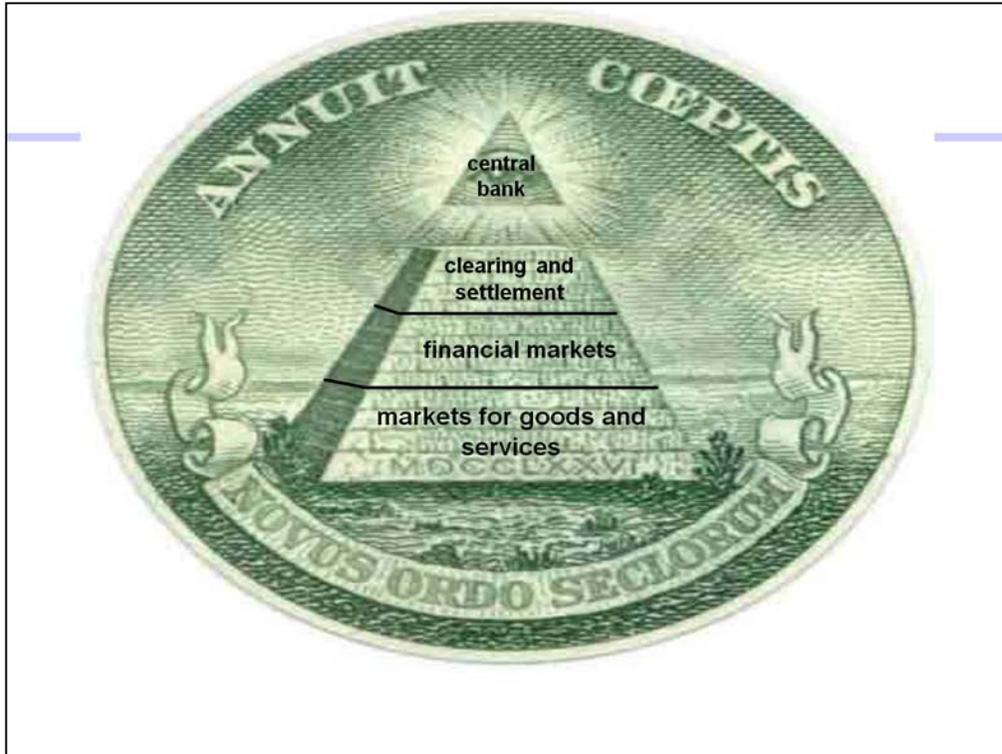
- I would like to thank Scott Frame for putting together a great conference and for allowing us the opportunity to present our paper

# The Big Picture

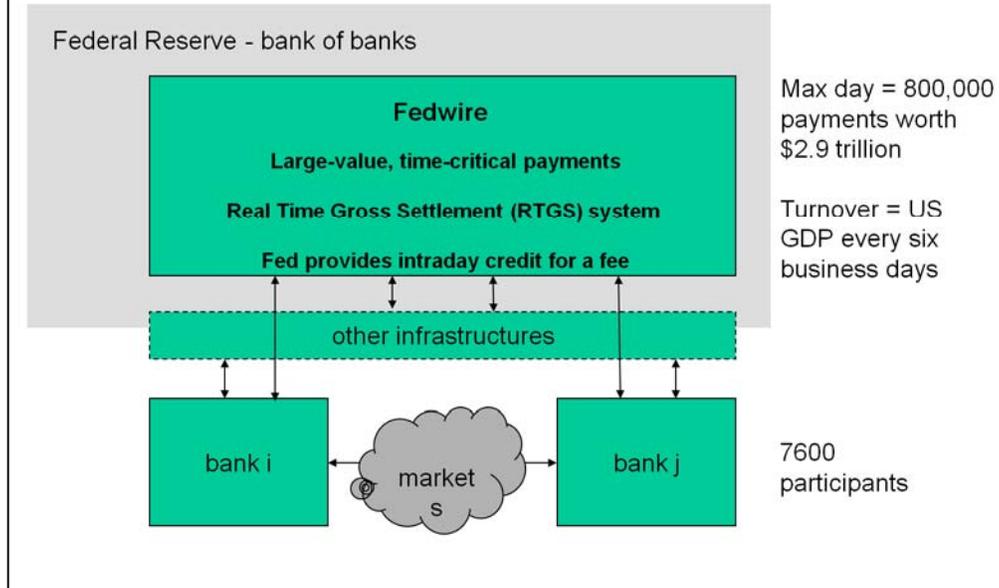
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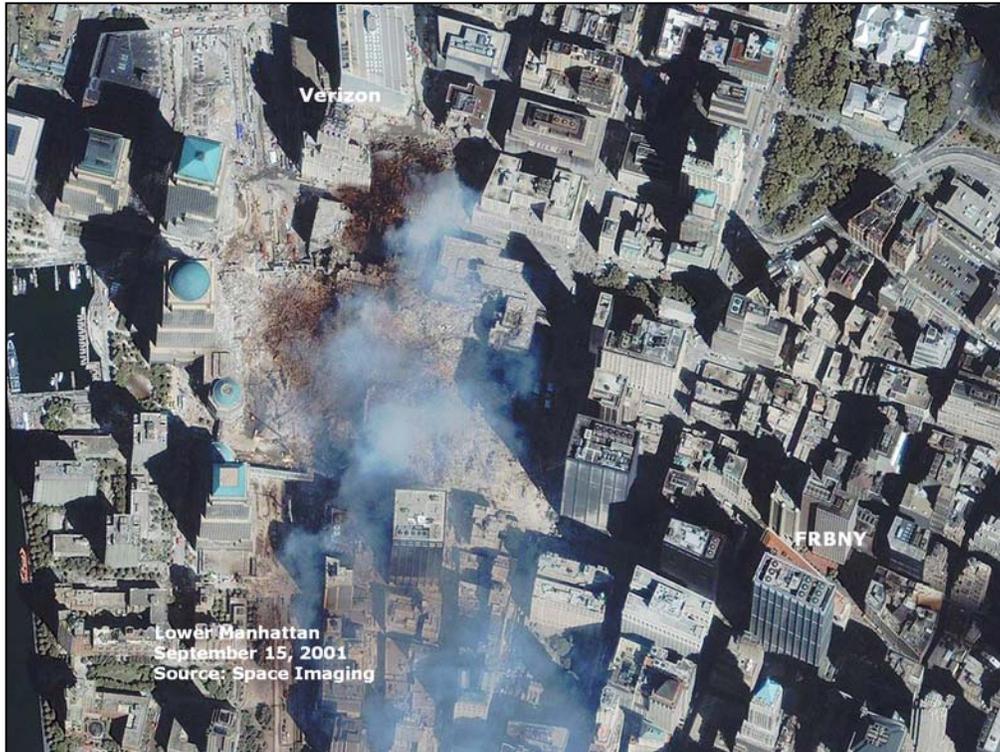


Complex, Adaptive System



# Primer on Interbank Payment System

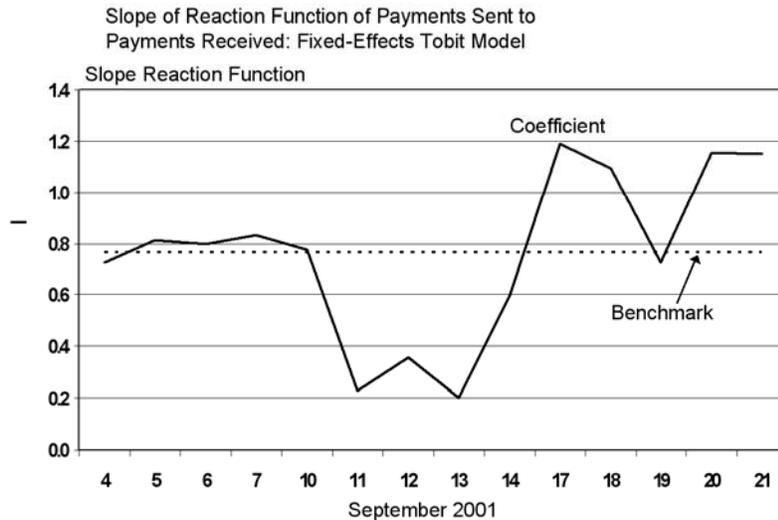




- Fedwire continued to operate during the events of September 11, 2001, but in the Federal Reserve had to intervene by extending the operating hours and by providing emergency liquidity .
- However the massive damage to property and communications systems in lower Manhattan made it more difficult, and in some cases impossible, for many banks to execute payments to one another.
- The failure of some banks to make payments also disrupted the payments coordination by which banks use incoming payments to fund their own transfers to other banks.
- Once a number of banks began to be short of incoming payments, some became more reluctant to send out payments themselves. In effect, banks were collectively growing short of liquidity.
- The Federal Reserve recognized this trend toward illiquidity and provided liquidity through the discount window and open market operations in unprecedented amounts in the following week. Federal Reserve opening account balances peaked at more than \$120 billion compared to approximately \$15 billion prior.
- Moreover, the Federal Reserve waived the overdraft fees it normally charges. On September 14, daylight overdrafts peaked at \$150 billion, more than 60 percent higher than usual.

# A Break Down in Coordination

$$\text{Payments Sent}_t = \alpha + \beta \cdot \text{Payments Received}_t + \varepsilon_t$$



McAndrews and Potter (2002)

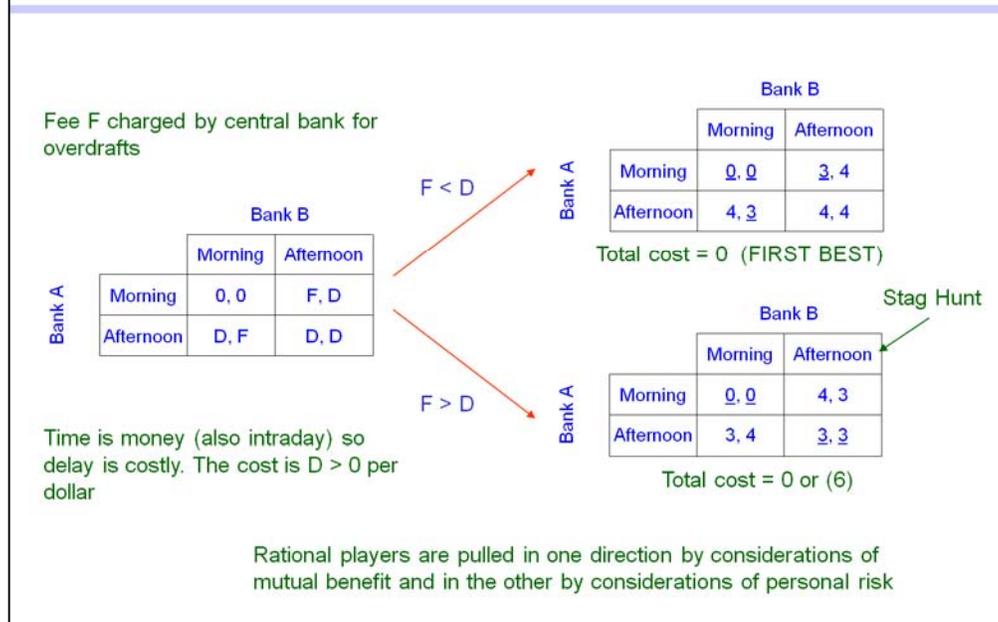
This graph shows the slope of the reaction function of Payments sent to payments received.

Prior to September 11<sup>th</sup> banks were sending out 80 cent for every dollar received looking over 10 min intervals.

This dropped to 20 cents per dollar on September 11<sup>th</sup> and the days immediately following.

The following week it increased to a dollar twenty presumably due to the availability of ample liquidity and bent up demand.

# The Intraday Liquidity Management Game

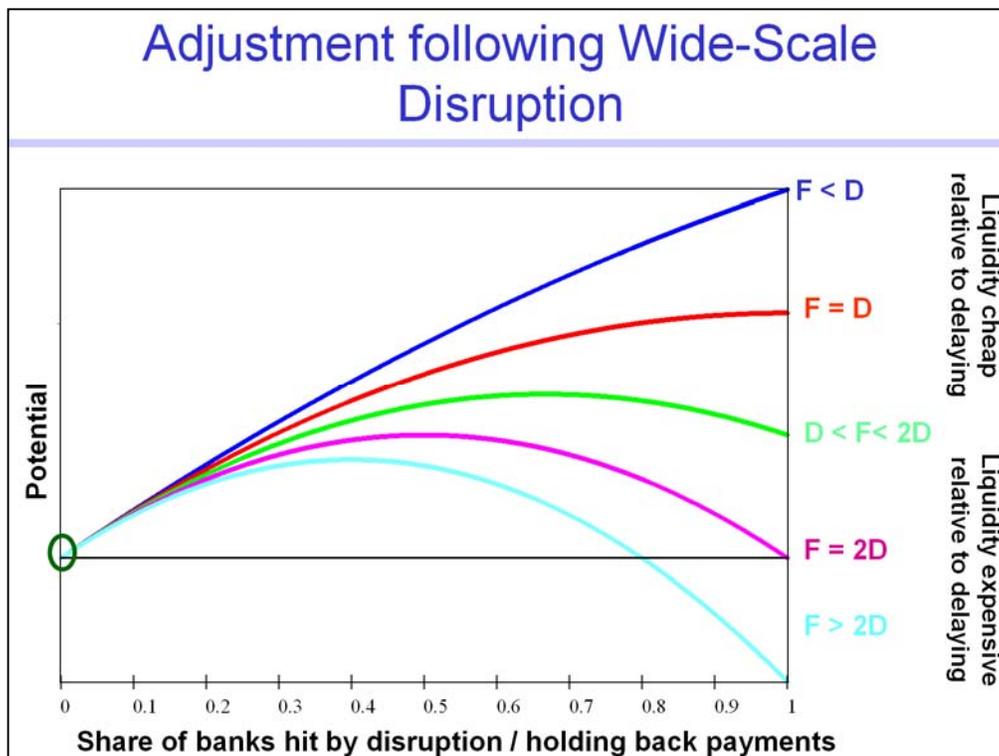


An Economist is someone that sees something in practice and wonder whether it would work in theory.

We use a modified version of the intraday liquidity management model in Bech and Garratt (2003).

Assume that we have

- 2 banks with \$0 in their Fedwire Account
- Each have to send \$1 on behalf of a customers with the beneficiary being a customer of the other bank
- Banks can either send the \$1 in the morning or in the afternoon
- If banks do not coordinate on sending payment at the same time one of them will incur overdraft at noon. The Fed charges the fee  $F$  for overdrafts.
- Time is money also intraday so it costly for banks to delay. Think of customer dissatisfaction. The cost is  $D$  per dollar
- Depending on the relative cost of delay and the cost of liquidity (the overdraft fee) we have two possible games
- If the cost of liquidity is less than the cost of delay. Banks have no incentive to delay and will process payments immediately. The equilibrium is morning, morning
- The interesting case is when the cost of delay is less than the cost of liquidity. This case we get a stag hunt coordination game were both morning, morning and afternoon, afternoon are equilibria.
- The morning, morning equilibrium entails lower costs but is risky in the sense that your pay off depends on the action of other. The afternoon, afternoon equilibria yields higher cost but are independent of the actions of others.



Extend a game to  $n$  players

Use the concept of a **potential function** to characterize the state of the system

Use the simple adjustment process suggested by Monderer and Shapley (1996) to describe the off equilibrium dynamics of the game

we take a wide-scale disruption to mean an event that prevents a subset of banks from making payments as normal.

Specifically, some banks are temporarily forced to play to the afternoon strategy, which takes the system out of equilibrium.

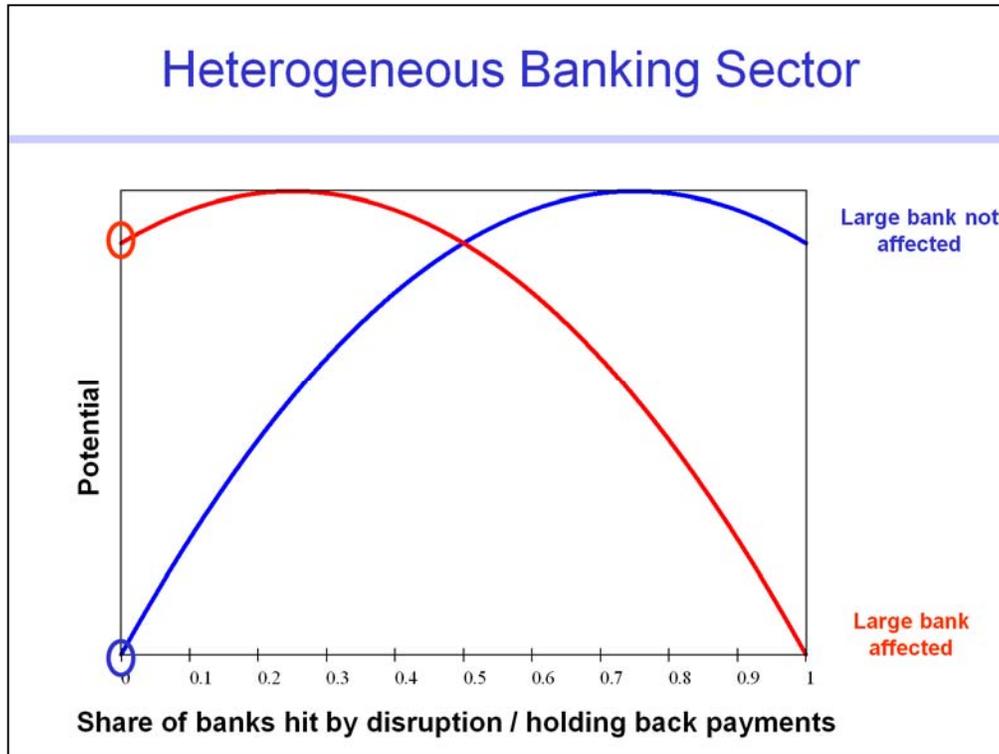
The size of the disruption can be measured by the share of banks that are disrupted.

After the disruption we assume that the disrupted banks again become operational and that they are, like the non-disrupted banks, free to choose either the morning or afternoon strategy.

The graph shows -1\*the potential function as function of the share of banks that play afternoon for different level of the cost of delay relative to the cost of liquidity. Hence NEs are now the minima of the function.

If the cost of liquidity is less than the cost of delay the system will be self-

## Heterogeneous Banking Sector

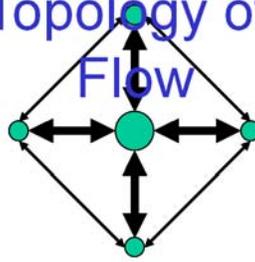


Unilateral deviations back to the morning strategy are profitable from the perspective of the small banks if and only if the merged bank is not affected by the disruption. Hence, if the merged bank is not affected by the disruption, then the system will revert back to the morning equilibrium on its own. CLICK!

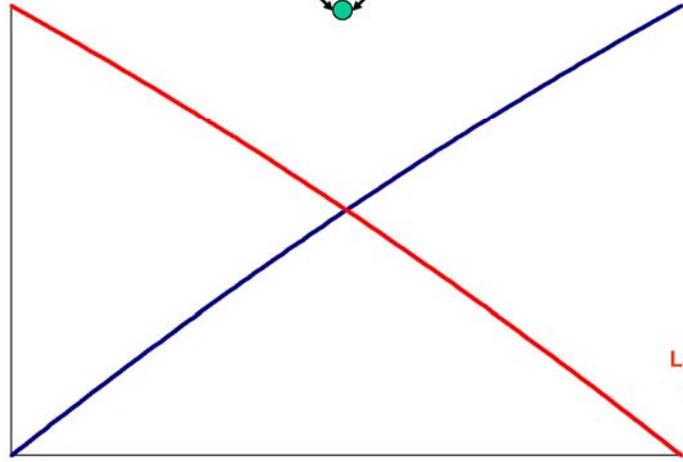
On the other hand, if the merged bank is affected by the disruption, then it is profitable for small banks not affected to change their strategy to afternoon and for small banks that are affected to stick with the afternoon strategy. Immediately following the disruptions, it is profitable for a merged bank to revert back to the morning strategy. However, this will not continue to be true after enough small banks have adjusted to the afternoon strategy

Basically, the adjustment process following the disruption is a horse race between the merged bank becoming operational again and the number of small banks deciding to cease coordinating on early processing

# Network Topology of Payment



Potential



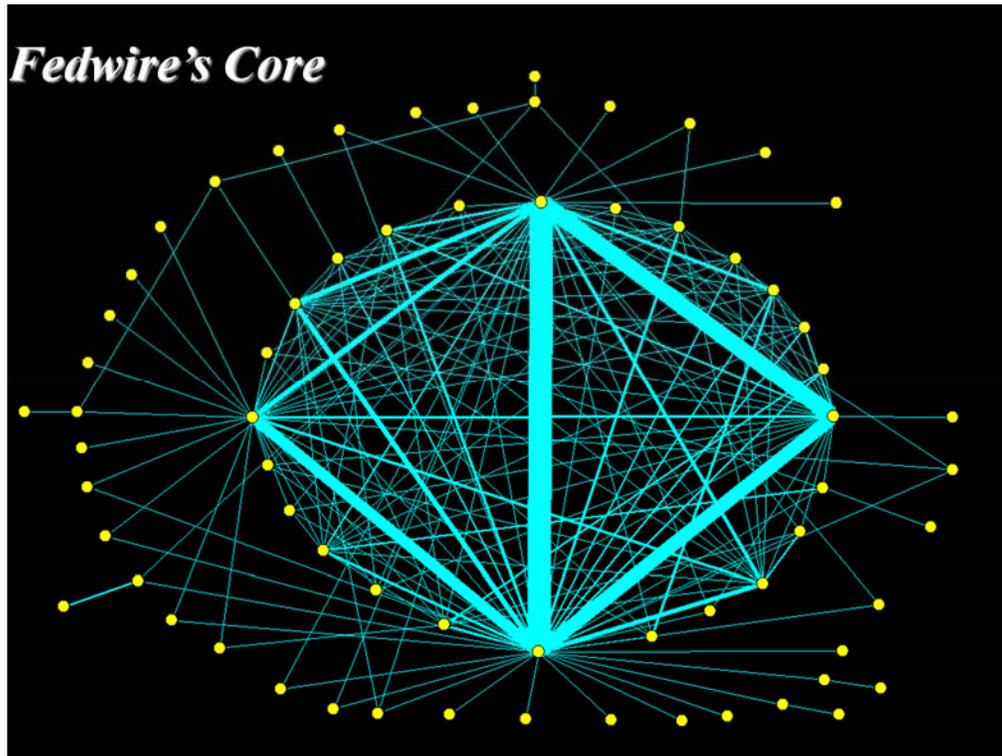
Large bank not affected

Large bank affected

## Research Goals

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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



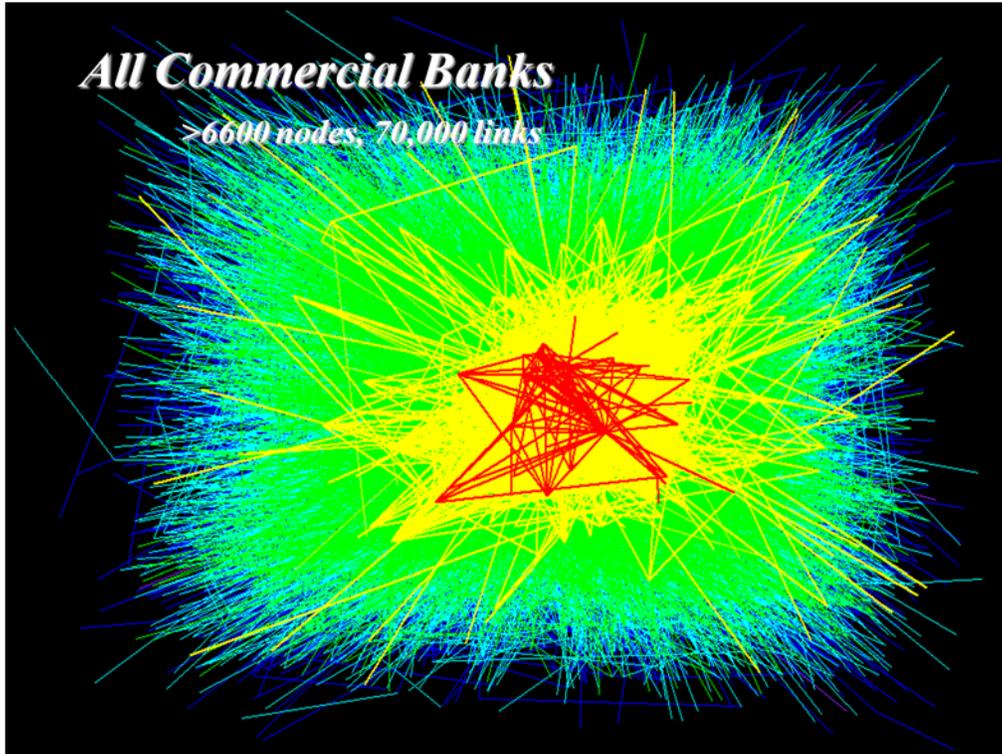
Compact Core:

75% of value transferred by 66 nodes and 181 links

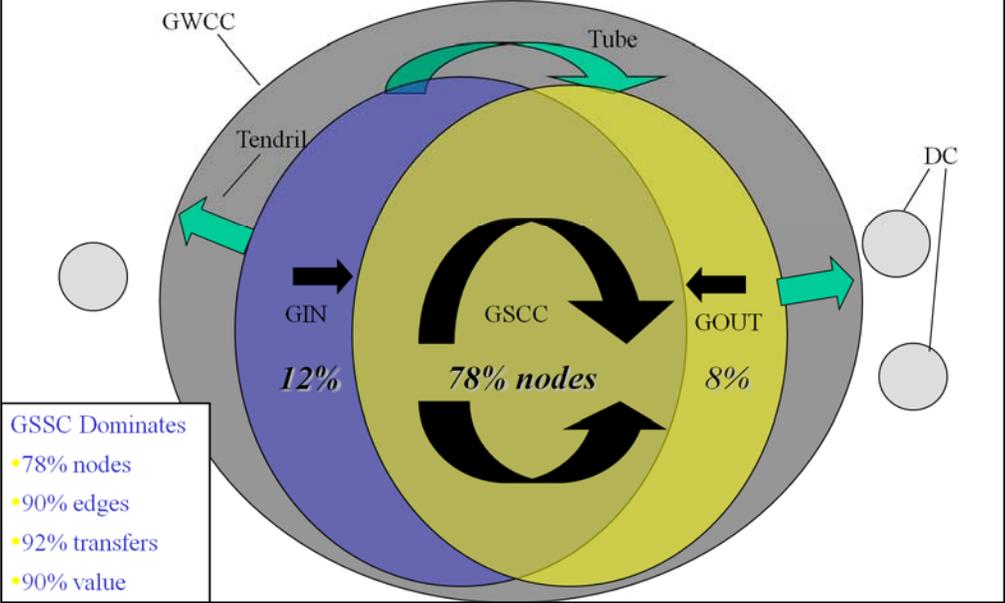
25 nodes of this group form a nearly complete sub-network

***All Commercial Banks***

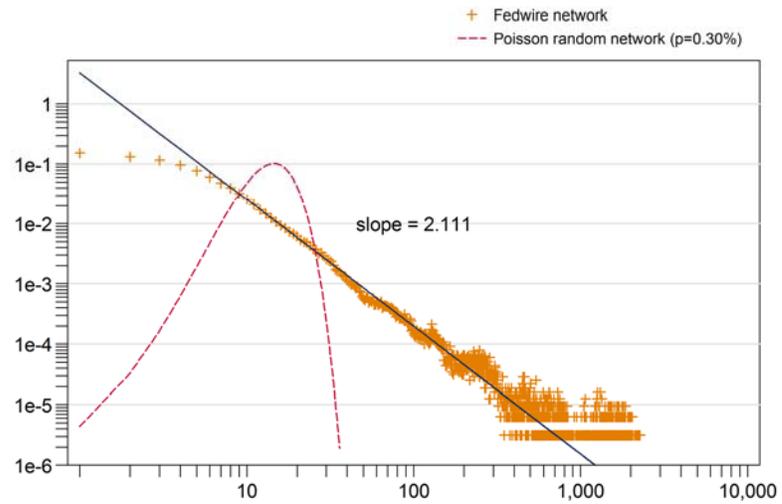
*>6600 nodes, 70,000 links*



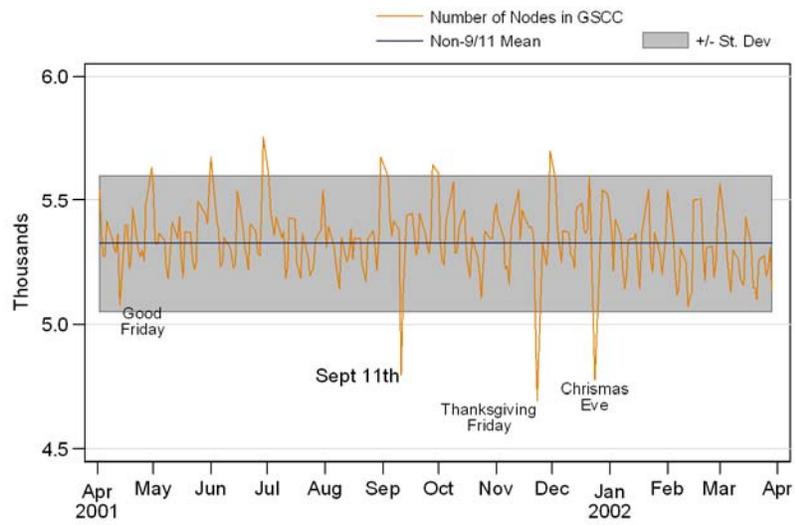
# Network Components



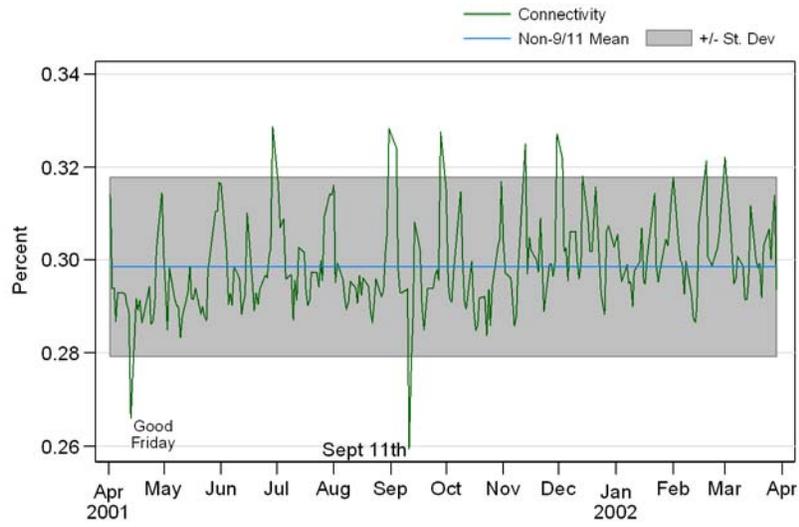
# Out-Degree Distribution



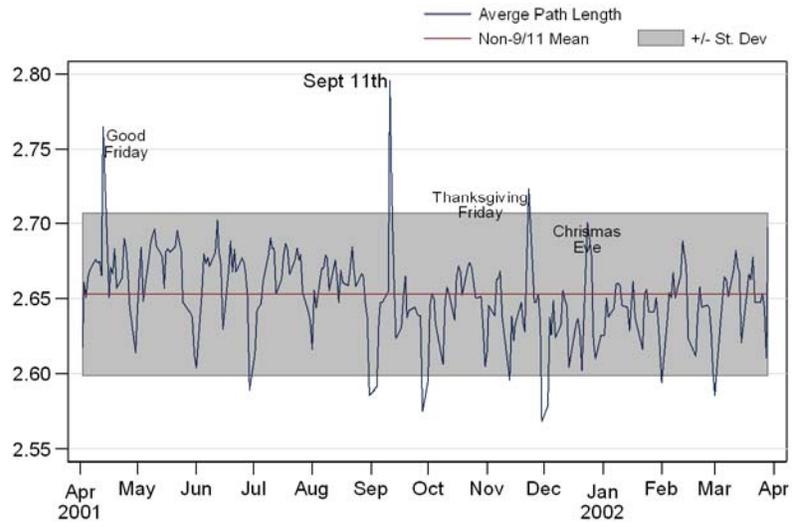
# Number of Nodes in GSCC



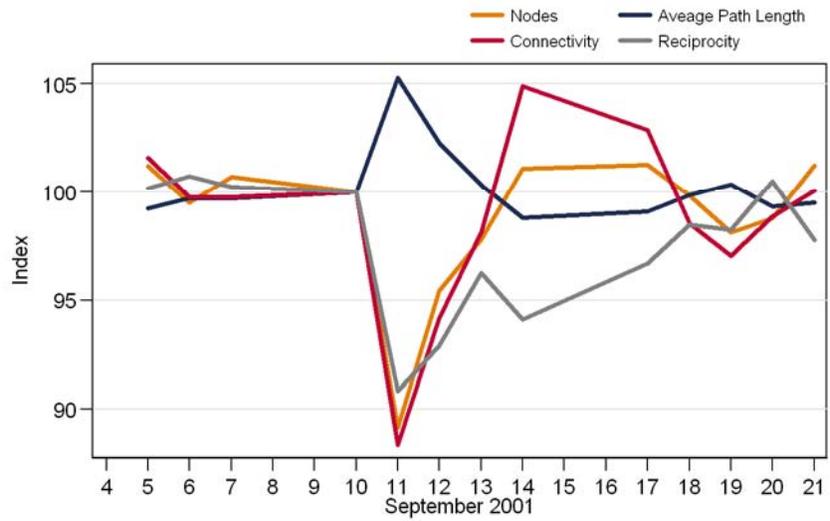
# Connectivity



# Average Path Length

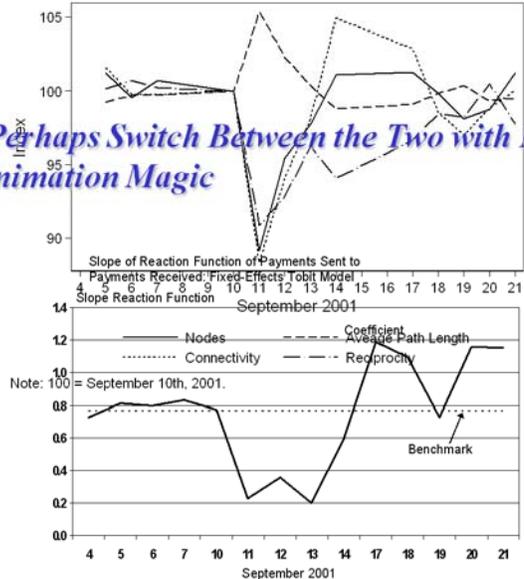


# 9/11



# Structure ↔ Behavior

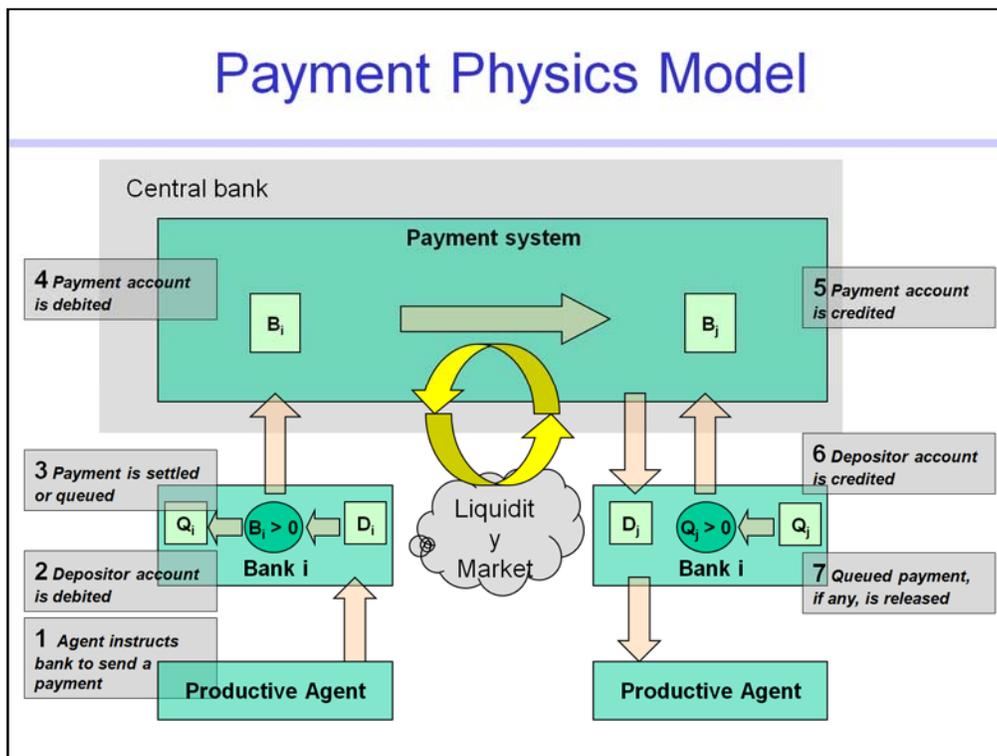
• Perhaps Switch Between the Two with Morten Animation Magic



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We've decided to begin simply, adding features and processes once we understand how the system works without them. This model was developed in the spirit of SOC models, which try to understand how a collection of agents, following simple rules that respond to local stresses, produce a system that has interesting properties, such as fat-tailed distributions. The art is to capture the critical agent processes as simply as possible.

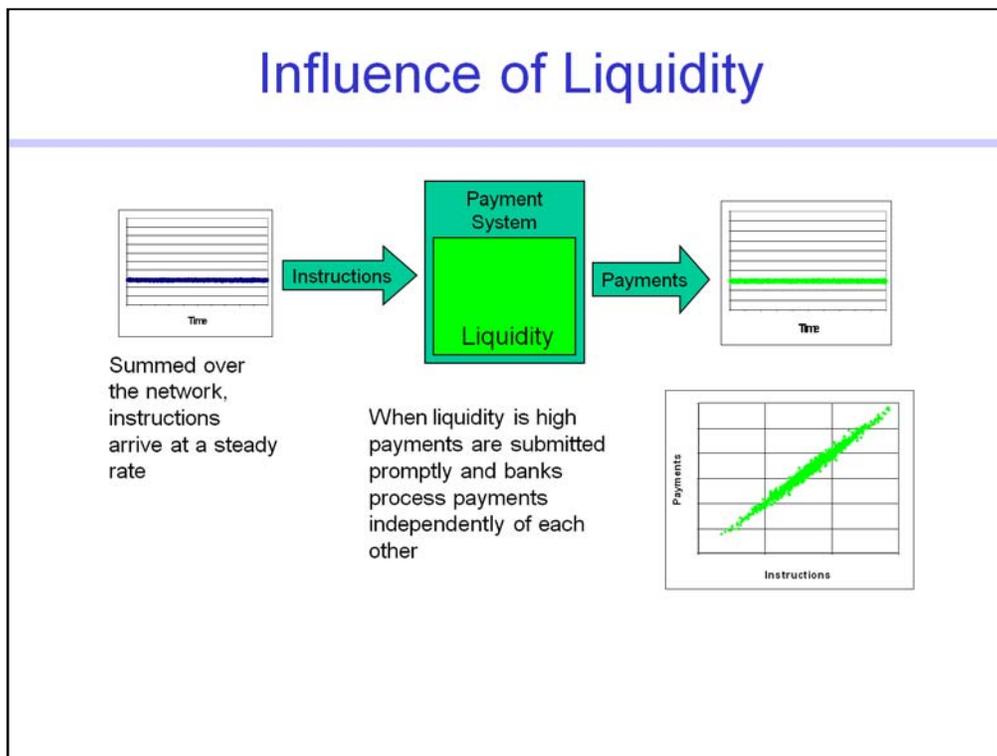
Banks form the network nodes, and payment relationships among banks define the network links. Here we depict the processes that control the states of two nodes I and J connected by a payment link.

Real-world bank's decisions can include many factors (we are studying this in a more complex model). Here they only consider balance, and they pay if possible. They are reflexively cooperative, and so any loss of coordination we see is only a result of liquidity shortages (the first factor Morten discussed) and not to hoarding.

Payments allow receiving banks to send a queued payment: processing becomes coupled when liquidity is scarce.

In the "primitive" system banks must wait for incoming payments to fund their operations. This is unpredictable and inefficient. Real systems include other procedures for managing this scarce resource. Here we include a liquidity market that creates a second set of pathways for banks to share liquidity. This is a simple linear diffusion process in which excess funds flow into the market from some banks and out of the market to others.

## Influence of Liquidity



Here we look at aggregate behavior of the system: input (total instructions) and output (total payments) in intervals

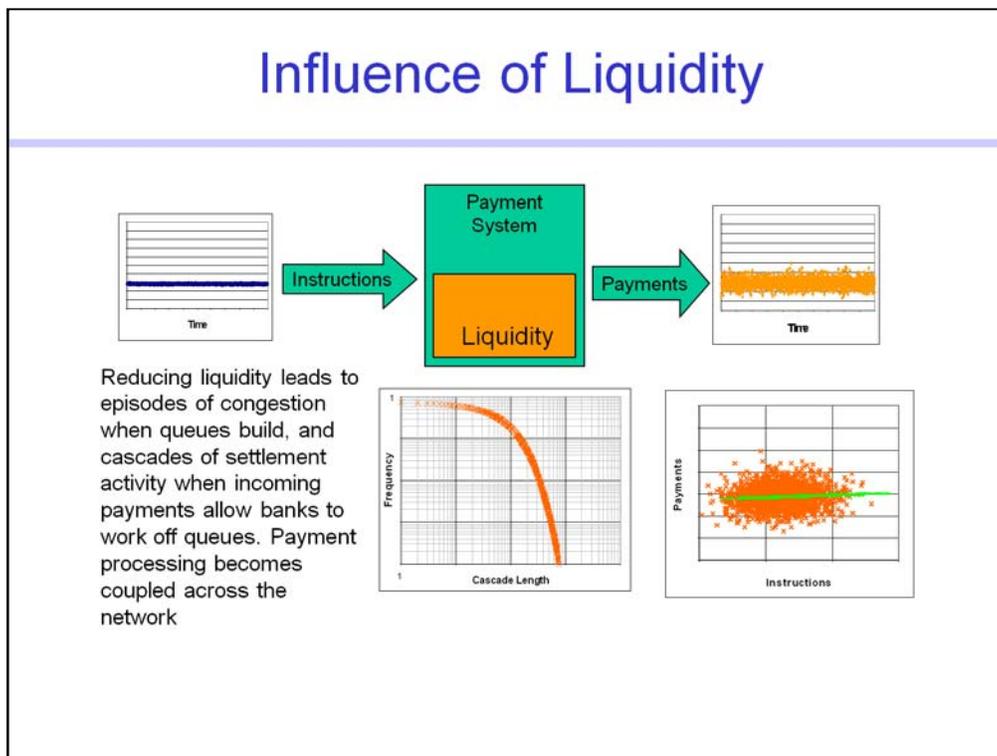
Banks see independent random instruction streams. Adding over all banks produces a fairly uniform stress

High-liquidity output closely tracks input; easier to see on scatter plot because variations are small

Lowering liquidity couples processing across banks. Payments loose correlation with input because their timing becomes determined by internal dynamics of the system.

NOTE: we would see increasing correlation of payment activity between neighboring banks as correlation with instructions declines. This is akin to reaction function.

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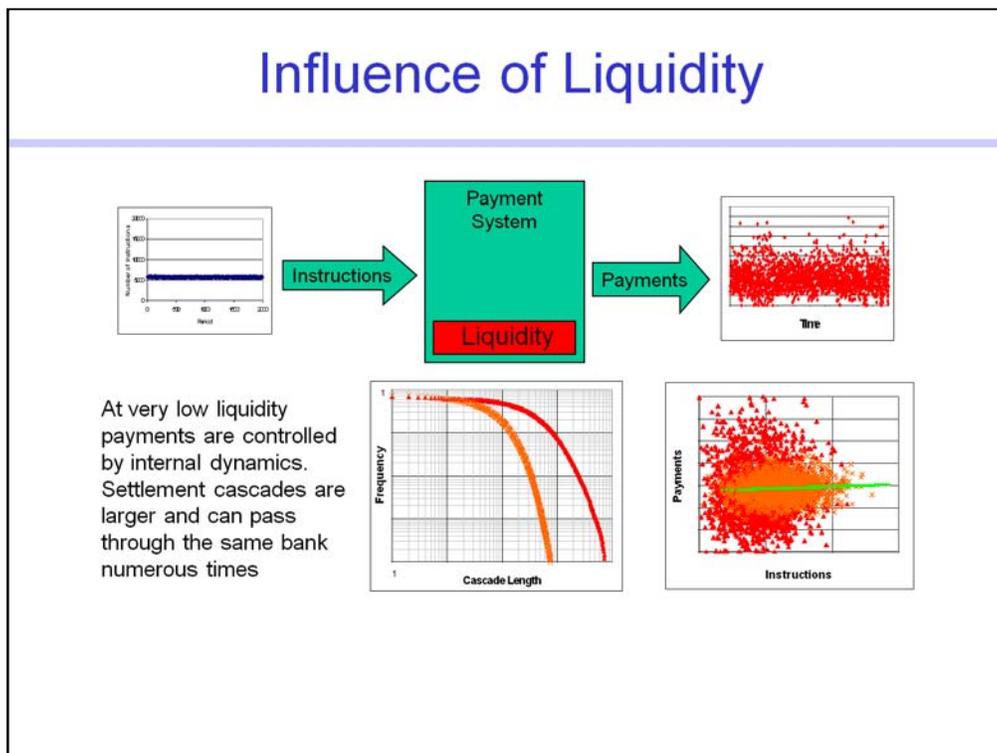
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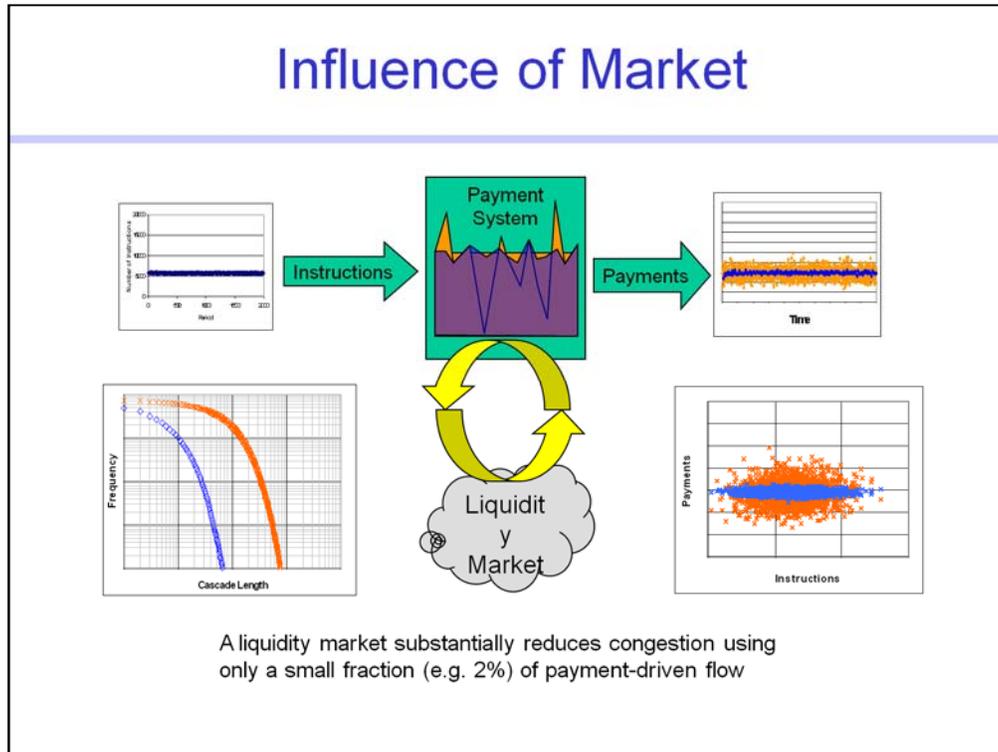
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## Influence of Market



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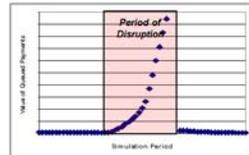
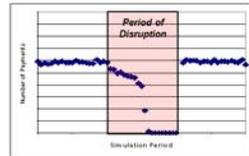
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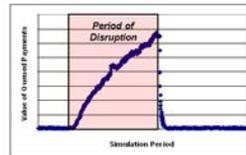
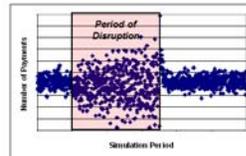
## Ongoing Disruption Analyses

Disruption of a bank creates a liquidity sink in the system



System throughput can be rapidly degraded

Disruptions to liquidity market represented as decreased conductance



Queues build; system becomes increasingly congested; recovery quickly follows restoration

One next step is to see how the model responds to disruptions. We're just starting, these are initial preliminary results.

## What we're learned

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- 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 researchers 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