Discussion of the formulation of models of payment systems

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19 October, 2010
Big events are rare in systems with independent components. 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?

Big events are not rare in many natural and engineered systems.
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
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

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

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.
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.
Influence of Liquidity

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.
Liquidity and Markets Influence Congestion

![Graph showing the influence of liquidity and markets on congestion. The graph plots liquidity factor on the x-axis and average settlement cascade size on the y-axis. Different markers represent different market conditions: No Market, c=1E-4, c=1E-3, and c=1E-2. The graph illustrates how market conditions affect congestion levels.]
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? …
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

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

Settlement Time Differences
Create Exposures

System liquidity controls congestion, thereby Settlement delays and cascades

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

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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

- 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
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Conference Papers and Presentations

- 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)
- 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
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- 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
- Complexity Science: Implications for Critical Infrastructures, RJ Glass, WE Beyeler, SH Conrad, PG Kaplan, TJ Brown
Critical behavior is associated with phase changes.

What keeps the system at a phase boundary?

- Dissipation
- External Drive