Discussion of the formulation of models of payment systems

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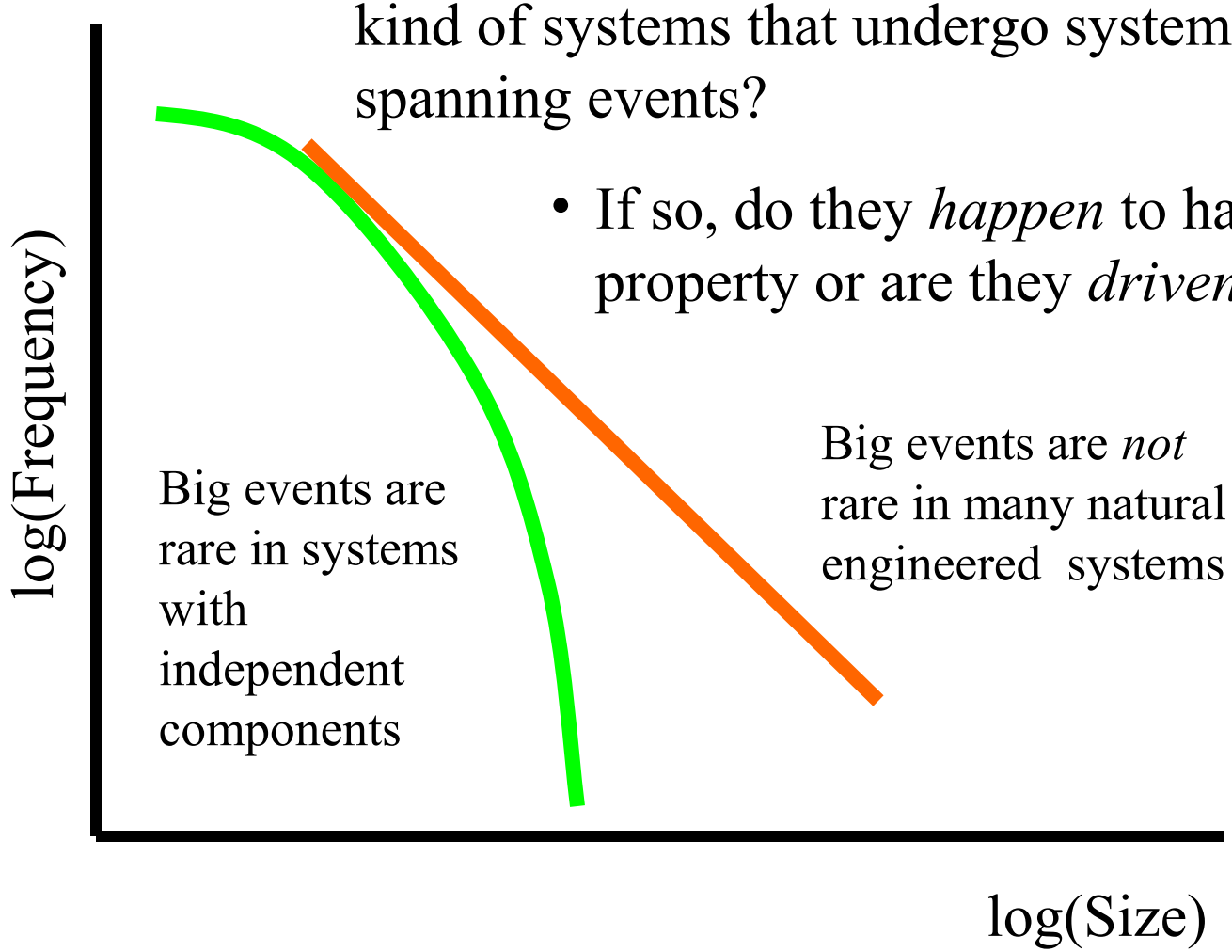
- Are particular (multi)infrastructures the kind of systems that undergo system-spanning events?
  - If so, do they *happen* to have this property or are they *driven* to it?



Physics of Financial Systems

- Purpose of “complexity” models
  - Understand how interactions among many agents might generate system-level behavior
  - Understand regimes of behavior and what governs transitions among them

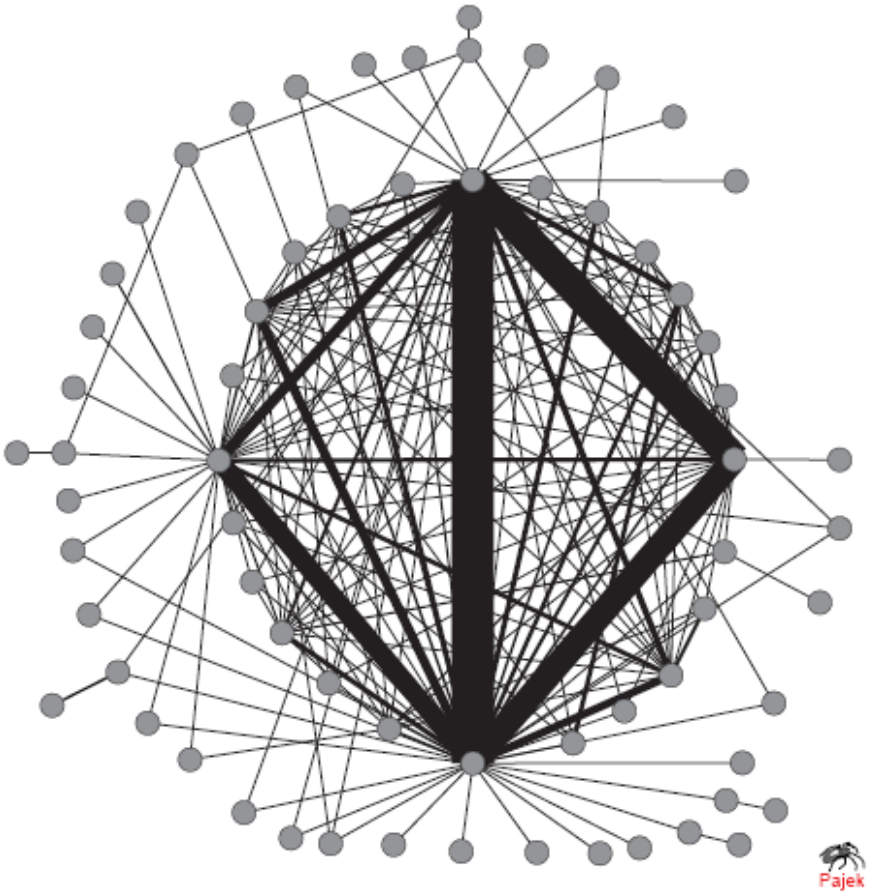


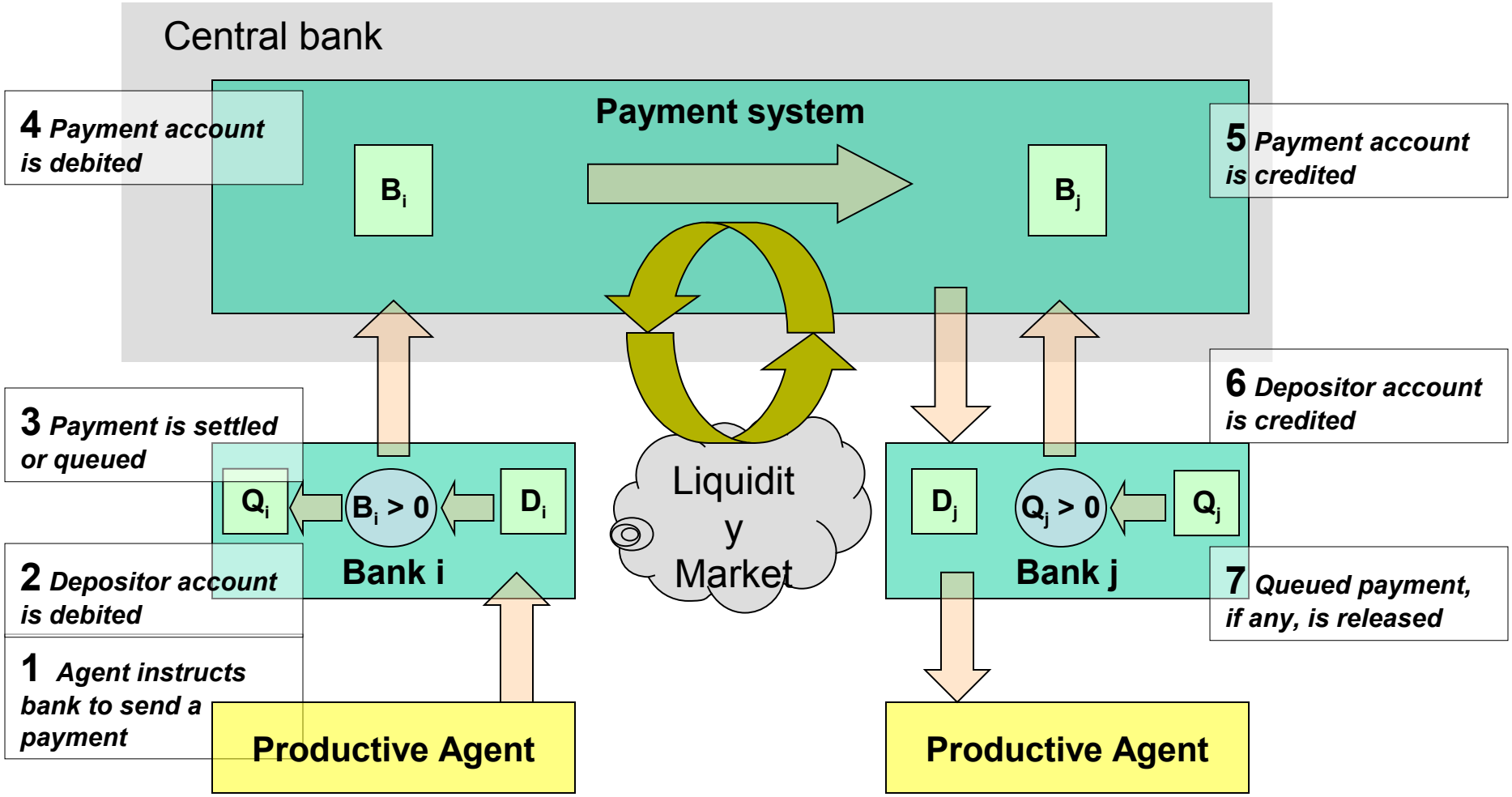
Fig. 2. Core of the Fedwire interbank payment network; largest undirected links equivalent to 75 percent of daily value transferred.

There are several network layers: we concentrate on how the system is used by banks

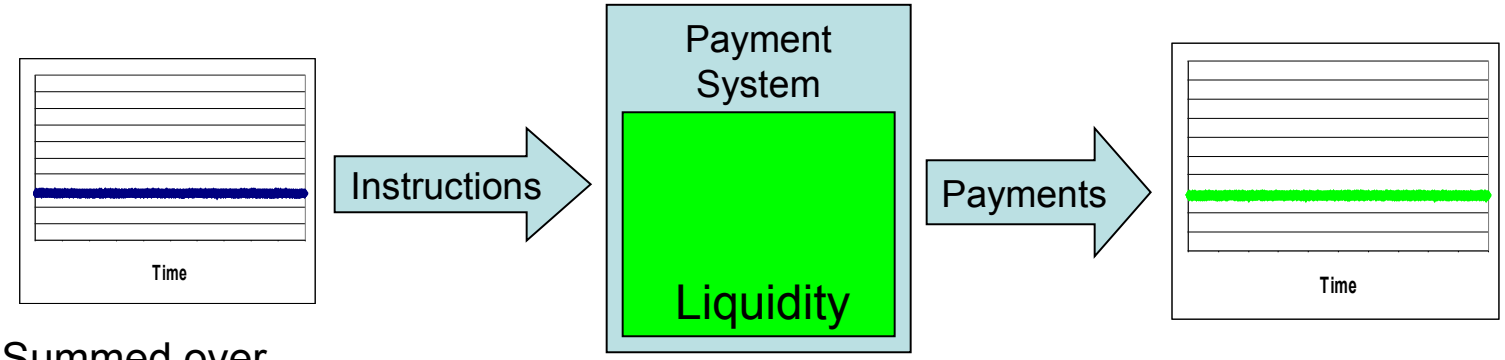
A bank's decision problem is analogous to managing a checking account: how do I meet demands for prompt payments without maintaining a wasteful balance?

-Use income to fund payments
-Delay payments
-Borrow funds

Payment Physics Model

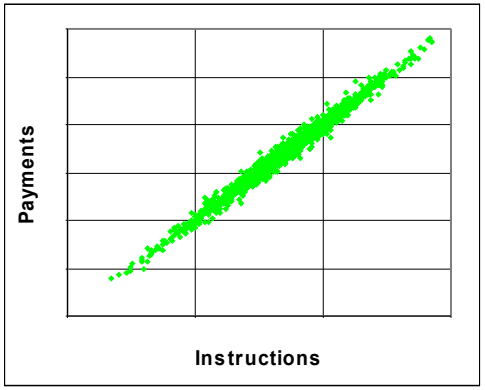


Influence of Liquidity



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



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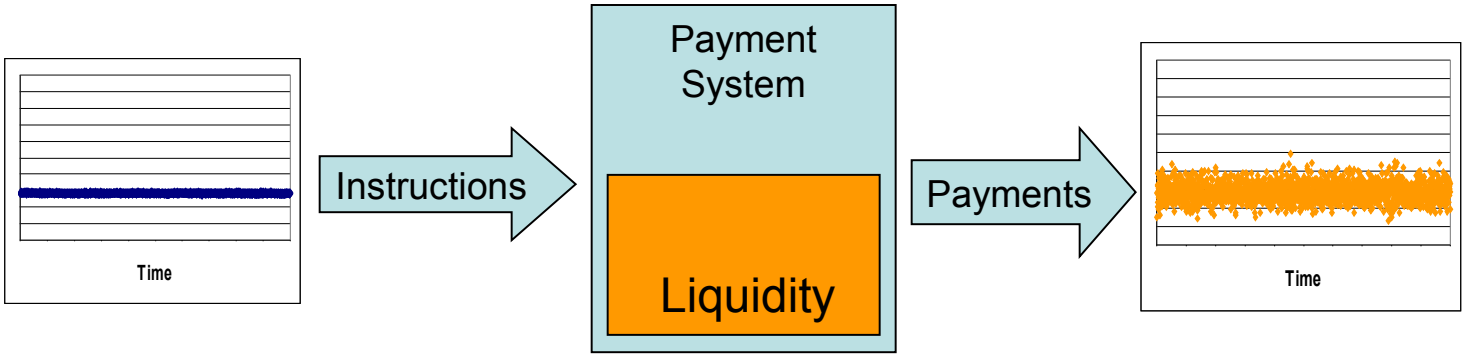
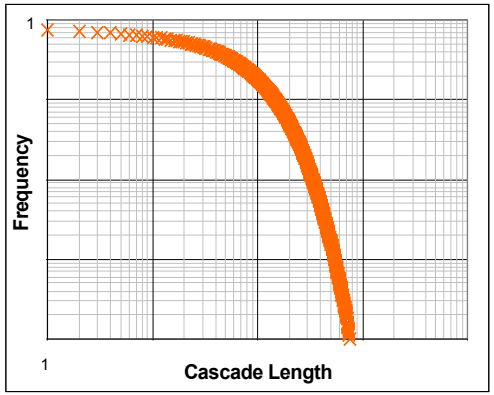
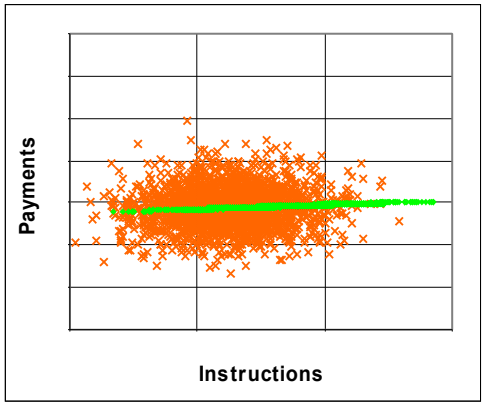


Reducing liquidity leads to episodes of congestion when queues build, and cascades of settlement activity when incoming payments allow banks to work off queues. Payment processing becomes coupled across the network





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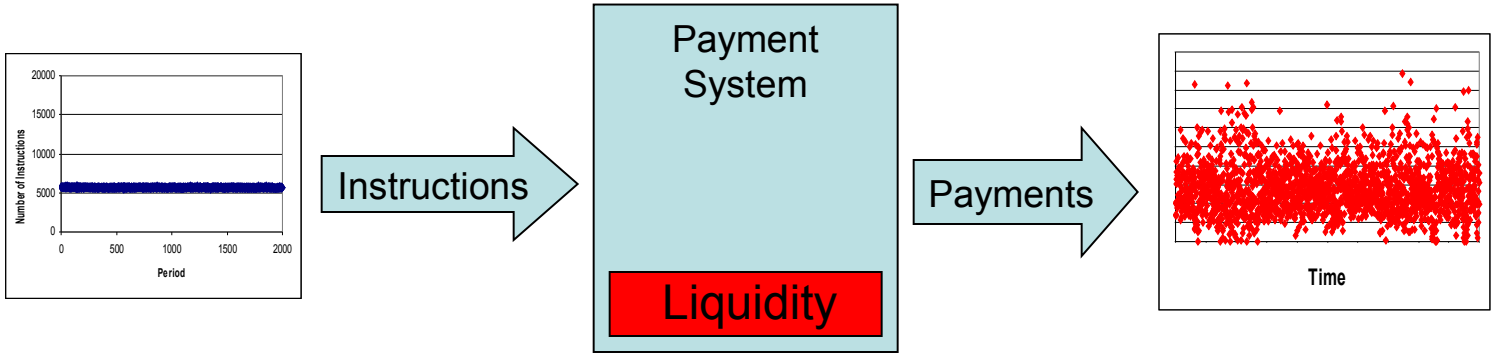
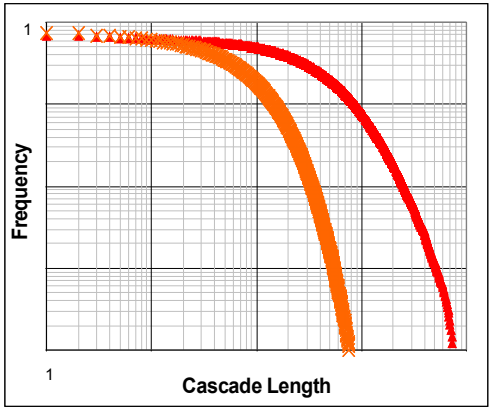
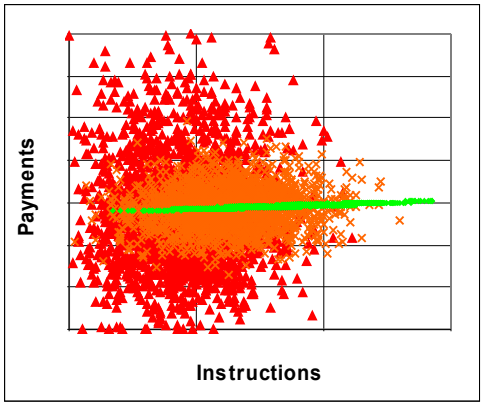
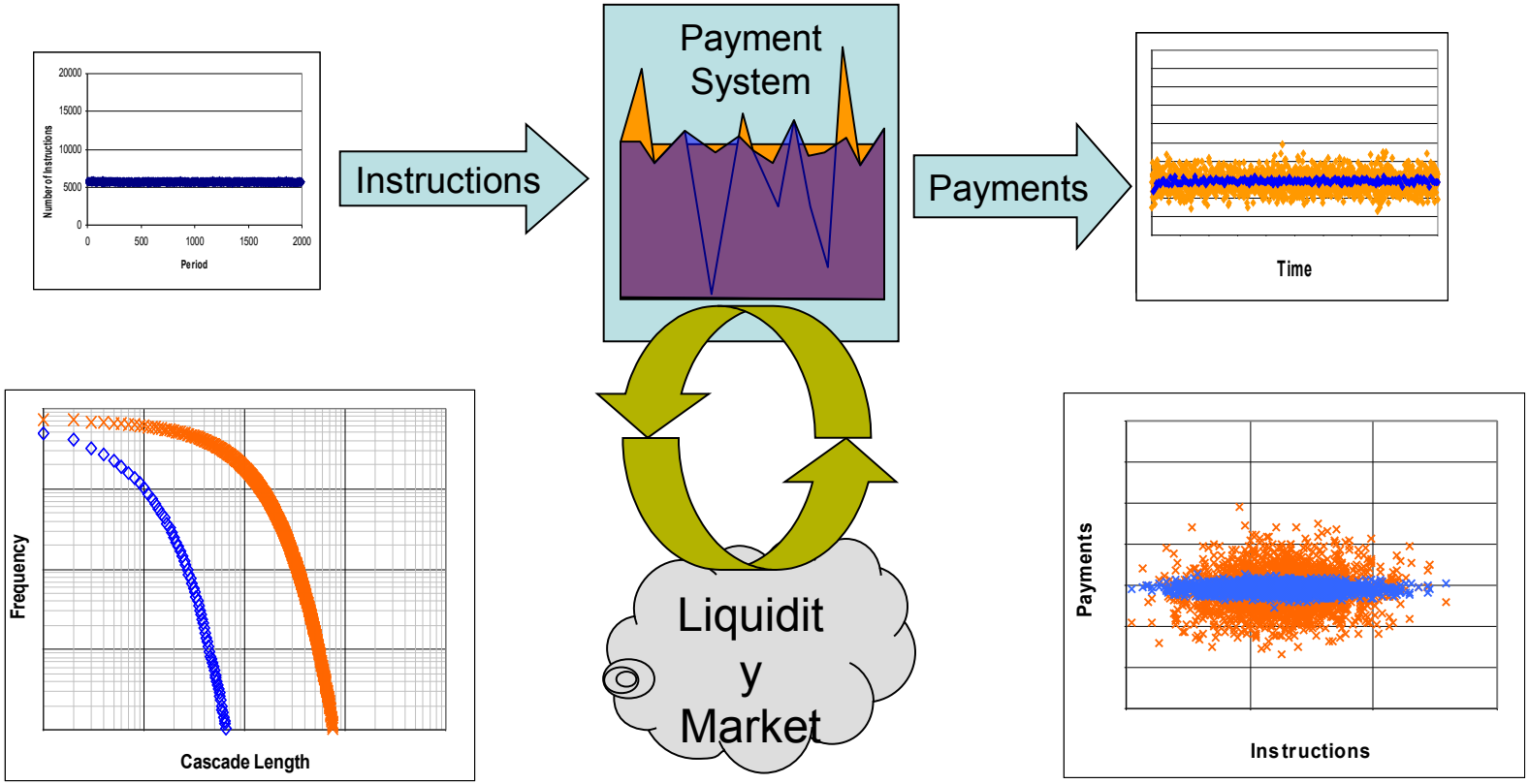


At very low liquidity payments are controlled by internal dynamics. Settlement cascades are larger and can pass through the same bank numerous times



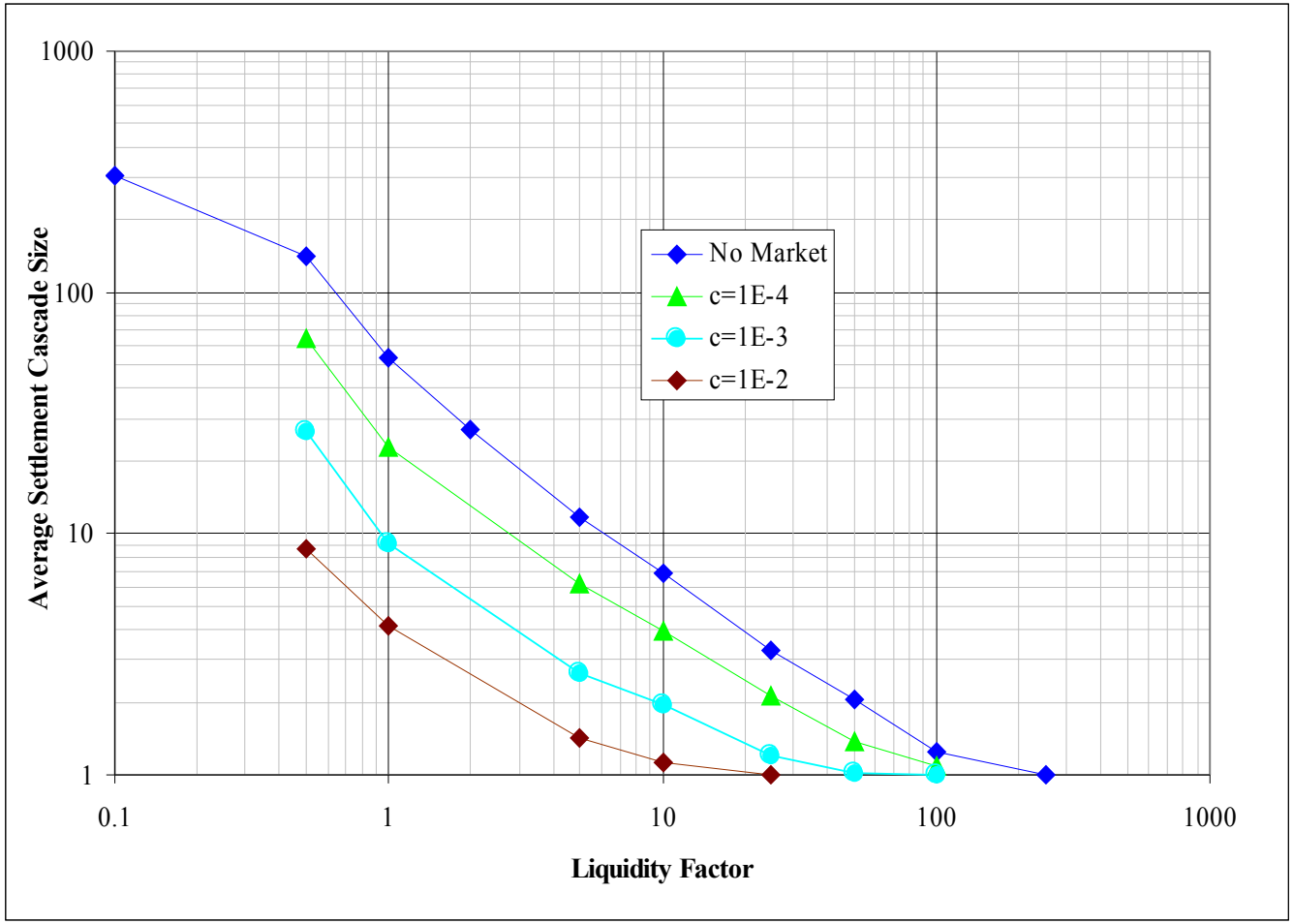


Influence of Market

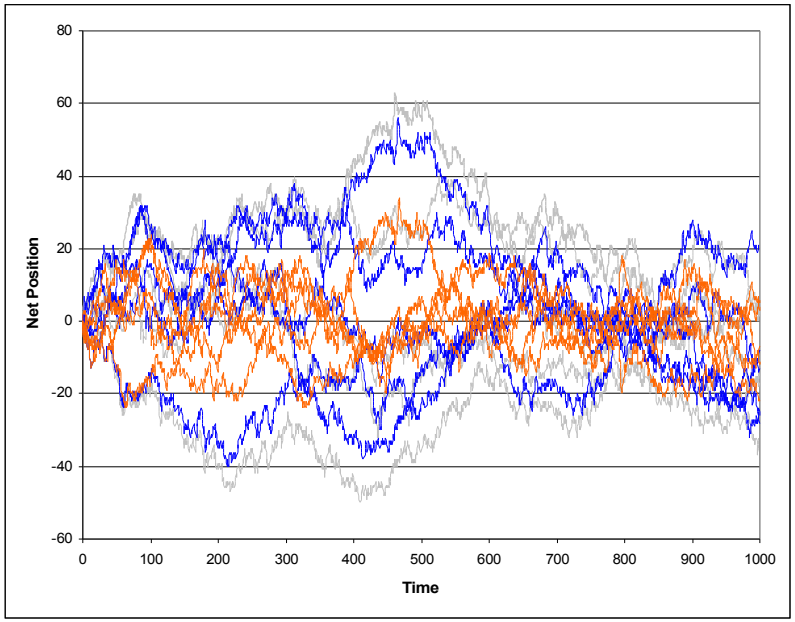


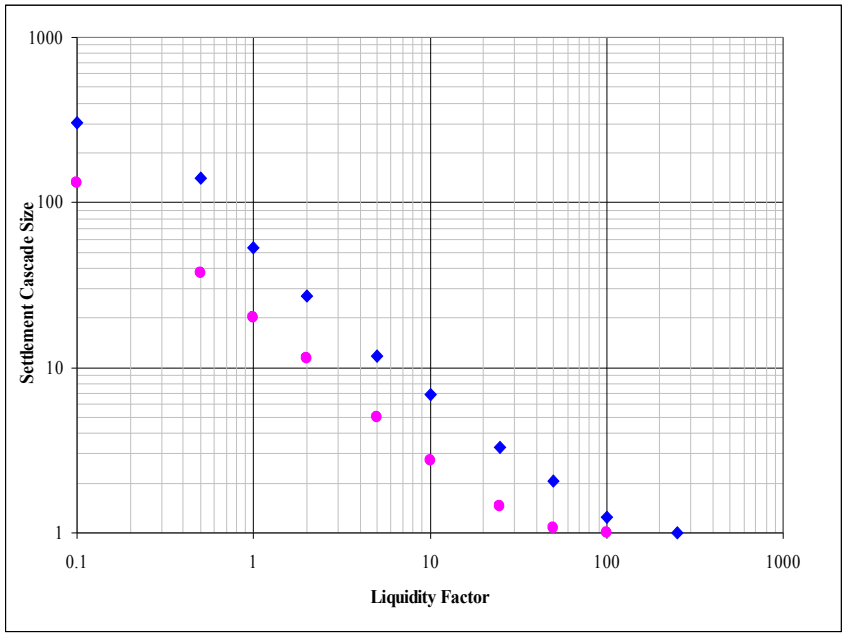
A liquidity market substantially reduces congestion using only a small fraction (e.g. 2%) of payment-driven flow

Liquidity and Markets Influence Congestion



Influence of Return Time on Congestion



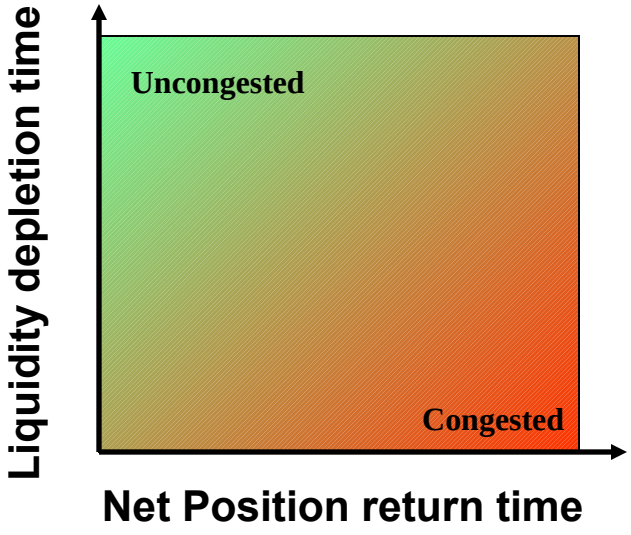


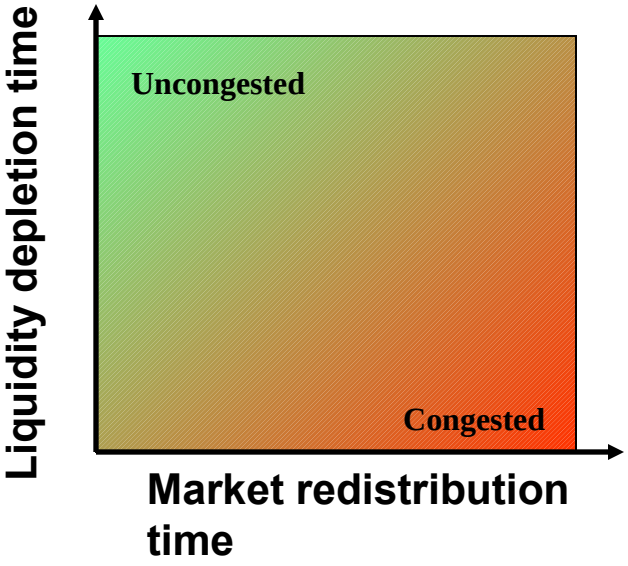
Amount of deposits determines the variability of a bank's net position

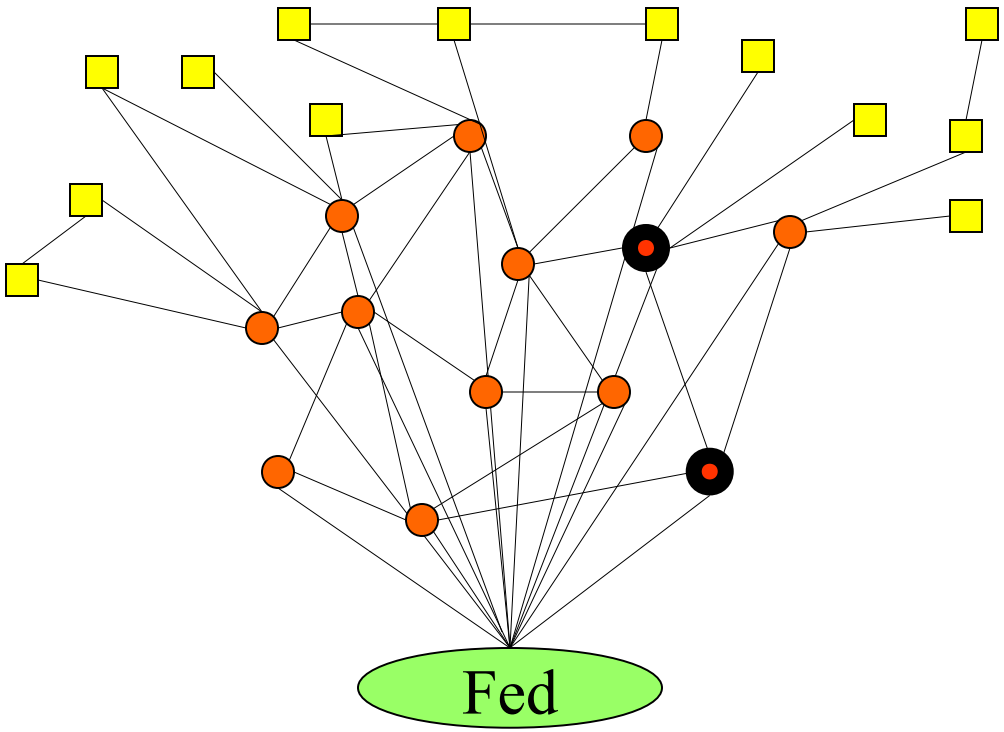
Less variability leads to less congestion

What influences congestion?

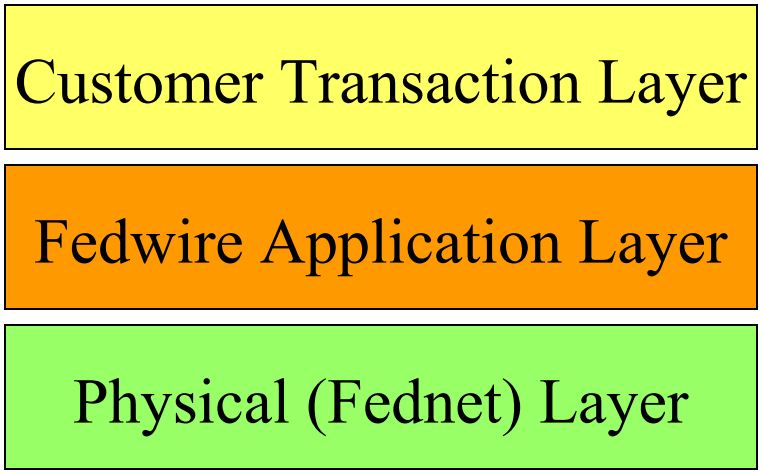
- Three key time constants
  - Time over which a bank is in surplus or deficit (d_0)
  - Time to deplete initial liquidity (L)
  - Time for the market to redistribute liquidity (1/c)







The payment system can revert to a “star” topology at the bank level through market transactions or Fed intervention



And what about transactions that are more strongly tied to specific counterparties?

What we're learned

- System performance can be greatly improved by moving small amounts of liquidity to the places where it's needed
- System congestion seems to be determined by the relative values of three time constants
  - Liquidity depletion time
  - Net position return time
  - Liquidity redistribution time through the market

- *What about disruptions?* …

Congestion and Cascades in Coupled Payment Systems

Motivation for the model

- The 2001 Group of Ten *"Report on Consolidation in the Financial Sector"* (the Ferguson report) noted a possible increased interdependence between the different systems due to:
  - The emergence of multinational institutions with access to several systems in different countries
  - The emergence of specialized service providers offering services to several systems
  - The development of DvP procedures linking RTGS and SSS
  - The development of CLS

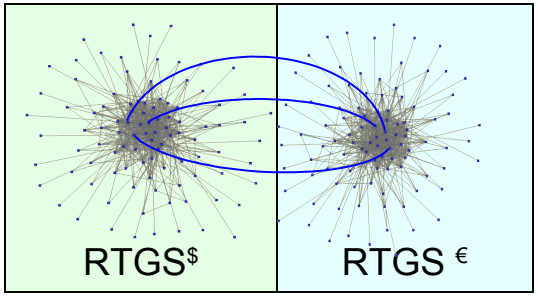
- The report suggested that these trends might accentuate the role of payment and settlement systems in the transmission of disruptions across the financial system.
- To complement this previous work, the CPSS (Committee on Payment and Settlement Systems) commissioned a working group to:
  - describe the different interdependencies existing among the payment and settlement systems of CPSS countries
  - analyze the risk implications of the different interdependencies

- Tools used by the group:
  - Fact-finding exercise (data from CB and questionnaire sent to the 40 largest financial institutions in the world)
  - Interviews with the banks and systems
  - Case studies…

- Could a modeling approach provide any useful additional information to the regulators ?

Payment Systems Coupled through Foreign Exchange

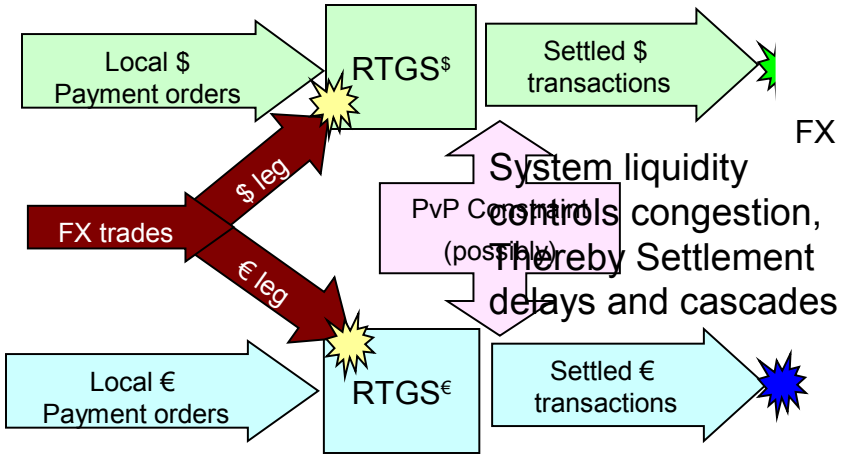
- RTGS$^{\$}$ and RTGS$^{€}$ are two large-value payment systems with two different currencies: $ and €
- RTGS$^{\$}$ and RTGS$^{€}$ have similar structures, based on the network statistics of the large core banks in the Fedwire and TARGET systems
- 6 large "global" banks make FX trades (at constant exchange rate) among themselves

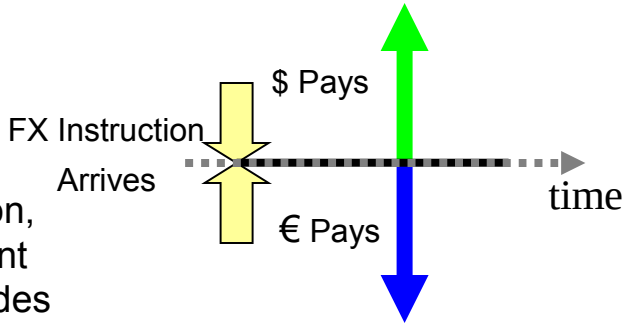


Settlement Time Differences Create Exposures

Each system processes:

- Local payment orders
- Their leg of FX trades





- **The systems are coupled:**
  - At input via the coupled instructions from FX trades
  - At output via a possible PvP constraint

Payment vs. Payment (PvP) *Eliminates* Exposures by Requiring Simultaneous Settlement

Findings: Settlement Cascades

High liquidity PvP or non-PvP

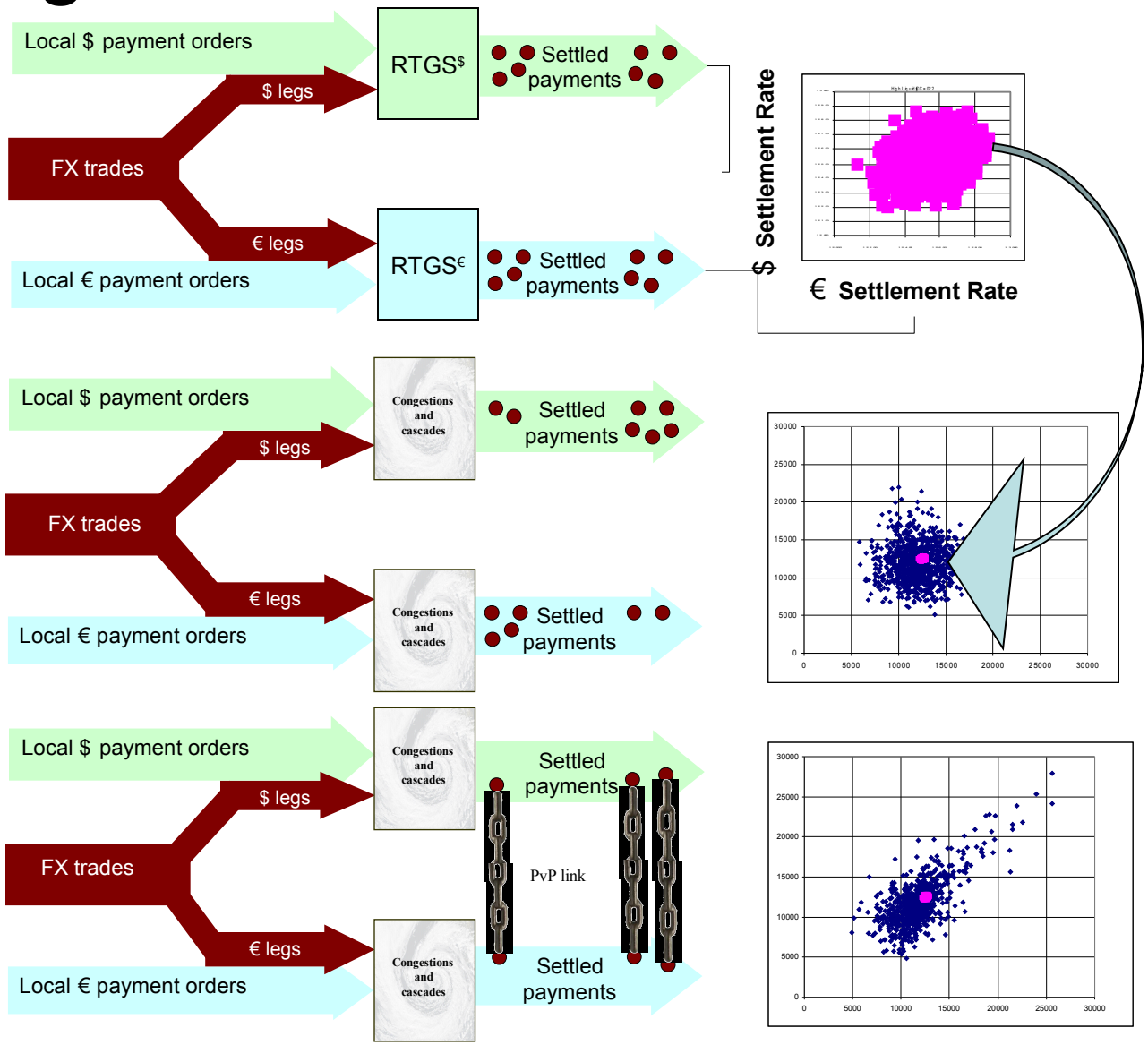
- Output tracks input
- Little variance in settlement rate
- Output correlation reflects common FX input

Low liquidity non-PvP

- Congestion greatly increases settlement variance
- Common input is no longer visible

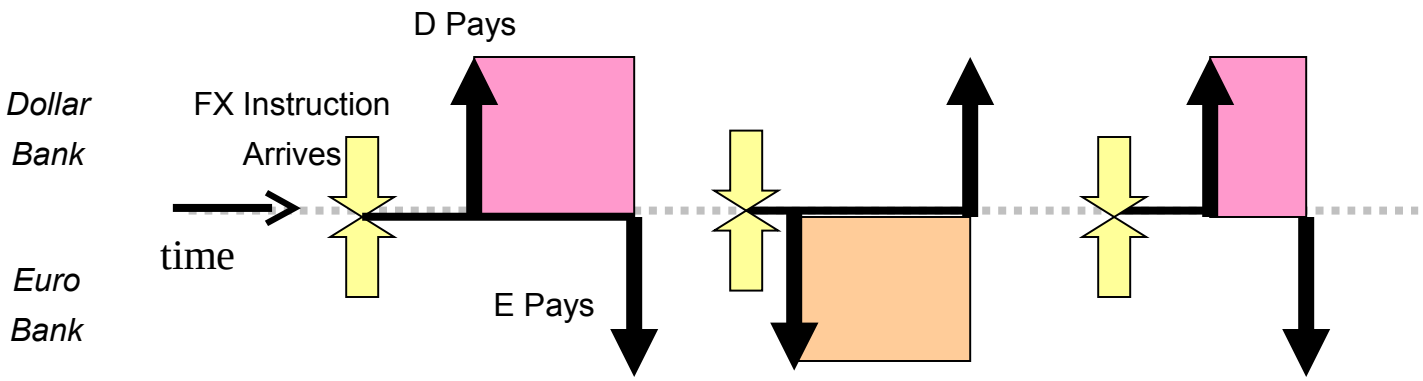
Low liquidity PvP

- PvP constraint *coordinates* and enlarges cascades
- Settlements have high variance and *more correlation than input*



Exposure of Banks

Non-PvP Creates Exposure due to Differences in Settlement Times

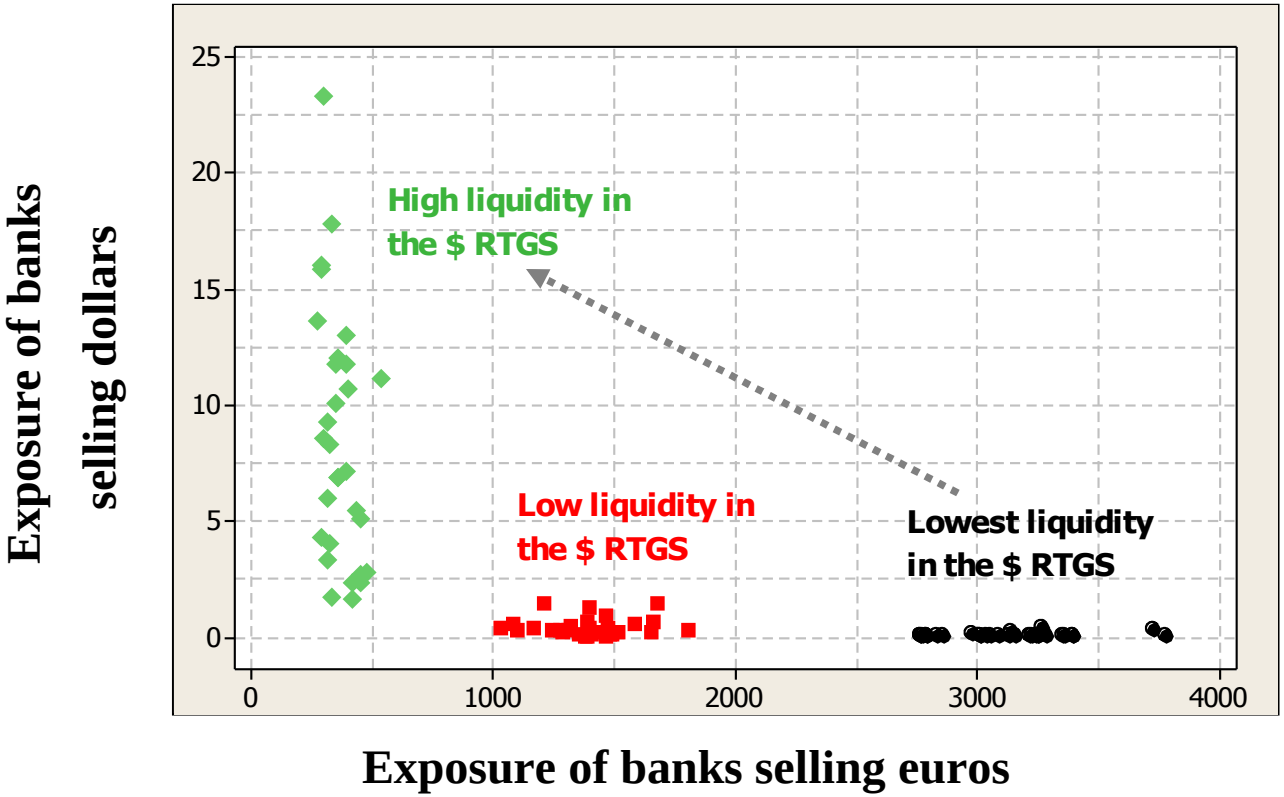


Settlement times may differ due to:

- structural differences (e.g. time zone differences or topology).
- Liquidity differences

Findings: Exposure

Adding liquidity to a system improves its performance, but may *increase* exposure to the other system while *decreasing* the other system's exposure to the first: one system bears the costs and the other receives the benefits



Conclusions

- At high liquidity the common FX drive creates discernable correlation in settlement
- At low liquidity
  - Congestion destroys instruction/settlement correlation in each system,
  - Coupling via PvP *amplifies* the settlement/settlement correlation by coordinating the settlement cascades in the two systems
- Queuing in systems increases and becomes interdependent with PvP
- Congestion and cascades becomes more prevalent with PvP
- Exposure among banks in the two systems
  - Is inversely related to liquidity available.
  - Is reduced by prioritizing FX
- Banks selling the most liquid currency are exposed

- Results are not confined to FX; other linked settlements will create the same kinds of interdependencies

Performance During Disruptions

Performance and resilience to liquidity disruptions in interdependent RTGS payment systems

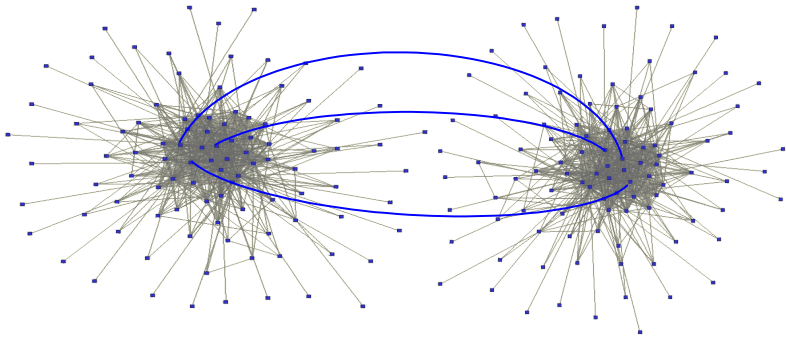
Joint Banque de France / European Central Bank conference on
"Liquidity in interdependent transfer systems"
Paris, 9 June 2008

Fabien Renault[1], Morten L. Bech[2], Walt Beyeler[3], Robert J. Glass[3], Kimmo Soramäki[4]

[1]Banque de France, [2]Federal Reserve Bank of New York, [3]Sandia National Laboratories, [4]Helsinki University of Technology

Conclusions

- **During normal operation, the two RTGS are interdependent**
- **When a liquidity crisis affects one RTGS, the crisis propagates to second RTGS in all considered cases**
  - PvP:
    - sharp decrease in activity (local and FX) in second RTGS
  - Non-PvP:
    - Decrease in activity in second RTGS due to fewer FX trades emitted
    - At low liquidity, local payments in second RTGS are also affected
    - Large increase of FX exposures during crisis and recovery



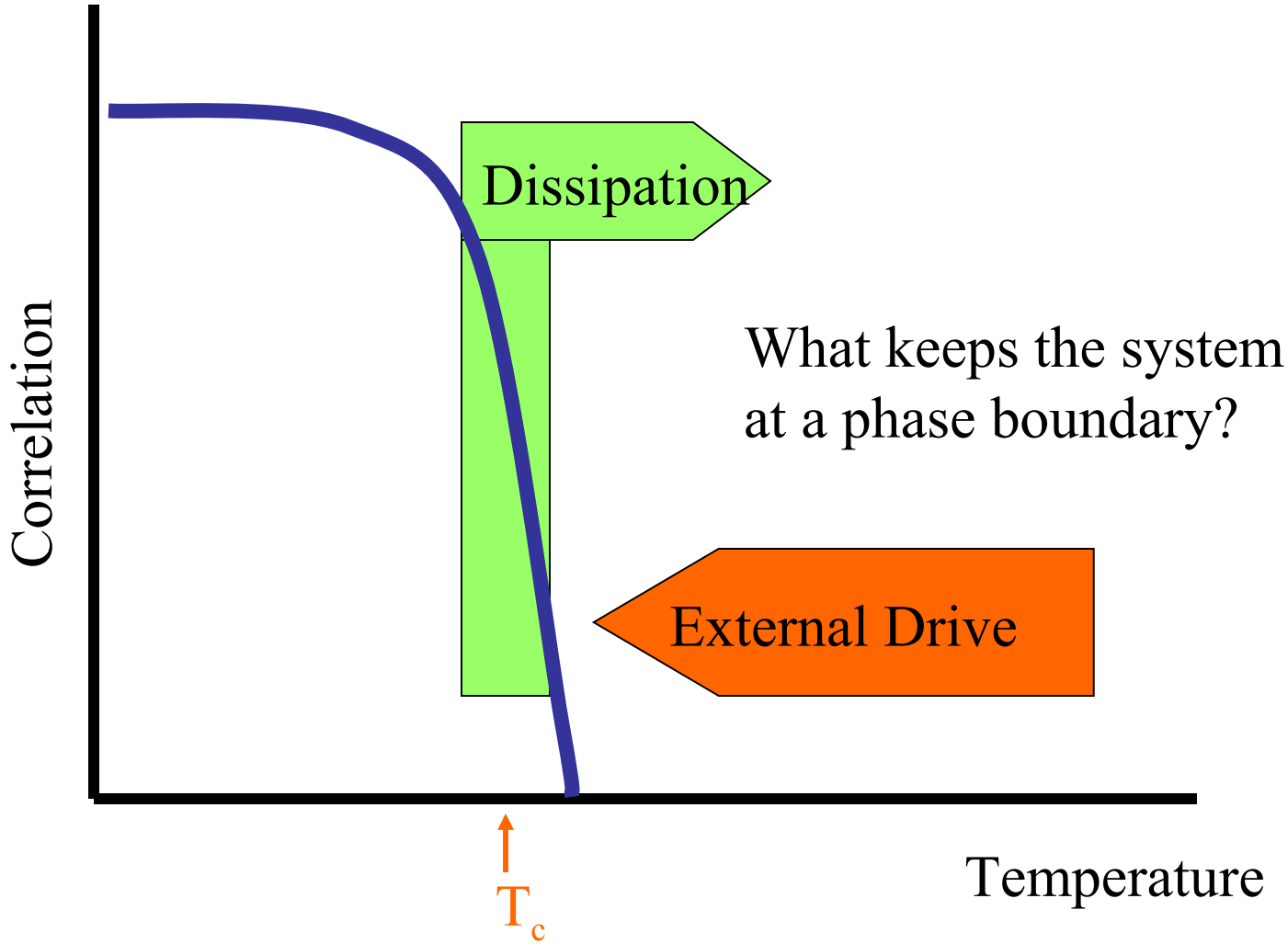
References

Publications

- A General Engineering Framework for the Definition, Design, Testing and Actualization of Solutions within Complex Adaptive Systems of Systems (CASoS) with Application to the Global Energy System (GES), Robert J. Glass, Arlo L. Ames, Walter E. Beyeler, Bernard Zak, David A. Schoenwald, Sean A. McKenna, Stephen H. Conrad , S. Louise Maffitt, Sandia National Laboratories SAND 2008-7952, December 2008
- The Payments System and the Market of Interbank Funds, Morten L. Bech, Walter E. Beyeler, Robert J. Glass, and Kimmo Soramäki, Part 4 in New Directions for Understanding Systemic Risk, Economic Policy Review, Federal Reserve Bank of New York, 2007, .
- Congestion and Cascades in Interdependent Payment Systems, Fabien Renault, Walter E. Beyeler, Robert J. Glass, Kimmo Soramäki, Morten L. Bech, Submitted to International Journal of Central Banking, 2009 .
- New Approaches for Payment System Simulation Research, Kimmo Soramäki, Walter E. Beyeler, Morten Bech, and Robert J. Glass in: Simulation studies of liquidity needs, risks and efficiency in payment networks, Proceedings from the Bank of Finland Payment and Settlement System Seminars 2005-2006, Harry Leinonen ed., (Bank of Finland Studies E:39/2007)
- Congestion and cascades in payment systems (2007-7271), Walter E. Beyeler, Robert J. Glass, Morten Bech and Kimmo Soramäki, Physica A, 15 Oct. 2007; v.384, no.2, p.693-718, accepted May 2007 (also available from Elsevier B.V. /Physica A)
- The Topology of Interbank Payment Flows, Kimmo Soramaki, Morten L. Bech, Jeffrey Arnold, Robert J. Glass, Walter E. Beyeler, Physica A: Statistical Mechanics and Its Applications, June 2007; vol.379, no.1, p.317-33.(also available from Elsevier B.V. /Physica A)
- Congestion and Cascades in Payment Systems, Walter E. Beyeler, Robert J. Glass, Morten L. Bech, Kimmo Soramaki, Federal Reserve Board of New York Staff report, July 2006
- The Topology of Interbank Payment Flows (2006-1984 J), Soramäki, K, ML Bech, J Arnold, RJ Glass, and WE Beyeler, Federal Reserve Bank of New York Staff Reports, no. 243, March 2006
- Advanced Simulation for Analysis of Critical Infrastructure: Abstract Cascades, the Electric power grid, and Fedwire (2004-4239), Robert J. Glass, Walt E. Beyeler, and Kevin L. Stamber
- Defining Research and Development Directions for Modeling and Simulation of Complex, Interdependent Adaptive Infrastructures (2003-1778), Robert J Glass, Walter E Beyeler, Stephen H Conrad, Nancy S Brodsky, Paul G Kaplan, and Theresa J Brown

References (continued)

Conference Papers and Presentations

- Joint Bank of France / European Central Bank Conference on Liquidity in interdependent transfer systems, Paris, 9-10 June 2008
- *Performance and Resilience to liquidity disruptions in interdependent RTGS payment systems* , F. Renault, WE Beyeler, RJ Glass, K. Soramäki and ML Bech
- Modeling Critical Infrastructures with Networked Agent-based Approaches, RJ Glass and WE Beyeler (also presented at Lawrence Livermore, March 2008)
- Joint Bank of England & European Central Bank Conference on Payments and monetary and financial stability, November 2007
- *Congestion and Cascades in Coupled Payment Systems* (paper), F. Renault, WE Beyeler, RJ Glass, K. Soramäki and ML Bech
- International Society of Dynamic Games Workshop, Rabat, Morocco September 2007
- Effect of Learning and Market Structure on Price Level and Volatility in a Simple Market, WE Beyeler, K Soramäki and RJ Glass
- Bank of Finland 5th Payment and Settlement Simulation Seminar and Workshop. Helsinki, Finland, August 2007
- *Congestion and Cascades in Coupled Payment Systems*, WE Beyeler, RJ Glass
- Bank of Finland 4th Payment and Settlement Simulation Seminar and Workshop, Helsinki, Finland, August 2006
- *Network Topology and Payment System Resilience - first results*, K Soramaki, WE Beyeler, ML Bech, RJ Glass
- *Congestion and Cascades in Payment Systems*, WE Beyeler, K Soramaki, ML Bech, RJ Glass
- The National Academy of Sciences of the National Academies/ The Federal Reserve Bank of New York: New Directions for Understanding Systemic Risk, New York City, May 2006
- *Contagion, Cascades and Disruptions to the Interbank Payment System* (2005-4915 C), ML Bech, WE Beyeler, RJ Glass, K Soramaki
- Bank of Finland 3rd Payment and Settlement Simulation Seminar and Workshop, Helsinki, Finland, August 2005
- Network relationships and network models in payment systems, K Soramaki, ML Bech, J Arnold, WE Beyeler, RJ Glass
- Modeling Banks' Payment Submittal Decisions, WE Beyeler, K Soramaki, ML Bech, RJ Glass
- Simulation and Analysis of Cascading Failure in Critical Infrastructure, RJ Glass, WE Beyeler, K Soramaki, ML Bech, J Arnold
- Working Together: R&D Partnerships in Homeland Security Conference, May 2005
- *Complexity Science: Implications for Critical Infrastructures*, RJ Glass, WE Beyeler, SH Conrad, PG Kaplan, TJ Brown

Critical behavior is associated with phase changes