Simulation analysis of payment systems

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Agenda

- Payment simulations in policy and oversight
- Payment simulation research
- How to start simulation analyses?
Short history of Simulations in oversight

• 1997 : Bank of Finland
  – Uncover liquidity needs of banks when Finland’s RTGS system was joined with TARGET
  – See Koponen-Soramaki (1998)

• 2000 : Bank of Japan
  – Test features for BoJ-Net upgrade

• 2001 : CLS approval process and ongoing oversight
  – Test risk management
  – Evaluate settlement’ members capacity for pay-ins
  – Understand how the system works

• Since: Bank of Canada, Banque de France, Nederlandsche Bank, Norges Bank, FRBNY, and many others

• 2010 - : Bank of England new CHAPS
  – Evaluate alternative liquidity saving mechanisms
  – Use as platform for discussions with banks
  – Denby-McLafferty (2011 forthcoming)
Topics

- Enhance understanding of system mechanics
- Evaluate alternative design features
- Stress testing and liquidity needs analysis
- Platform for communication among stakeholders

Why Simulate?
Agenda today

  
  Models payment flows as graphs (“Network topology”)

  
  Models payment flow mechanics (“System mechanics”)

  
  Models bank’s decision-making (“Economic behavior”)

Topology of interactions

Total of ~8000 banks
66 banks comprise 75% of value
25 banks completely connected

System mechanics

Central bank

Payment system

4 Payment account is debited

5 Payment account is credited

3 Payment is settled or queued

2 Depositor account is debited

1 Agent instructs bank to send a payment

B_i > 0

D_i

B_i

Payment account is credited

Bi > 0

Qi

Qi > 0

Qi

Bank i

Bank j

Depositor account is credited

Queued payment, if any, is released

Productive Agent

Productive Agent

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.

System mechanics

Central bank

Payment system

Payment account is credited

Payment account is debited

Payment is settled or queued

Depositor account is debited

Agent instructs bank to send a payment

Productive Agent

Liquidity Market

Bank i

Bi

Q_i

D_i

B_i > 0

Bank j

D_j

Q_j

Q_j > 0

Productive Agent

Queued payment, if any, is released

Simulations vs analytic models

- **Simulations** (e.g. e.g. Koponen-Soramaki 1998, Leinonen, ed. 2005, work at FRB, ECB, BoC, BoJ, BoE) have so far not endogenized bank behaviour
  - behaviour has been assumed to remain unchanged in spite of other changes in the system
  - or to change in a predetermined manner
  - due to the use of actual data, difficult to generalize

- **Game theoretic models** (e.g. Angelini 1998, Kobayakawa 1997, Bech-Garrat 2003) need to make many simplifying assumptions
  - on settlement process / payoffs
  - topology of interactions
  - do not give quantitative answers
Economic behavior

- Example: How much liquidity to post?

- Cost for a bank in a payment system depends on
  - Choice of liquidity and
  - Delays of settlement

- Banks liquidity choice depends on other banks’ liquidity choice

- We develop ABM
  - payoffs determined by a realistic settlement process
  - reinforcement learning
  - look at equilibrium
Funding behavior model

• Dynamic model of an RTGS interbank payment system with endogenous choices for funding by banks
  – Banks choose an opening balance at the beginning of each day. Intraday payments are released whenever sufficient liquidity is available.

• Banks have knowledge of settlement costs given their own liquidity and liquidity of other banks
  – Delays are evaluated by means of a large number of simulations of the “payment physics model” with different amounts of liquidity.

• Bank learn about the behavior of other banks, and choose their own liquidity to minimize costs
  – On each round, banks choose a “best reply” given beliefs about what other banks choose. The beliefs are updated on subsequent rounds

• We look at both normal operating conditions and an operational failure by one bank
Learning in the model

• In the model
  – Banks face uncertainty about the actions of other banks
  – Banks adapt their actions over time, depending on observed actions by others
  – This is modeled as fictitious play with given payoff functions
  – The game is played until convergence of beliefs takes place

• Properties of Fictitious play
  – If beliefs converge to 1 for some action, that action is a pure Nash-equilibrium
  – If beliefs converge to a distribution, then that distribution is the mixed Nash equilibrium of the game

• Our results
  – Beliefs converge mostly to a distribution, sometimes to a pure equilibrium
  – Results report weighted average in case of mixed equilibria
Delays as a function of own and others’ liquidity (N=13)

Galbiati and Soramäki (2011), JEDC, Vol. 35, Iss. 6, pp 859-875
Payoffs

- Recall, costs depend on own liquidity and others liquidity -> which jointly determine delays
- Red = high price for liquidity, Blue = low price for liquidity

\[ C(l_i, l_{-i}) = \lambda l_i + kD(l_i, l_{-i}) \]
Liquidity demand curve

- **Equilibrium - fitted**
- **Equilibrium**
- **Planner**

Observed liquidity choice

Inferred price of liquidity (standardized by $\kappa$)
How to start?

HR → DATA → TOOLS
Data

- **Historical transaction data**
  - From interbank payment systems
  - At minimum: date, time, sender, receiver, value
  - More data on type of payment, economic purpose, second tier (if any), type of institution, etc. useful

- **Artificial transaction data**
  - Based on aggregates (possible with Entropy maximization methods)
  - Based on a network model (defining bilateral flows)
  - Assumptions
    - Timing of payments
    - Value distribution
    - Correlations
  - System stability (net flows 0 over longer times)
Tools

• Bof-PSS2
  – Bank of Finland, 1997- (BoF-PSS1)
  – RTGS, RRGS, Net, many optimization methods
  – www.bof.fi/sc/bof-pss
  – Free, Support & training available, Annual workshop

• FNA Flow
  – Soramaki Networks, 2009-
  – RTGS, RRGS, many optimization methods
  – www.fna.fi
  – Free online, License, support & training available

• Proprietary tools or general purpose programs
  – Matlab, SAS, Excel, …
Thank you