

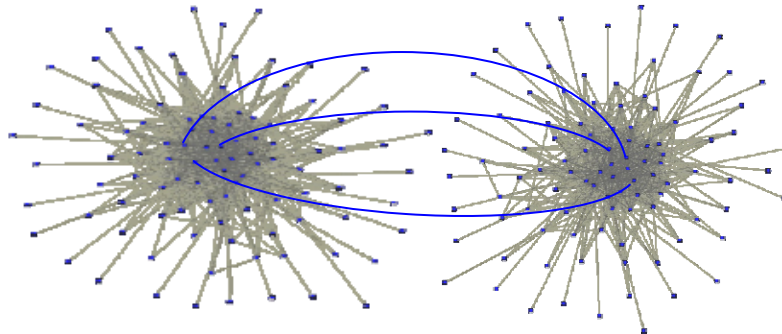


Sandia  
National  
Laboratories



TEKNILLINEN KORKEAKOULU  
TEKNISKA HÖGSKOLAN  
HELSINKI UNIVERSITY OF TECHNOLOGY

# Congestion and Cascades in Coupled Payment Systems



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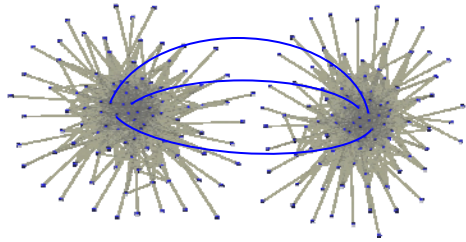
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*PAYMENT AND SETTLEMENT SIMULATION SEMINAR  
AND WORKSHOP*

*Helsinki*

*August 2007*

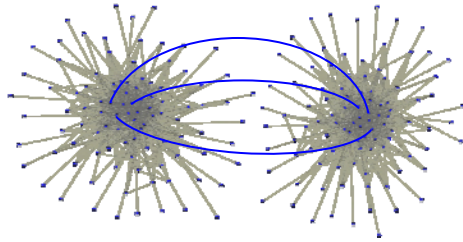
The views expressed in this presentation are those of the authors and do not necessarily reflect those of their respective institutions



# Overview

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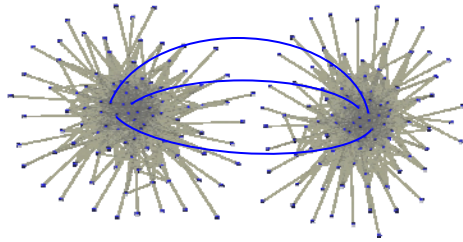
- Motivation for the model
- Structure of the model
- Single RTGS model
- Coupled RTGS model
- Behavior of the coupled systems
- Exposure of banks through FoP
- Conclusions
- Upcoming investigations



# Motivation for the model

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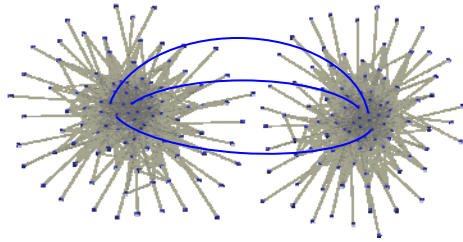
- The 2001 Group of Ten “*Report on Consolidation in the Financial Sector*” (the Ferguson report) noted a possible increased interdependence between the different systems due to:
  - The emergence of multinational institutions with access to several systems in different countries
  - The emergence of 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.



# Motivation for the model

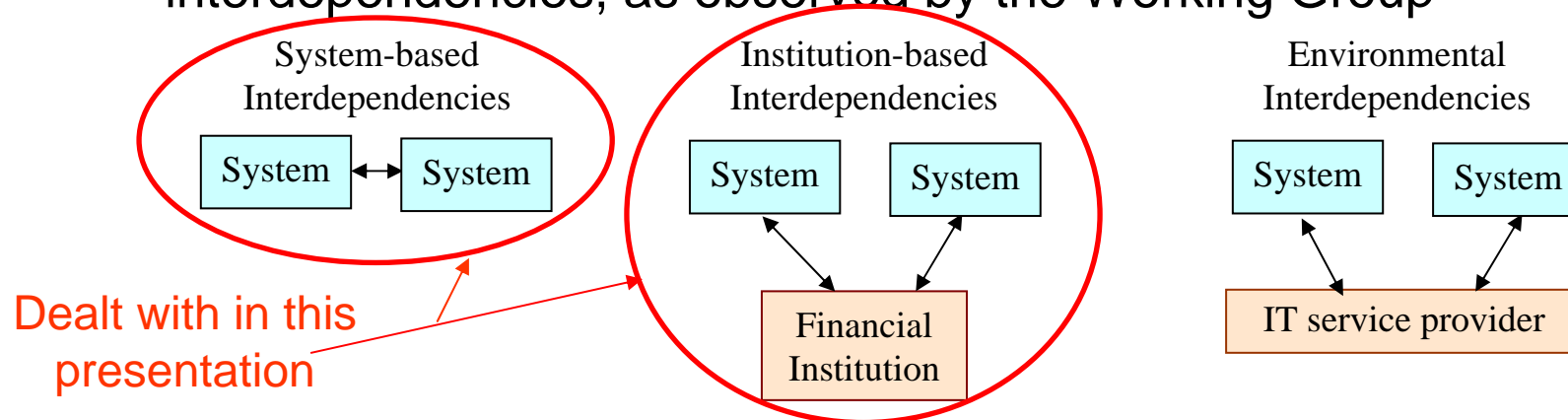
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- To complement this previous work, the CPSS (Committee on Payment and Settlement Systems) commissioned a working group to:
  - describe the different interdependencies existing among the payment and settlement systems of CPSS countries
  - analyze 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 ?

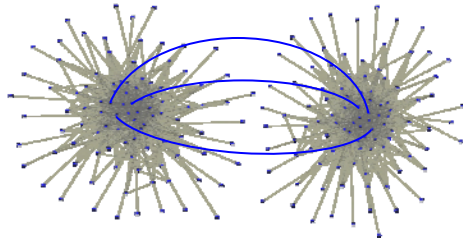


# Motivation for the model

- So far, payment and settlement system modeling has been mainly limited to a single system, with a few exceptions:
  - Interaction between RTGS and SSS (Bank of Finland)
  - Cross-border use of Collateral (Bank of England)
- We want to model the interactions between 2 RTGSs
- Our model should ultimately include the different forms of interdependencies, as observed by the Working Group

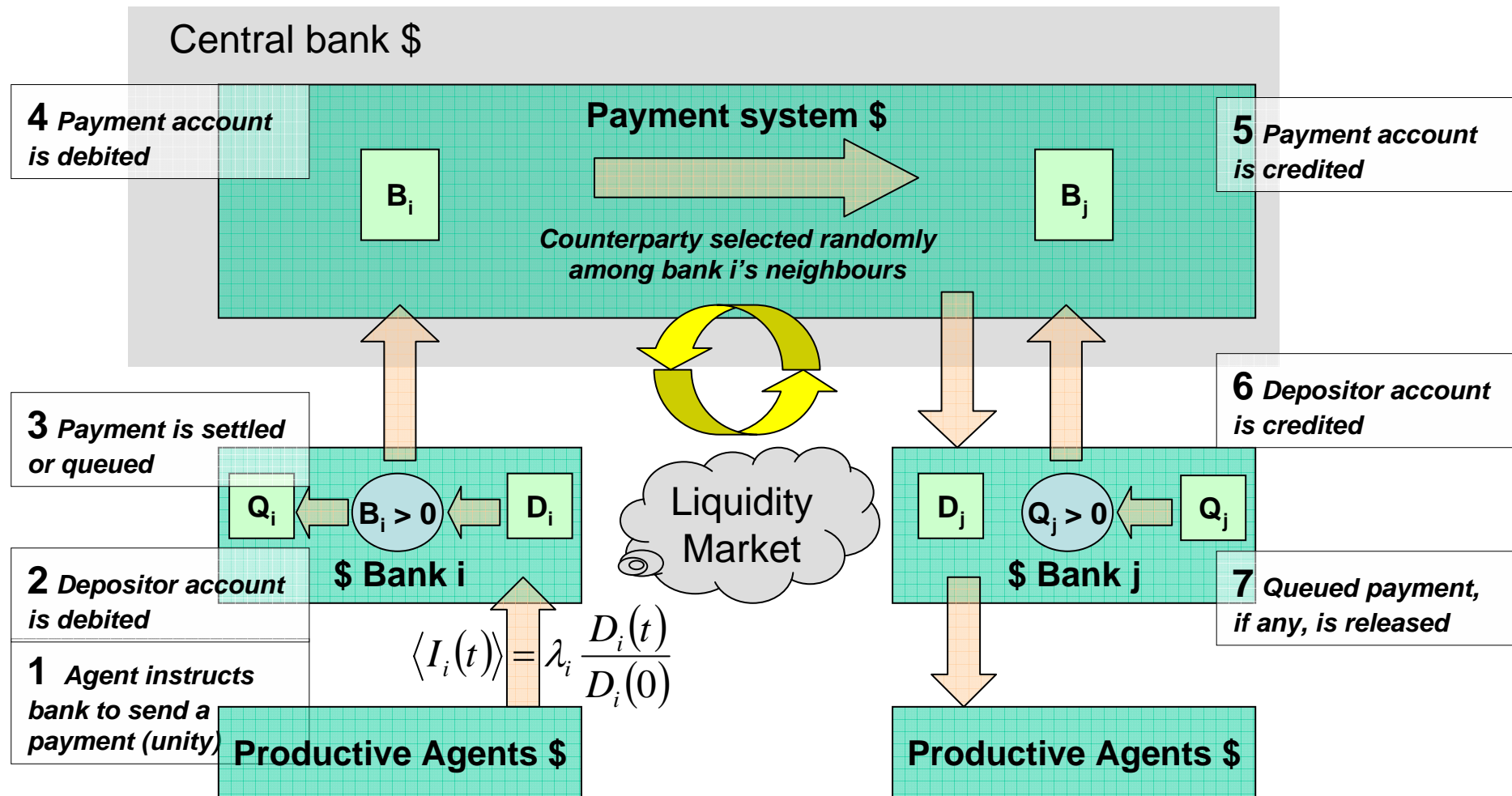


- Real data will not be available at individual level... need for generated data

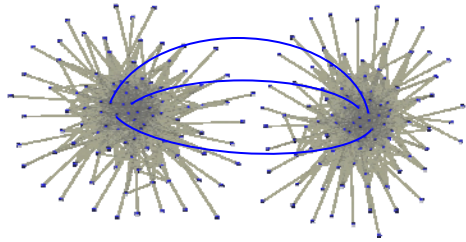


# Single RTGS model

## Local Payments Physics

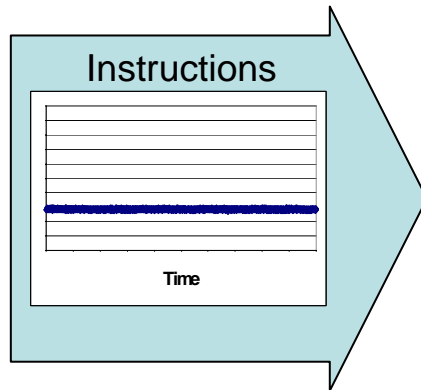


Walter E. Beyeler, Robert J. Glass, Morten Bech and Kimmo Soramäki, Congestion and cascades<sup>6</sup> in payment systems, *Physica A* (2007), doi:10.1016/j.physa.2007.05.061

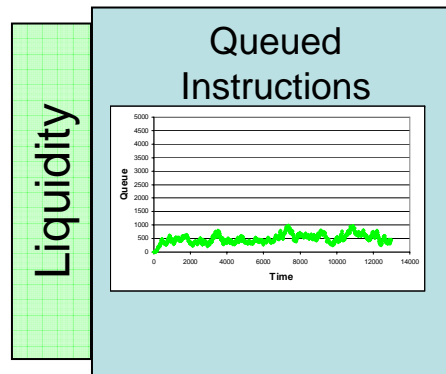


# Single RTGS model

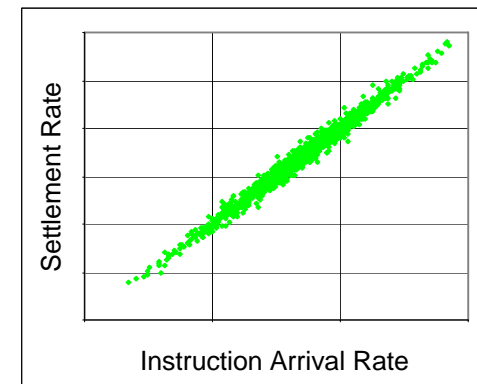
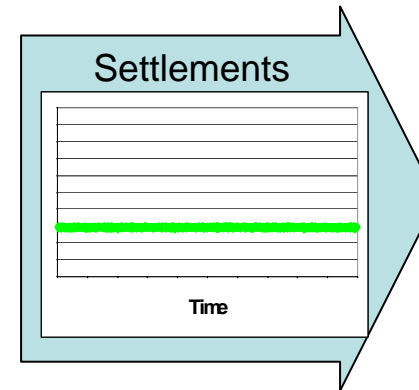
Results at high liquidity

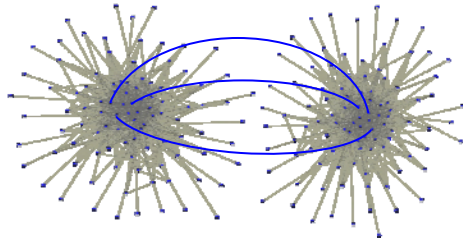


Summed over the network, instructions arrive at a roughly steady rate



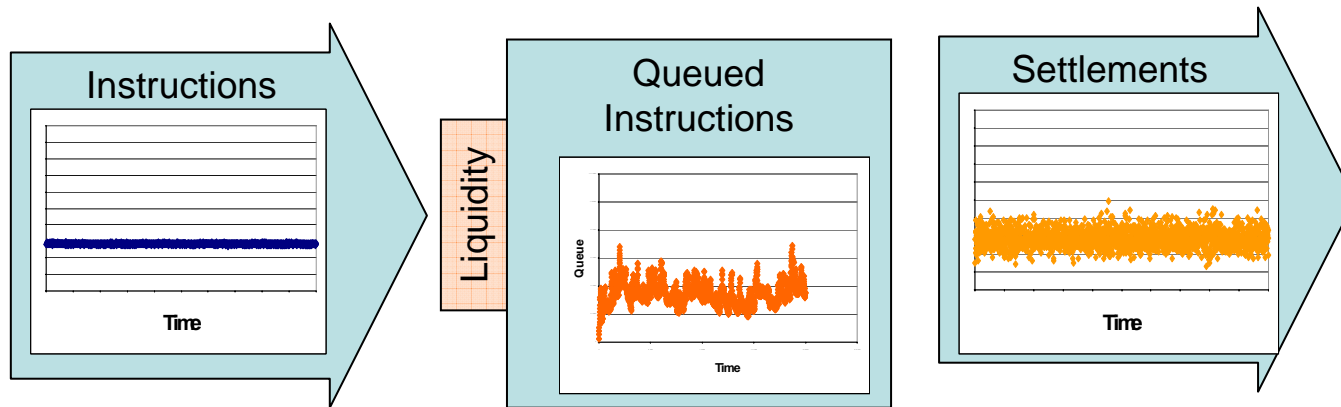
When liquidity is high, queues are small, payments are submitted promptly and banks process payments independently of each other



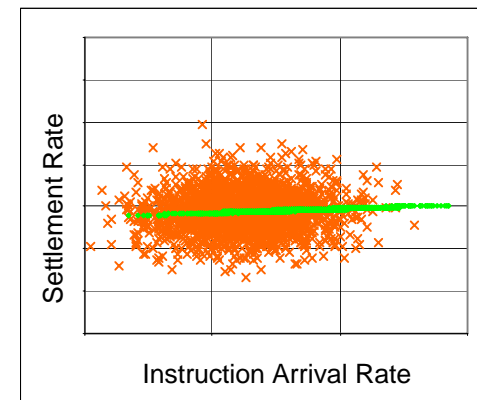


# Single RTGS model

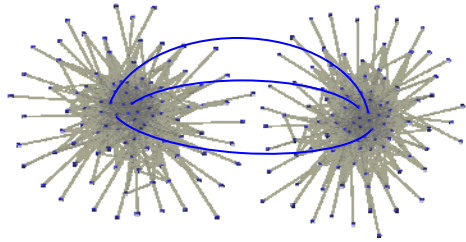
Results at low liquidity



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

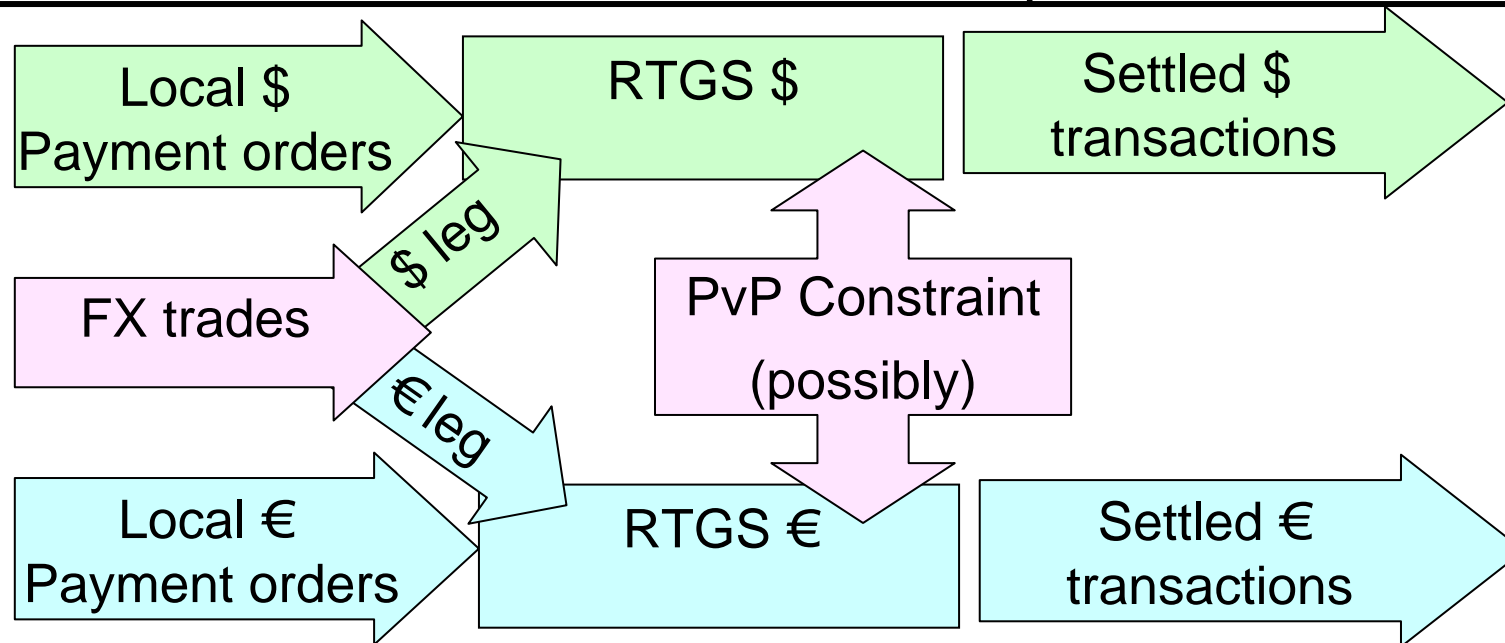




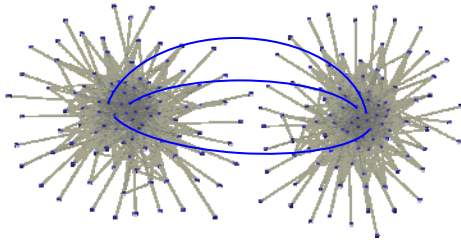


# Coupled RTGS model

## Model description



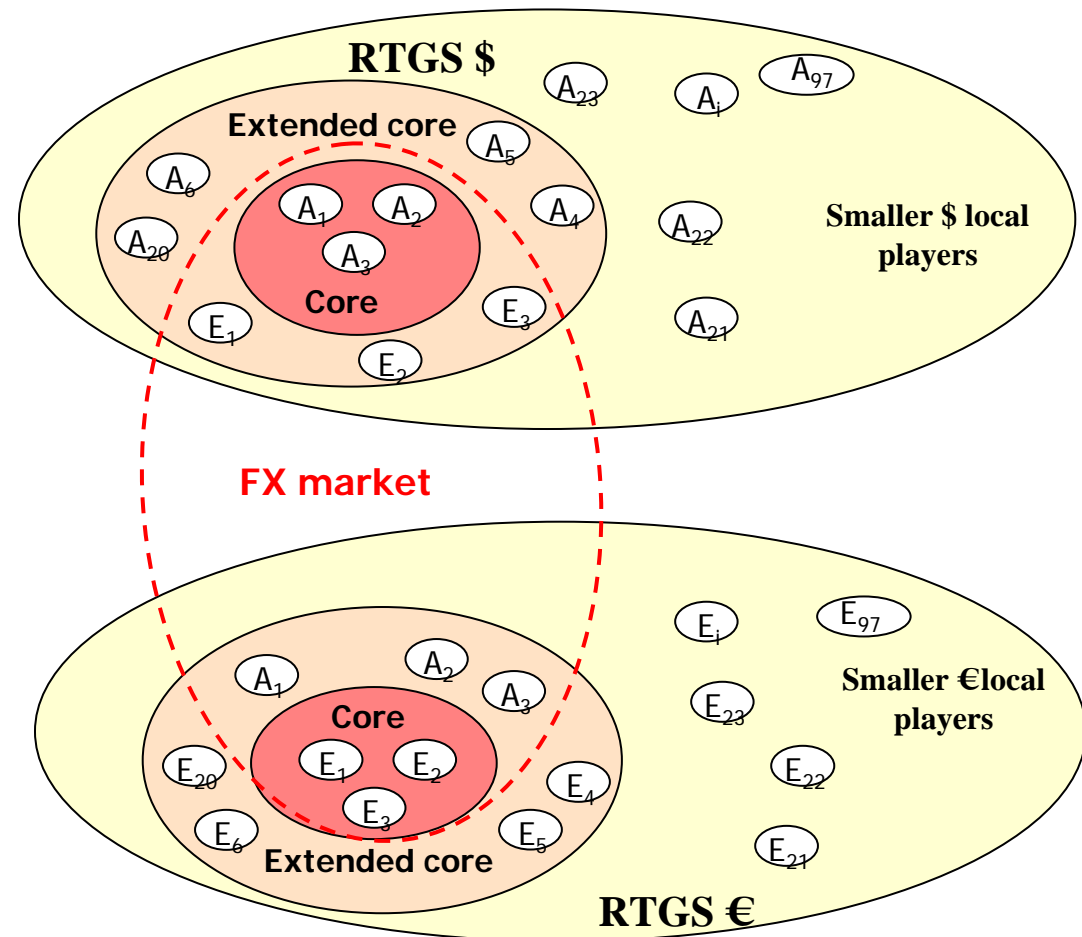
- We model 2 hypothetical RTGSs, each with a different currency (\$ and €)
  - Each RTGS processes:
    - “Local” payments
    - Their respective leg of FX trades
- Those 2 RTGSs are linked:
  - Via the dual participation of some global banks that can make FX trades
  - Via a possible PvP (Payment versus Payment) constraint on the FX trades (the alternative being called FoP for Free of Payment)

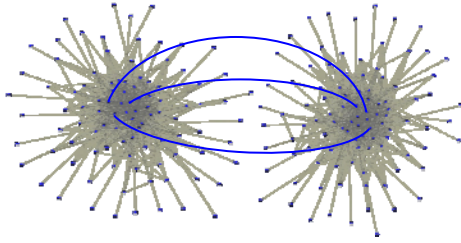


# Coupled RTGS model

## Model description

- RTGS \$ and € are similar
- 100 banks in each RTGS
- Scale-free networks
- 94 “local players” in RTGS \$ ( $A_4$  to  $A_{97}$ )
- 94 “local players” in RTGS € ( $E_4$  to  $E_{97}$ )
- 6 “global players”:
  - The 3 top banks in RTGS \$:  $A_1$ ,  $A_2$  and  $A_3$  which are also in the top 20 of RTGS €
  - The 3 top banks in RTGS €:  $E_1$ ,  $E_2$  and  $E_3$  which are also in the top 20 of RTGS \$
- The 6 “global players” make FX trades (at constant exchange rate) between themselves (complete network)





# Coupled RTGS model

## FX trades physics

- The probability of bank  $i$ 's emitting a \$ local payment order to one of its counterparties is proportional to bank  $i$ 's level of deposits in RTGS \$:

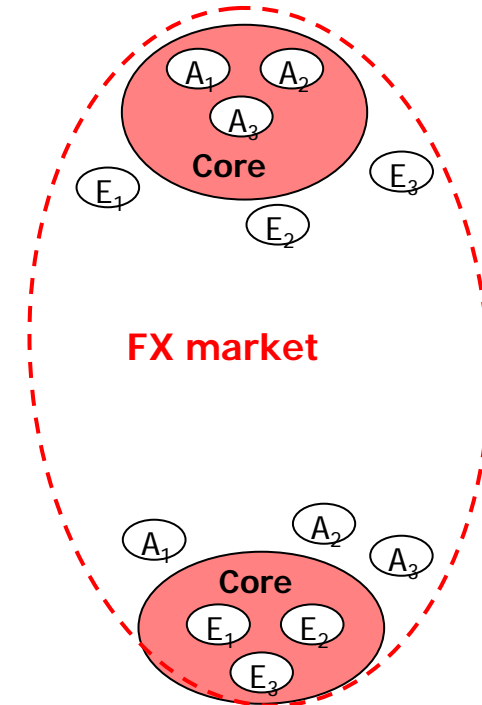
$$\langle I_{\$,i}(t) \rangle = \lambda_i \frac{D_i^{\$(t)}}{D_i^{\$(0)}}$$

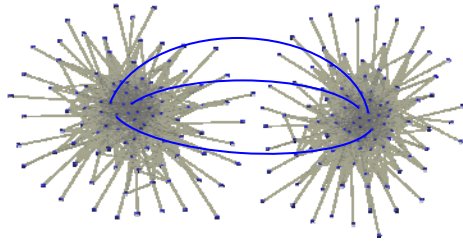
- The probability of bank  $i$ 's exchanging 1 \$ for 1 € with bank  $j$  is proportional to both banks' level of deposits:

$$\langle I_{\$,i}^{\epsilon,j}(t) \rangle = p_{FX} \varphi_{\$,i}^{\epsilon,j} D_i^{\$(t)} D_j^{\epsilon}(t)$$

- The constant (over time) normalization factor ensures long-term stability of initial distributions:

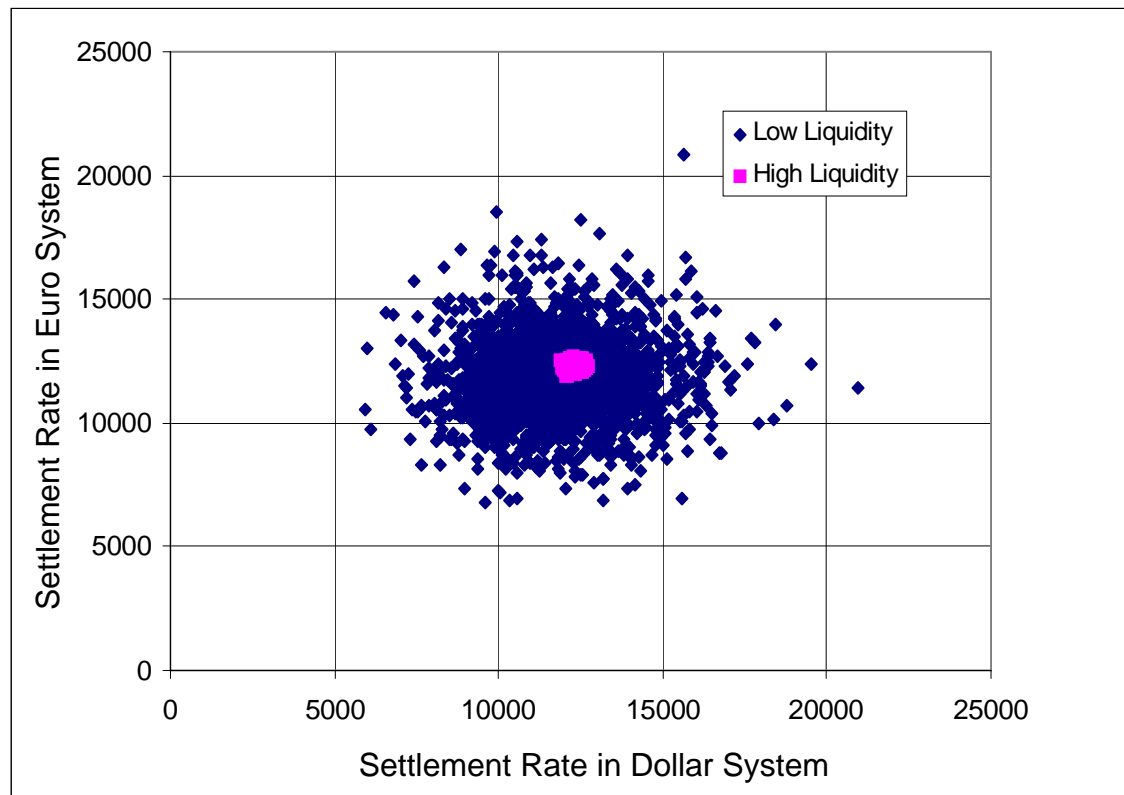
$$\varphi_{\$,i}^{\epsilon,j} = \sqrt{\frac{D_i^{\epsilon}(0)}{D_i^{\$(0)}}} \sqrt{\frac{D_j^{\$(0)}{D_j^{\epsilon}(0)}}} \quad \text{ensures} \quad \langle I_{\$,i}^{\epsilon,j}(0) \rangle = \langle I_{\$,j}^{\epsilon,i}(0) \rangle$$





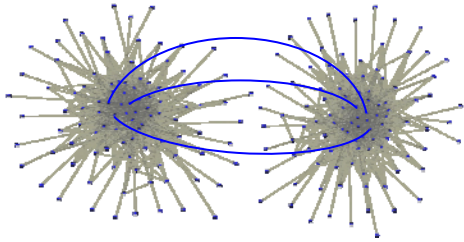
# Effect of Liquidity on Settlement Rate

## Free of Payment (FoP)



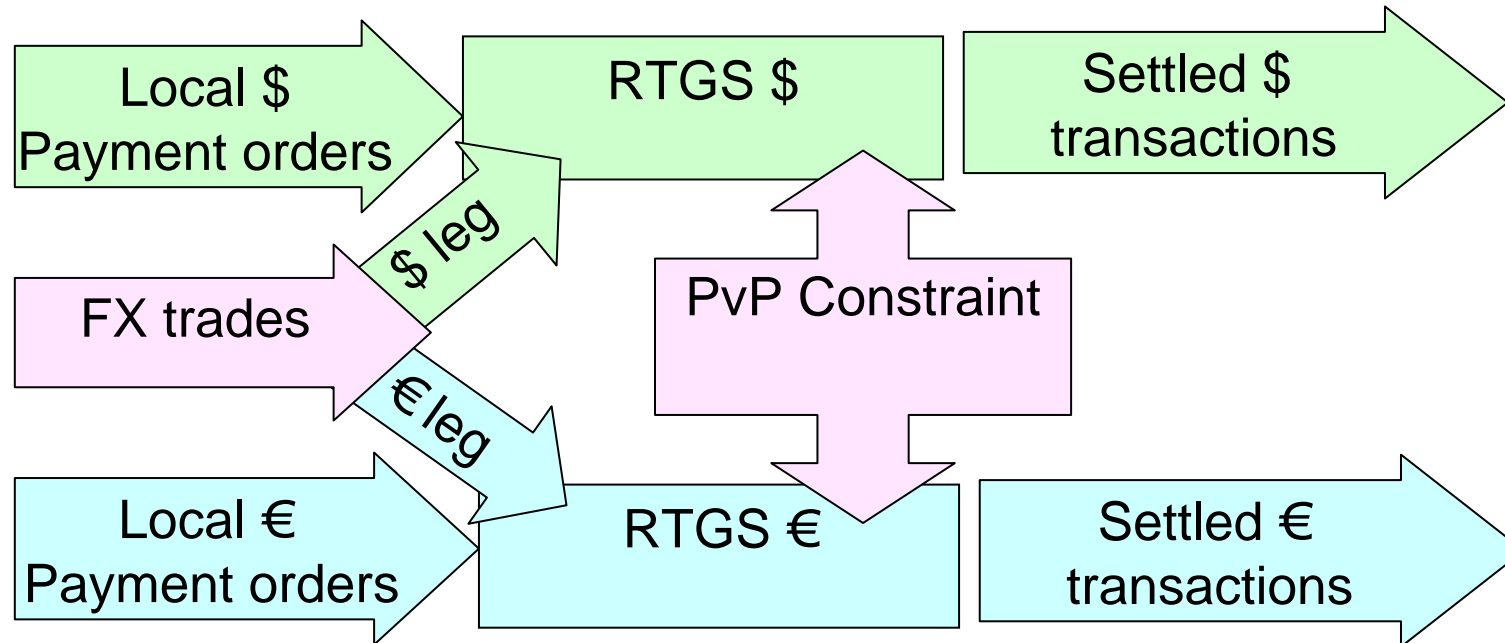
- Low liquidity causes payments to be controlled by internal system dynamics: influence of the common FX stream is invisible
- Output of the systems is correlated ( $\sim 0.18$ ) at high liquidity because settlements track instructions, but the variance of payments is quite small

Results of Monte Carlo sampling different network realizations in each system

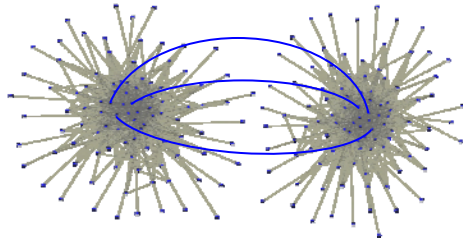


# Coupled RTGS model

## Model description

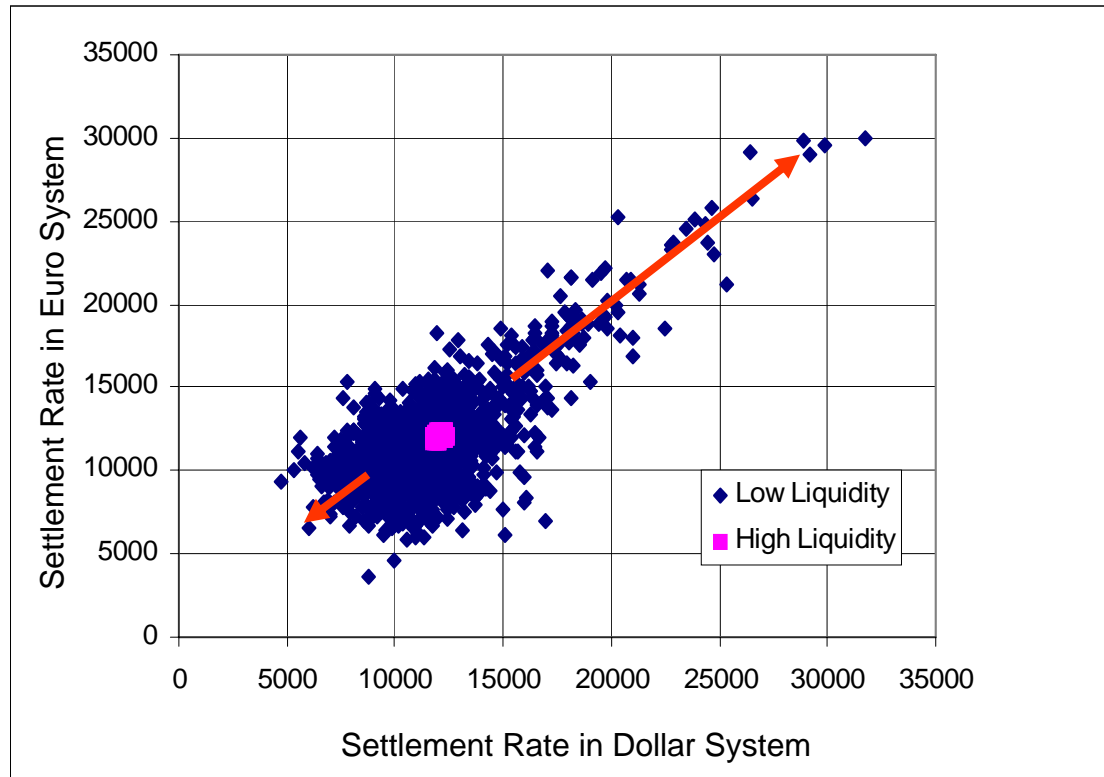


- Common input is one source of settlement correlation, apparent at high liquidity
- Settlement constraints (PvP) are another possible source



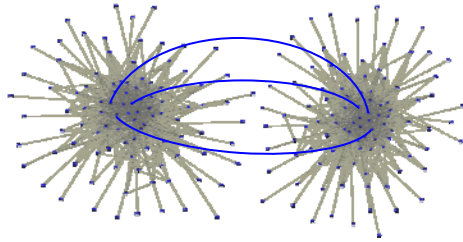
# Effect of Liquidity on Settlement Rate

## PvP: Settlement correlation



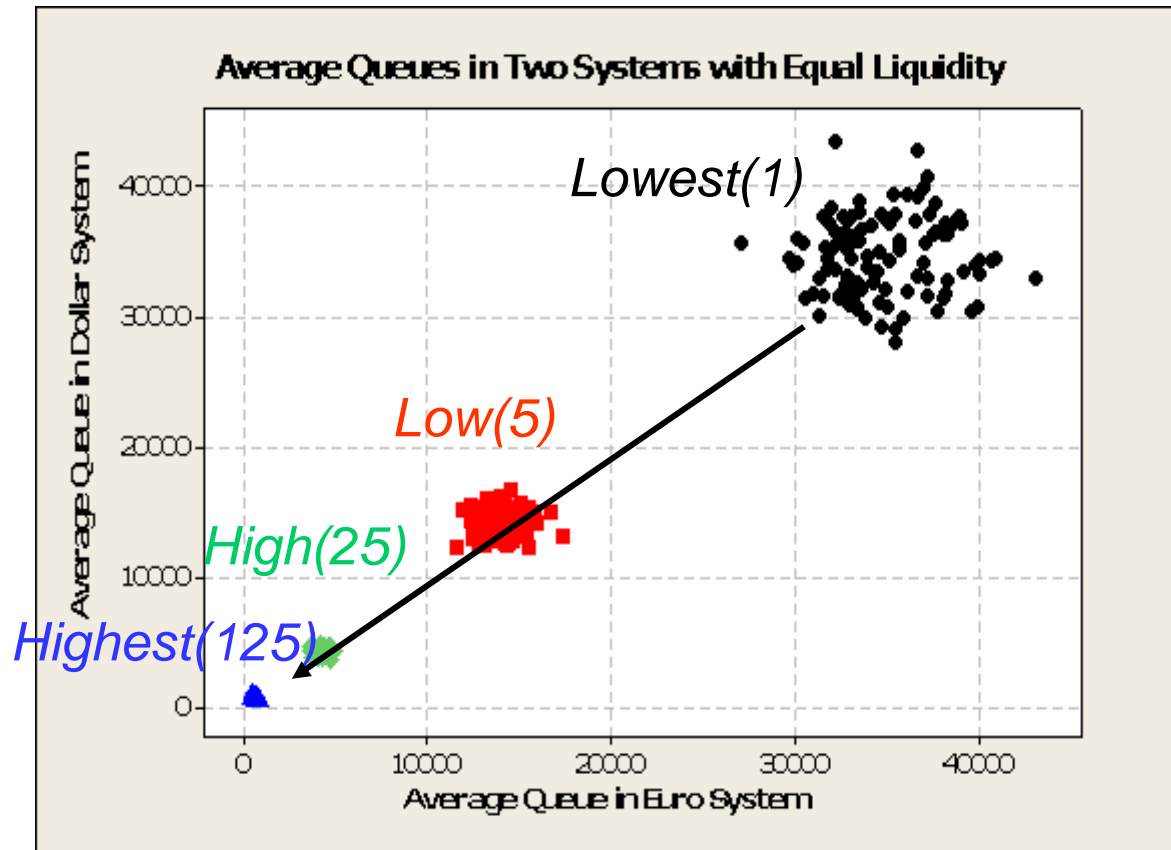
- High liquidity response tracks instructions as in FoP case.
- At low liquidity settlements occur in cascades. Many cascades are initiated by simultaneous PvP payments, which leverages their influence.  $R \sim 0.7$  in this example

Results of Monte Carlo sampling using different network realizations in each system



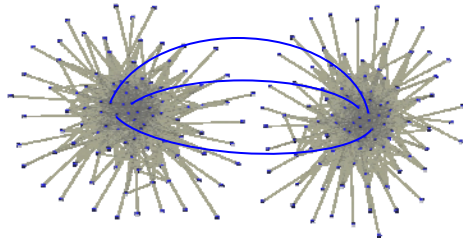
# Effect of liquidity on Queuing

## Equal liquidity in \$ and €, FoP



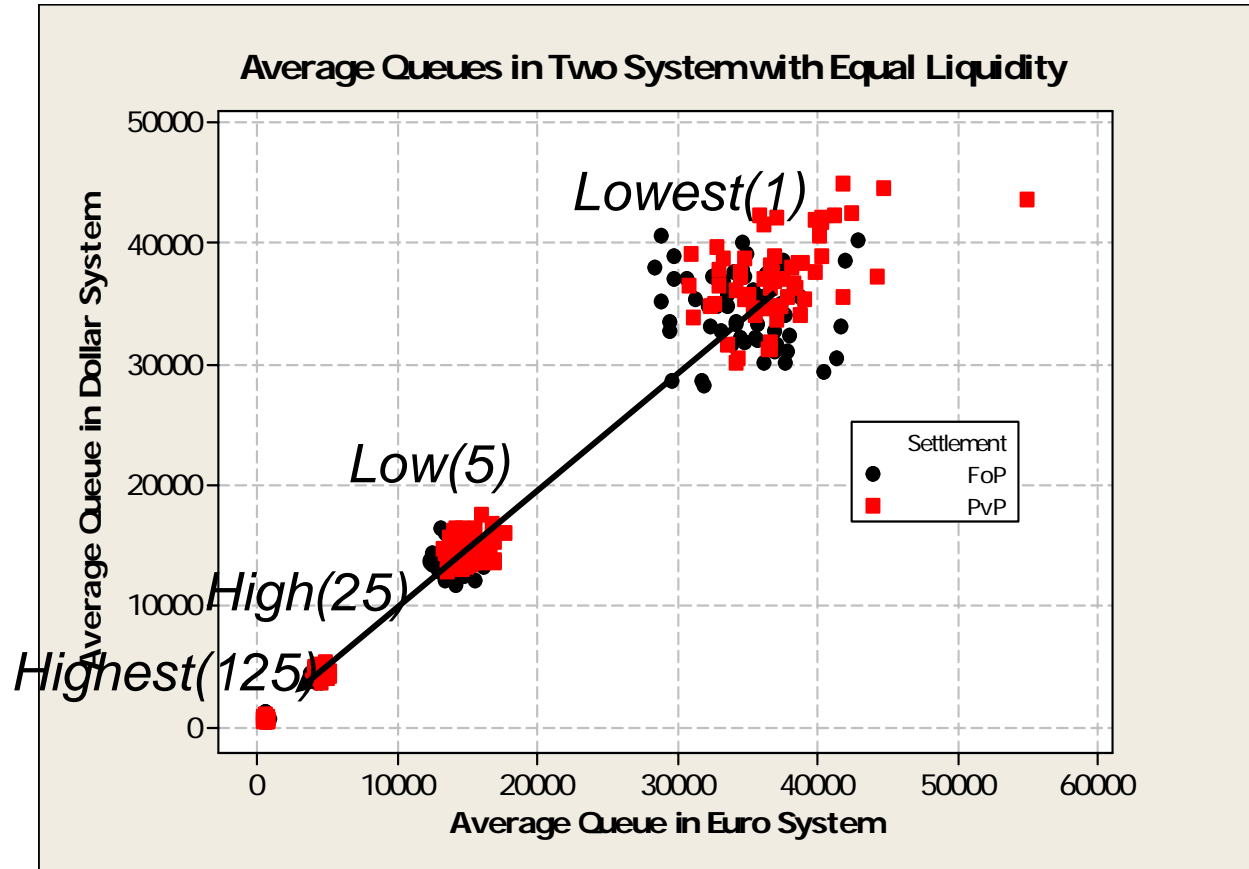
- Queuing is controlled by liquidity
- At high liquidity, queuing in the two systems is similar and does not depend on fine details of the network
- At low liquidity, details of the network matter

Results of Monte Carlo sampling using different network realizations and two FX levels



# Effect of liquidity on Queuing

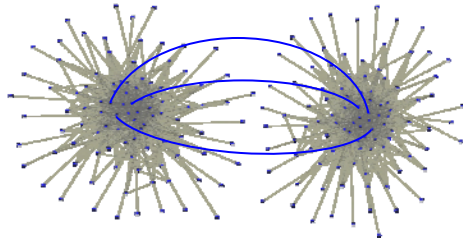
## Equal liquidity in \$ and €, FoP vs PvP



- PvP tends to increase queuing at lower liquidity levels
- Variation at low liquidity due to network heterogeneity is much larger than the influence due to PvP

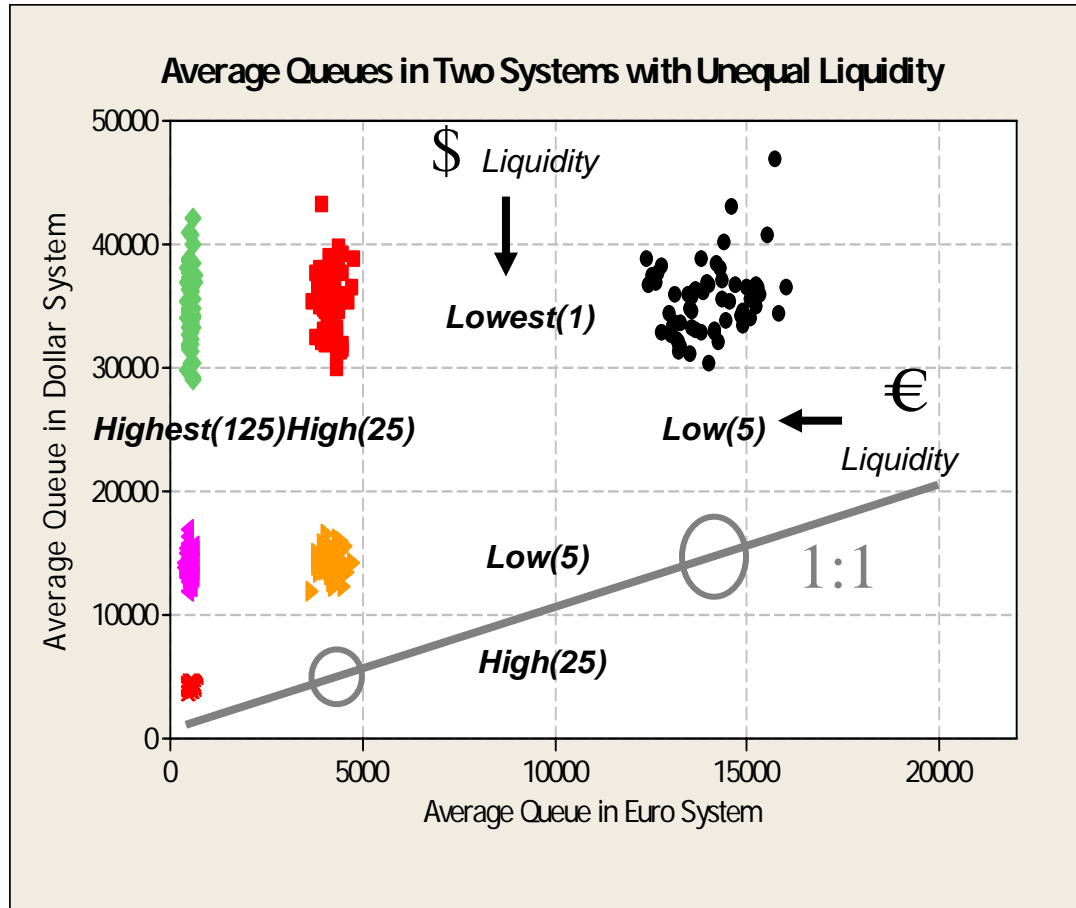
Results of Monte Carlo sampling using different network realizations and two FX levels





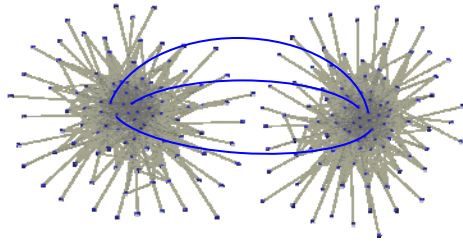
# Effect of Differential Liquidity on Queuing

\$ liquidity lower than €: FoP



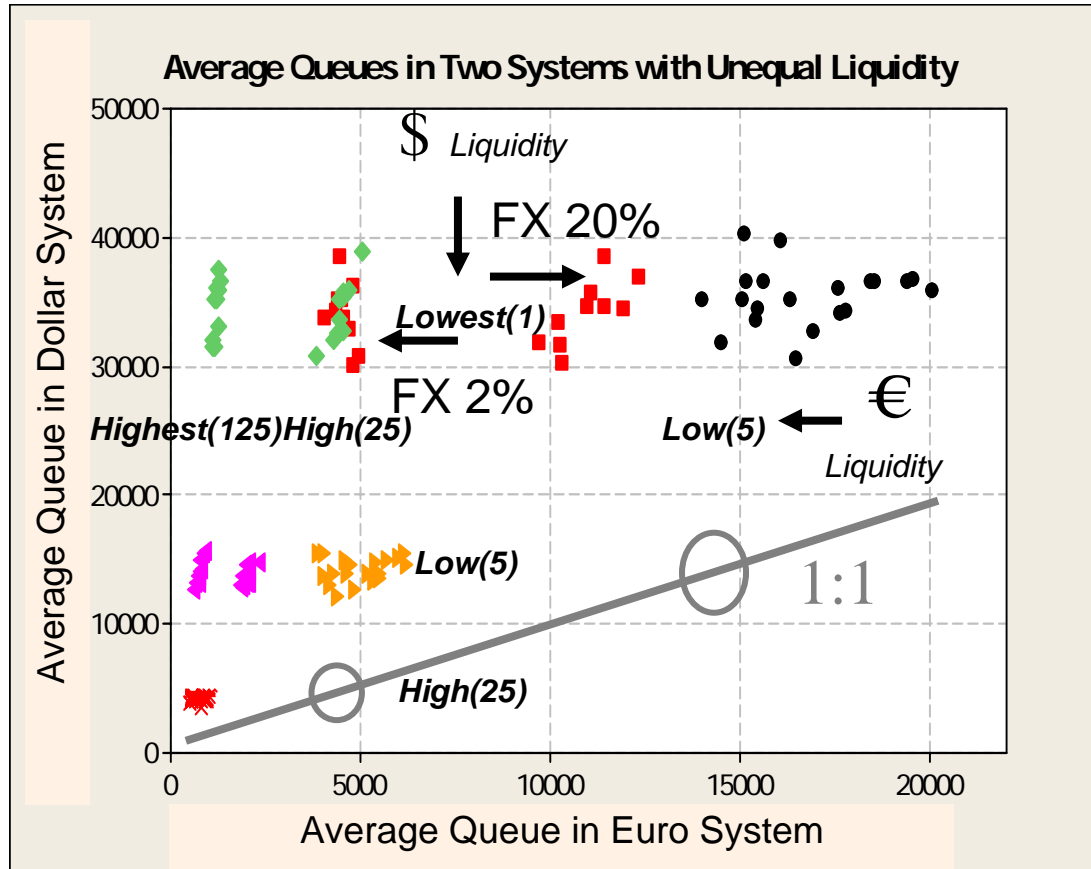
- Liquidity contrasts create systematic differences in queuing between the richer (higher liquidity) and poorer (lower liquidity) system
- Queuing in each system is determined by the liquidity in that system

Results of Monte Carlo sampling using different network realizations and two FX levels



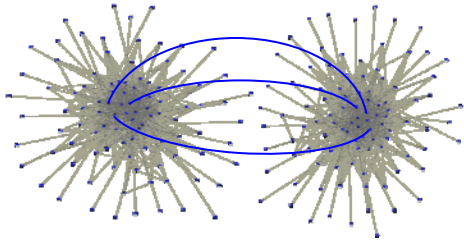
# Effect of Differential Liquidity on Queuing

\$ liquidity lower than €: PvP



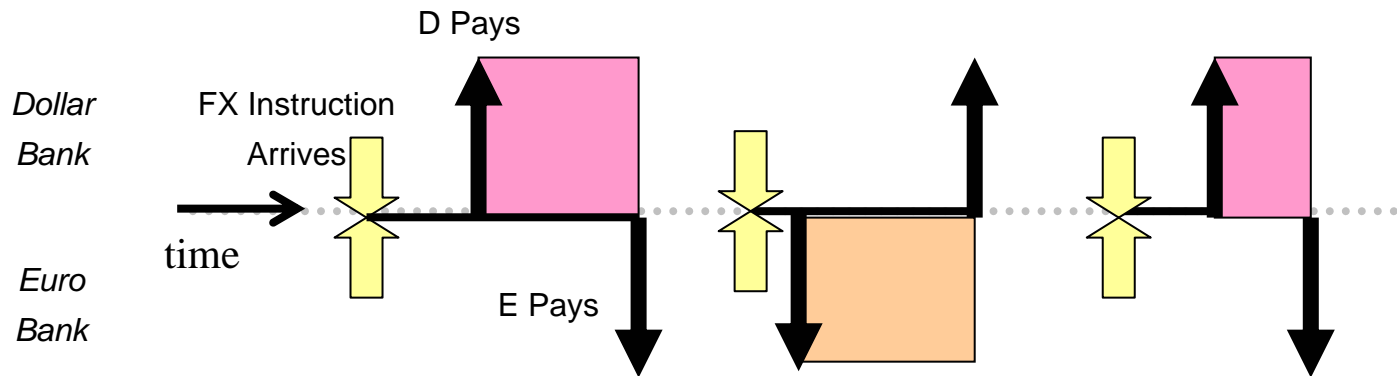
- Queuing in the poorer (lower liquidity) system is very similar to the FoP case
- Queuing in the richer (higher liquidity) system is increased relative to the FoP case
- FX level matters: queuing in the richer system increases with the FX level; queuing in the poorer system doesn't

Results of Monte Carlo sampling using different network realizations and two FX levels



# Exposure of Banks through FoP

FoP Creates Exposure due to Differences in Settlement Times



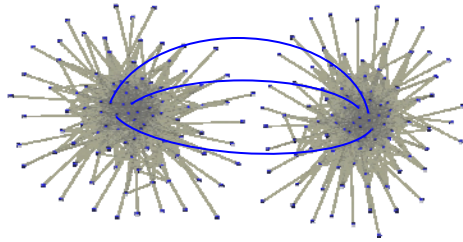
For each pair of banks  $D_i$  and  $E_j$

$$Exposure_{i,j} = \sum_k Value_k \max(0, t_{k,j} - t_{k,i}) / T$$

Differences in average delays create differences in total exposure.

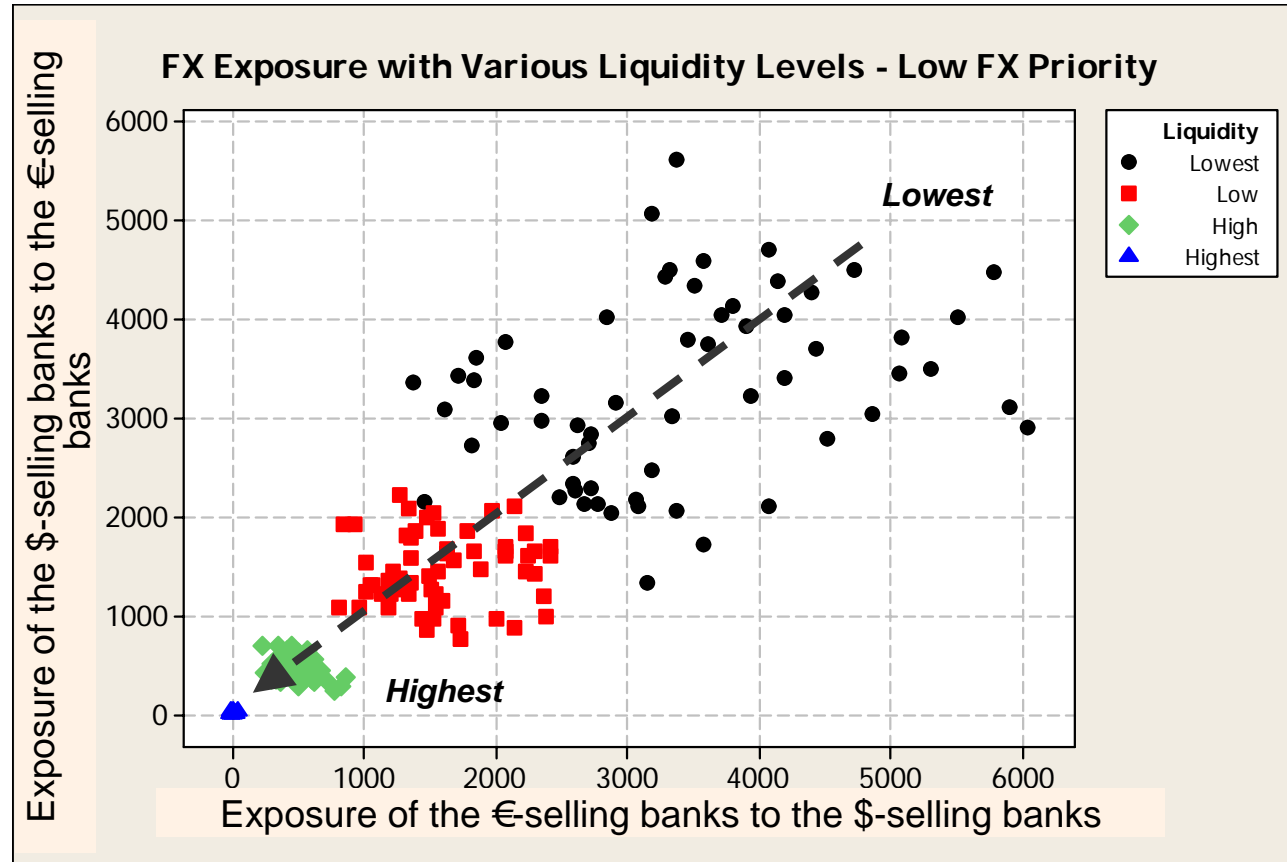
These may be structural (e.g. time zone differences). We consider how differences in liquidity availability can cause exposure.

The sum of exposures of all banks in one system to every bank in the other system is an overall measure of linkage or interdependency between the systems



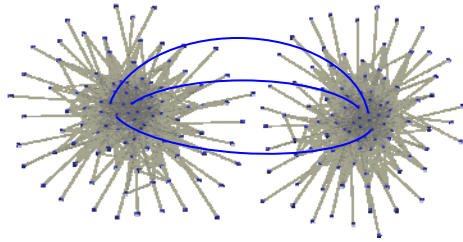
# Exposure of Banks through FoP

## Equal liquidity in \$ and €, Low FX Priority



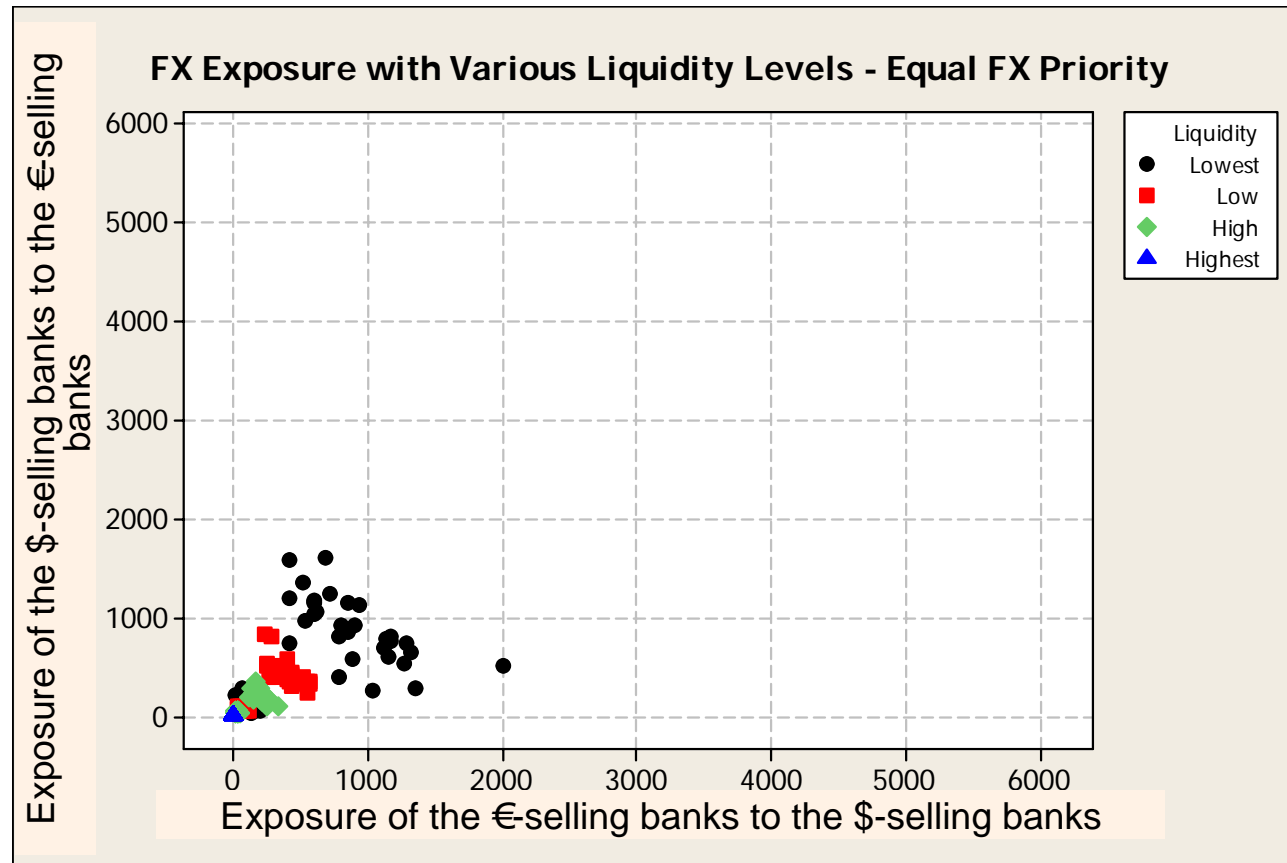
- Aggregate exposure is approximately equal when the systems have similar liquidity and operating rules
- Priorities given to FX instructions strongly influence exposure
- FX rate is important at low liquidity

Results of Monte Carlo sampling using different network realizations



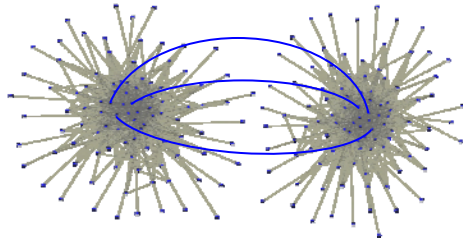
# Exposure of Banks through FoP

## Equal liquidity in \$ and €, Equal FX Priority



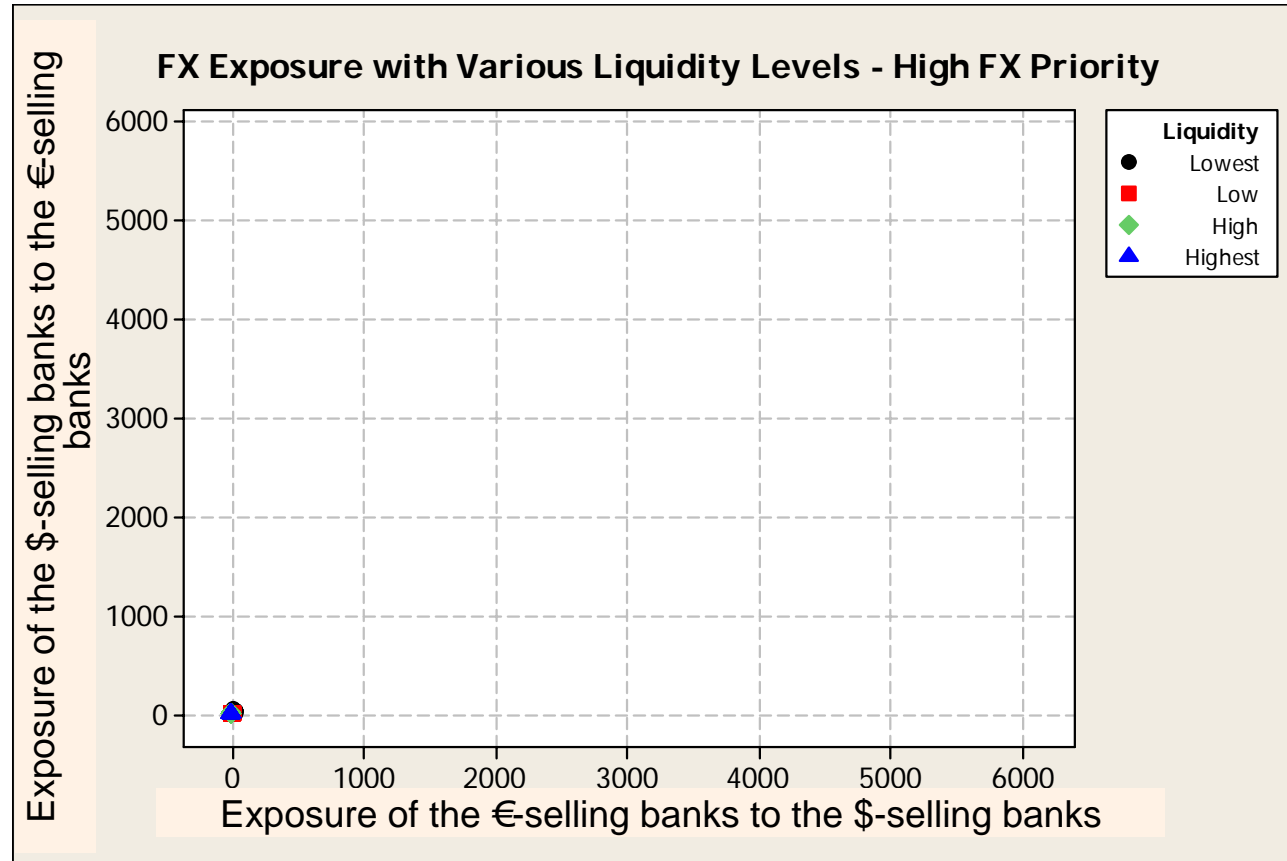
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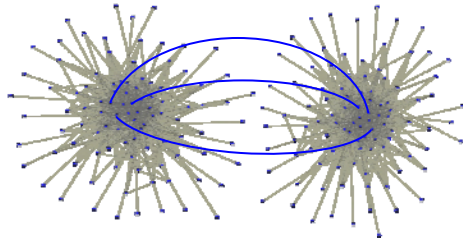
# Exposure of Banks through FoP

## Equal liquidity in \$ and €, High FX Priority



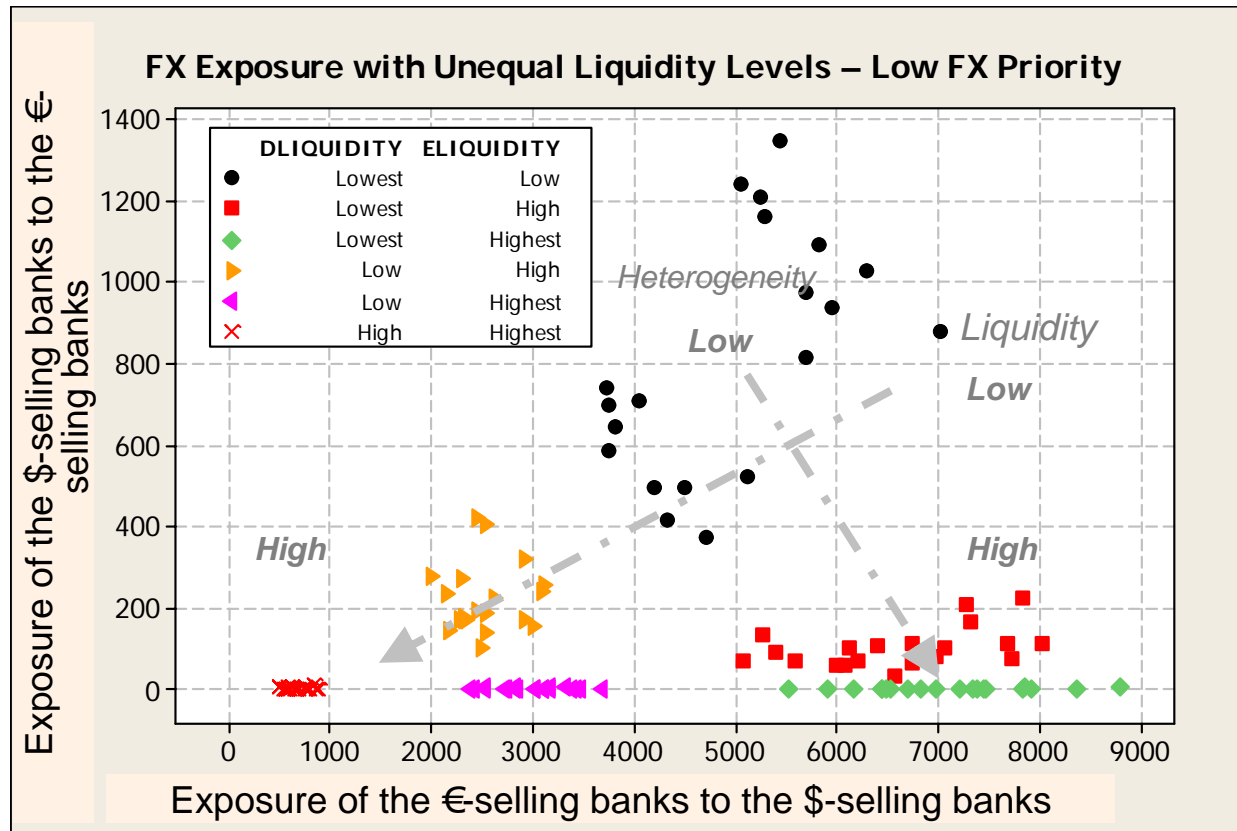
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Results of Monte Carlo sampling using different network realizations



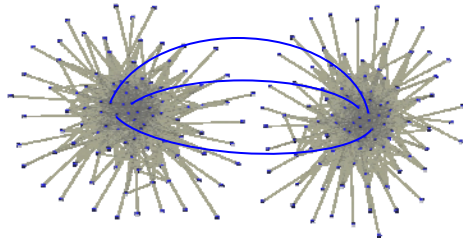
# Exposure of Banks through FoP

## \$ liquidity lower than €, Low FX Priority



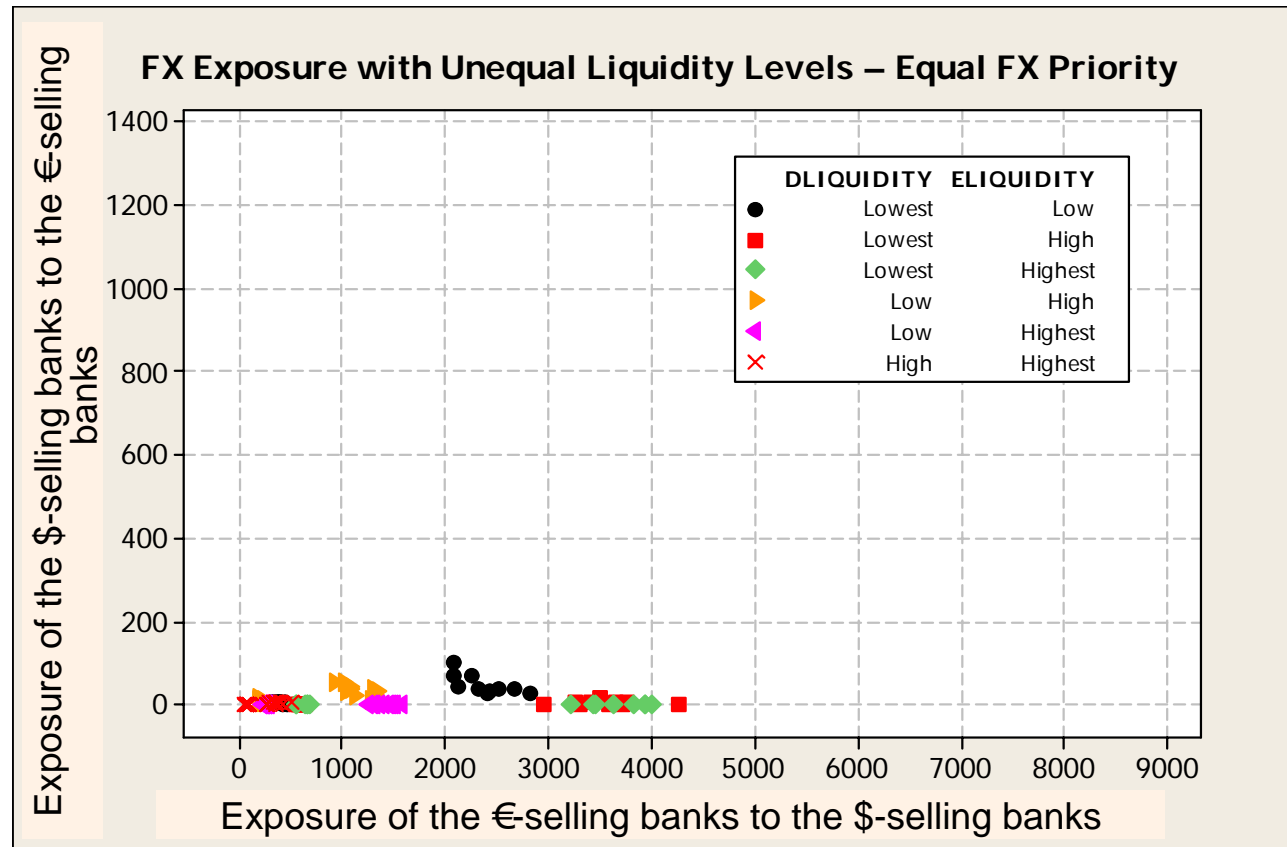
- Exposure is greater in the system with more liquidity
- Increasing liquidity in the richer system increases exposure

Results of Monte Carlo sampling using different network realizations



# Exposure of Banks through FoP

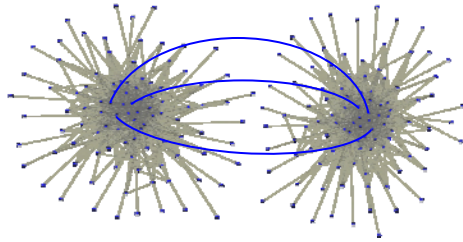
\$ liquidity lower than €, Equal FX Priority



- Priorities strongly influence exposure

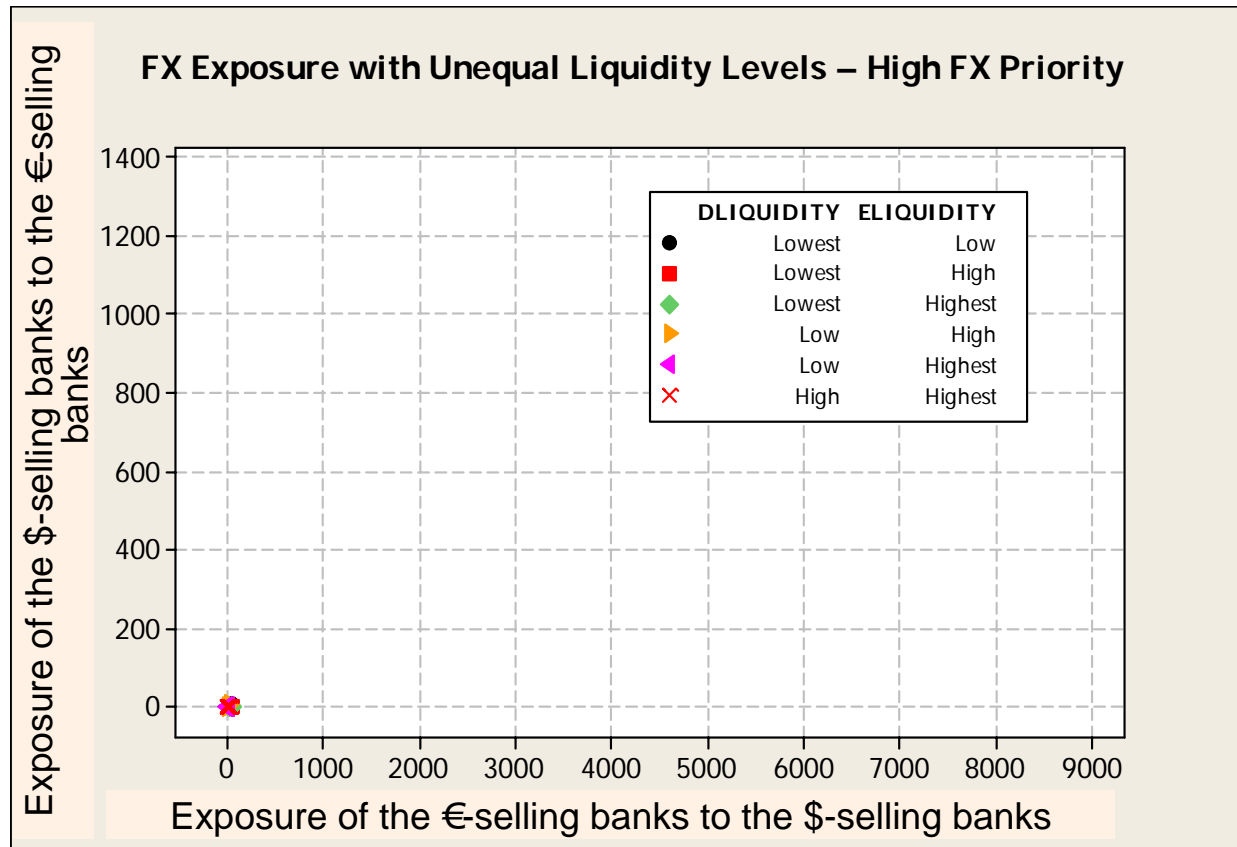
Results of Monte Carlo sampling using different network realizations





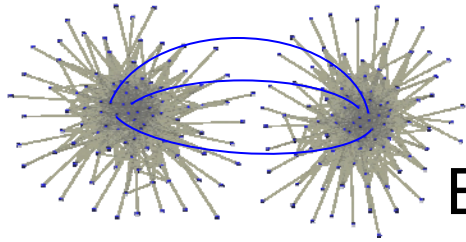
# Exposure of Banks through FoP

## \$ liquidity lower than €, High FX Priority



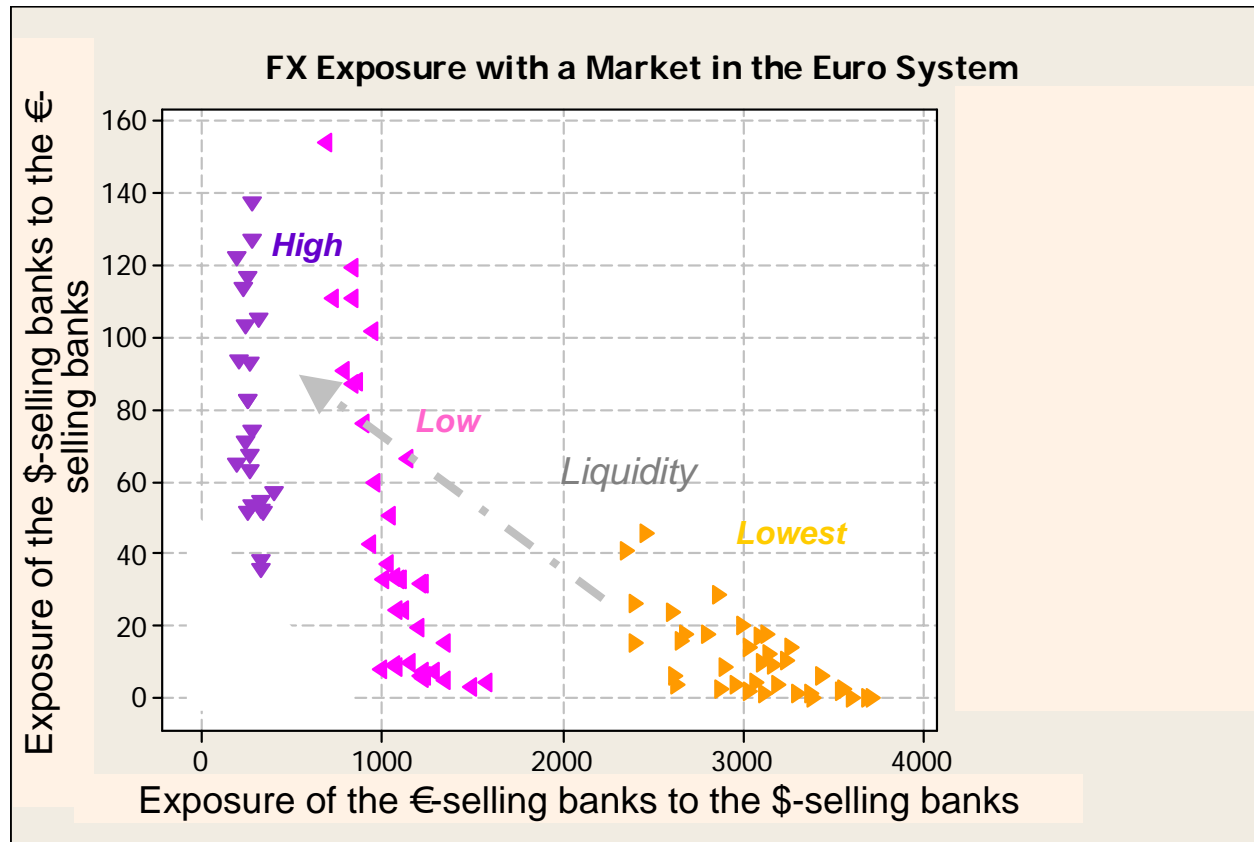
- Priorities strongly influence exposure

Results of Monte Carlo sampling using different network realizations



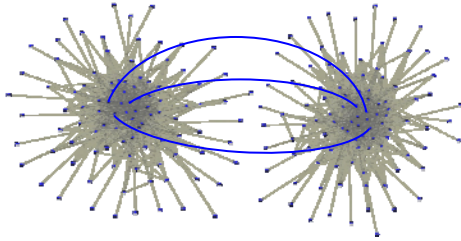
# Exposure of Banks through FoP

Equal liquidity in \$ and € with € liquidity market



- Exposure is greater in the system with a liquidity market (€system)
- Increasing liquidity mobility increases exposure

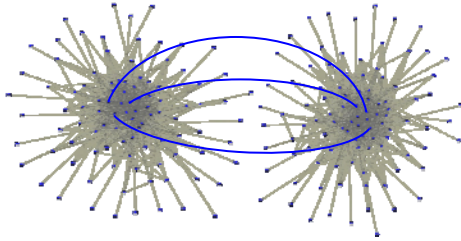
Results of Monte Carlo sampling using different network realizations



# Conclusions

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- At high liquidity the common FX drive creates discernable correlation in settlement
- At low liquidity
  - Congestion destroys instruction/settlement correlation in each system, and therefore €-settlement/\$-settlement correlation in the FoP case
  - Output coupling via *PvP amplifies* the settlement/settlement correlation by coordinating the settlement cascades in the two systems
- Queuing in systems when liquidity is unequal is
  - The same as in uncoupled systems for FoP
  - Higher in the more liquid system, and sensitive to FX rate, for *PvP*
- Total exposure among banks in the two systems
  - Is biased by differences in liquidity availability (liquidity level or presence of a liquidity market)
  - Is sensitive to the priority given to FX instructions



# Upcoming Investigations

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- Effect of settling FX trades through a net funding mechanism
  - Decrease of the interdependency ?
  - However, the time critical payments would force the banks to set some liquidity aside...
- Reaction of the global system to shocks
  - Contagion of a local shock from one RTGS to another
    - Default of a local player (will the crisis spread out to the other currency zone?)
  - Effects of global shocks
    - Default of a global player
    - Total shut-down of a RTGS
    - Operational problems affecting the FX link
- Influence of an intraday FX swap market
  - Reduced queuing in normal operation
  - As a mitigation of a local shock affecting one RTGS (beneficial interdependency)
- Additional market infrastructures (SSSs, CCPs, ICSDs, DNSs, markets...)