Office of Infrastructure Protection (IP)

National Infrastructure Simulation and Analysis Center (NISAC)

Global Finance as a Complex Adaptive System

MORS Workshop on Risk-Informed Decision Making

April 15, 2009

Homeland Security

UNCLASSIFIED

Outline

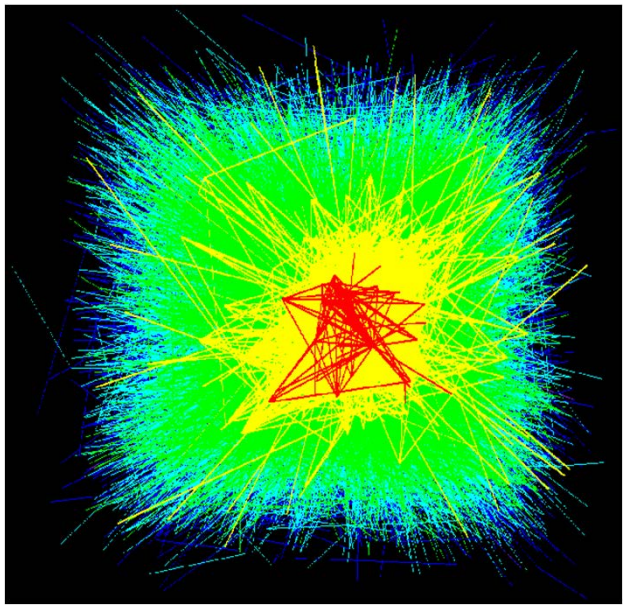
- **Financial interactions through payment systems**
- **Some effects of coupling through foreign exchange**
- **Controlling global financial instabilities**

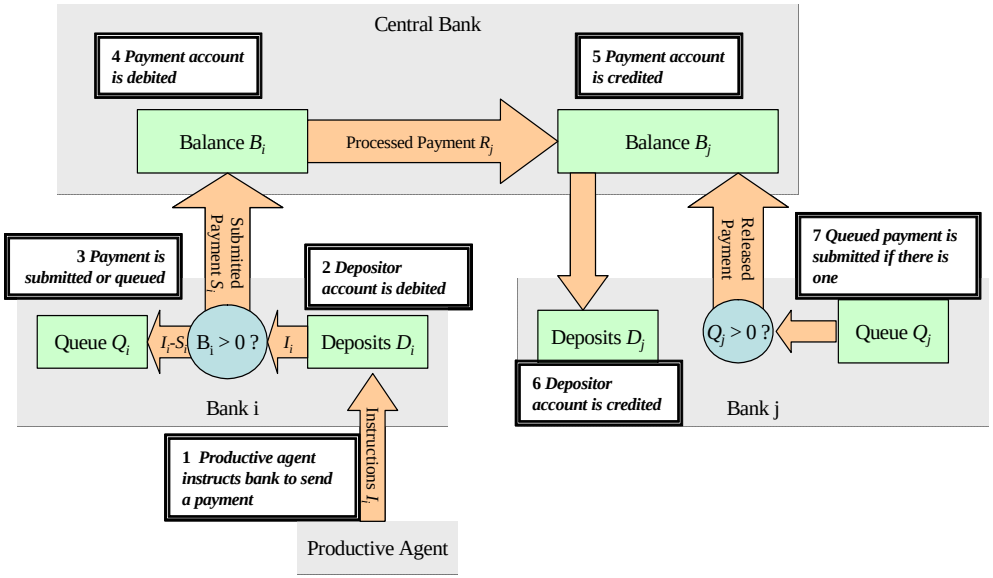
Payment Systems

- **Banking and Finance infrastructure makes and moves money; payment systems are an important mechanism.**
- **Fedwire is the operational backbone of the US banking system. Overnight lending of reserve account balances is the target of monetary policy.**
- **Opportunity to share data and ideas.**
  - Walt Beyeler and Robert J. Glass at Sandia National Laboratories
  - Morten L. Bech at Federal Reserve Bank of New York
  - Kimmo Soramäki at Helsinki University of Technology
- **Operation depends on perceptions of counterparty reliability.**

Congestion and Cascades in Payment Systems

- Network defined by Fedwire transaction data:
  - Payments among more than 6500 large commercial banks
  - Typical daily traffic: more than 350,000 payments totaling more than $1 trillion
  - Node degree and numbers of payments follow power-law distributions
- Bank behavior controlled by system liquidity:
  - Payment activity is funded by initial account balances, incoming payments, and market transactions
  - Payments are queued pending funding
  - Queued payments are submitted promptly when funding becomes available



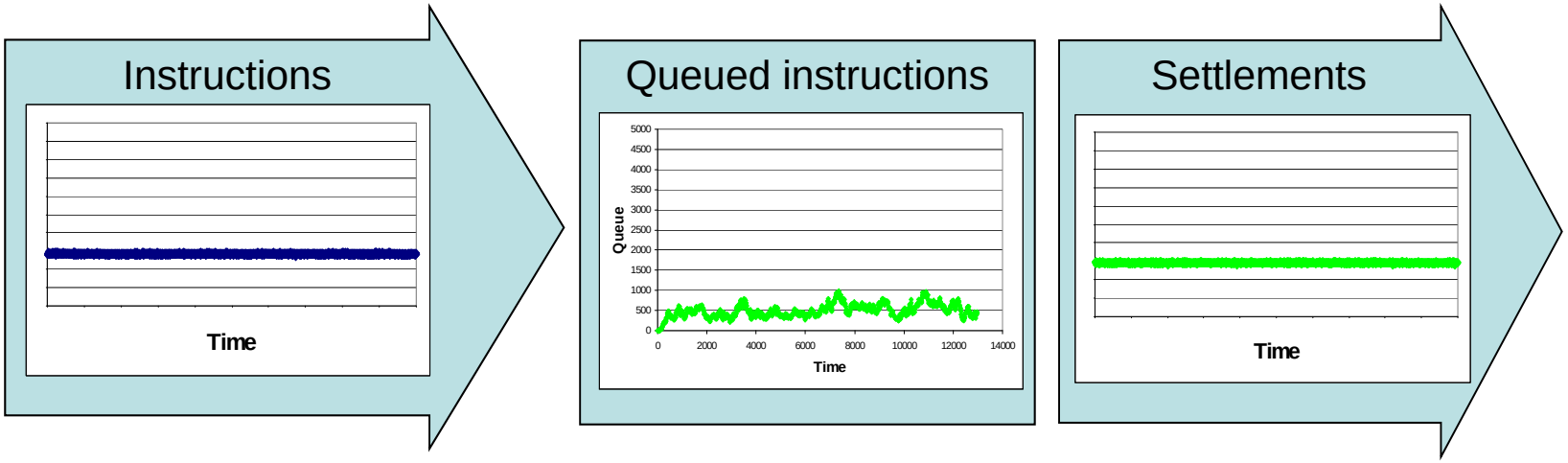


Findings

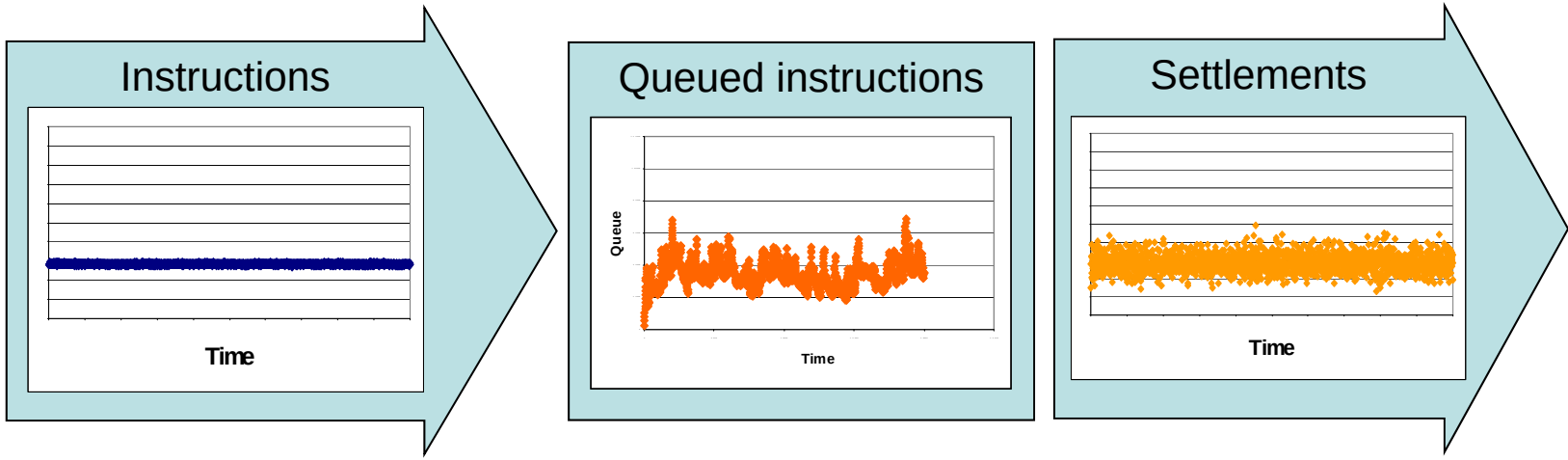
- Payment flows follow a scale-free distribution
- Performance is a function of both topology and behavior – neither alone can explain robustness
- Liquidity limits can lead to congestion and limit throughput, but performance can be greatly improved by moving small amounts of liquidity to the places where it's needed, e.g. through markets

Effect of Liquidity on Performance

High liquidity



Low liquidity



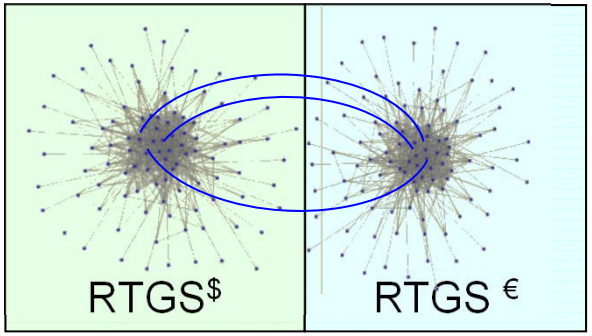
Reducing liquidity leads to episodes of congestion when queues build, and cascades of settlement activity when incoming payments allow banks to work off queues.

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

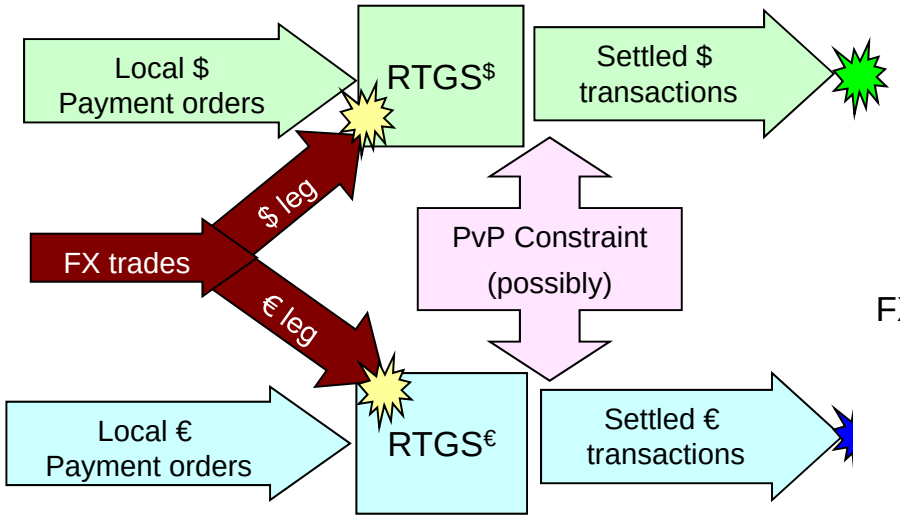


Each system processes:

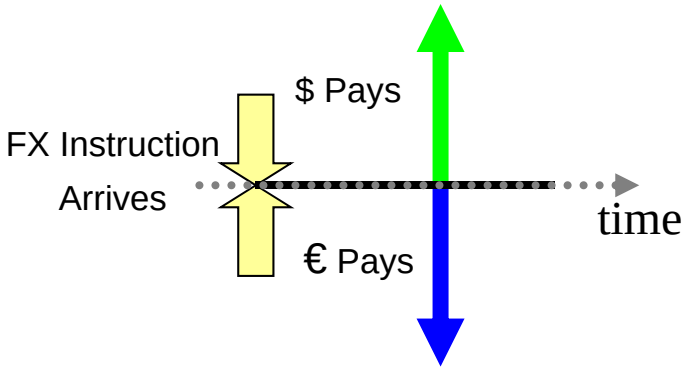
- Local payment orders
- Their leg of FX trades

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

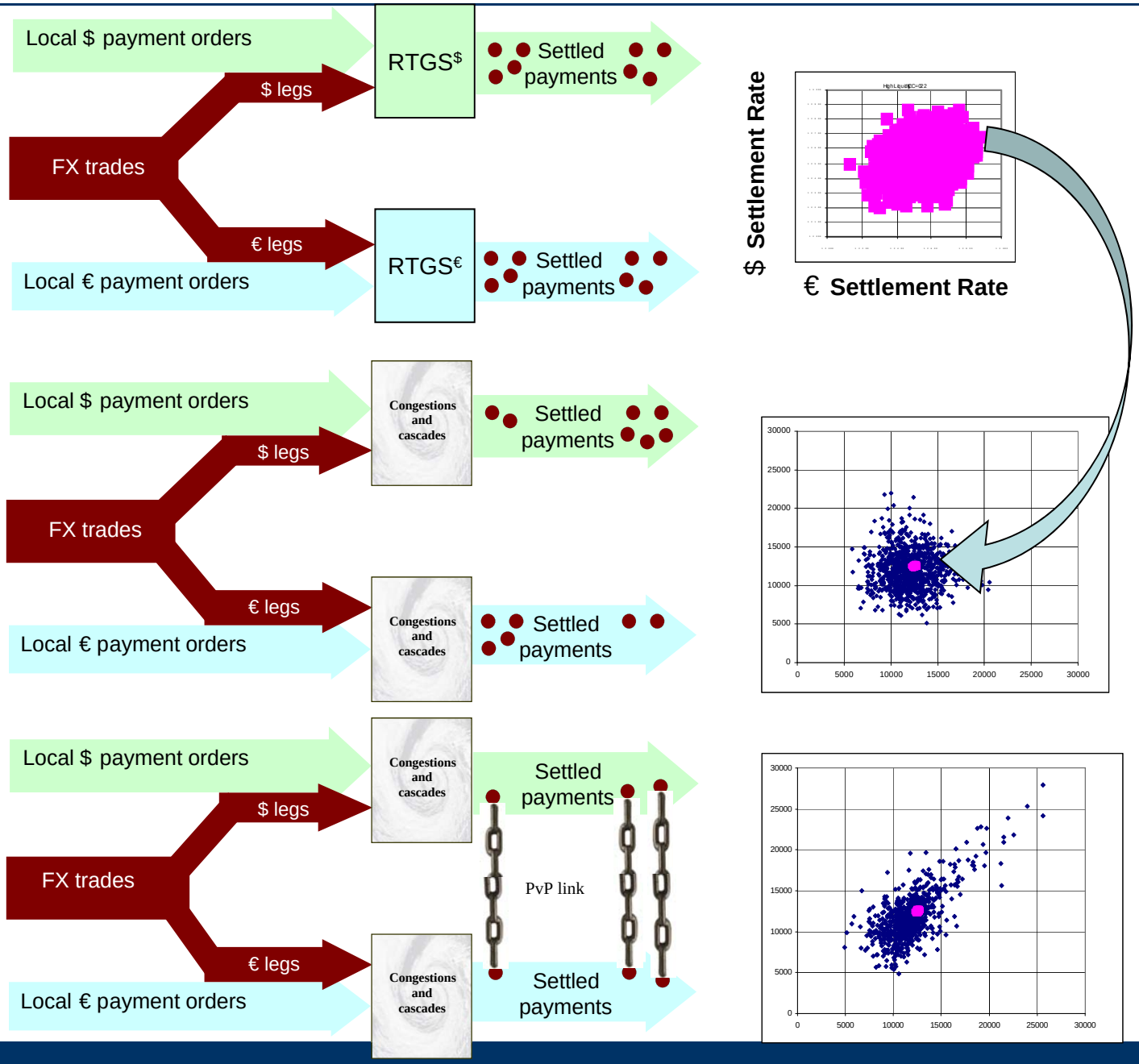
- Output tracks input
- Little variance in settlement rate
- Output correlation reflects common FX input

Low liquidity non-PvP

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

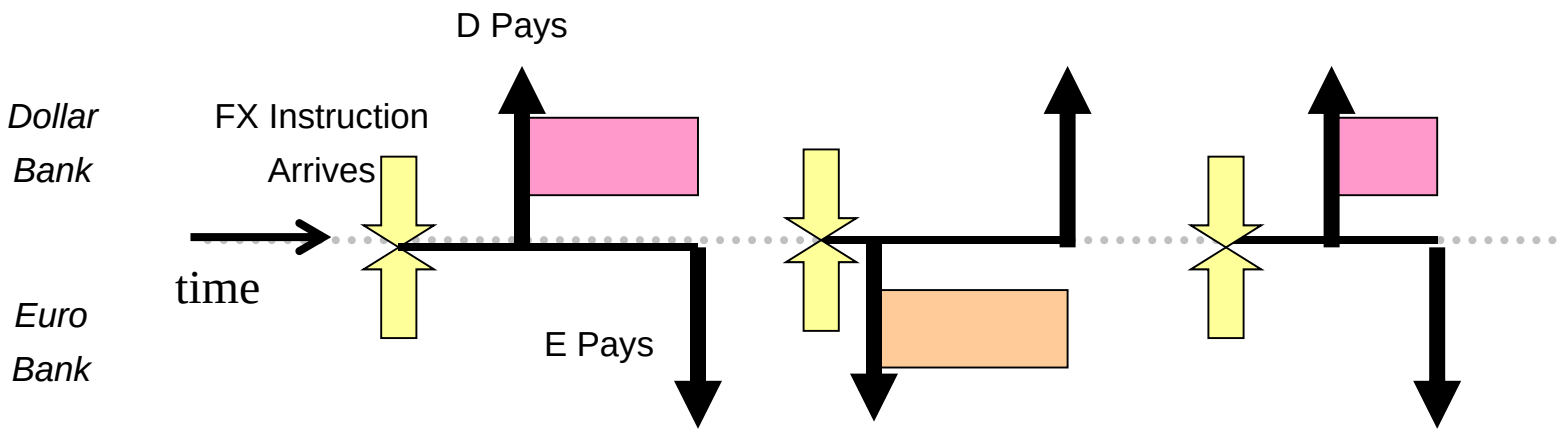
Low liquidity PvP

- 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

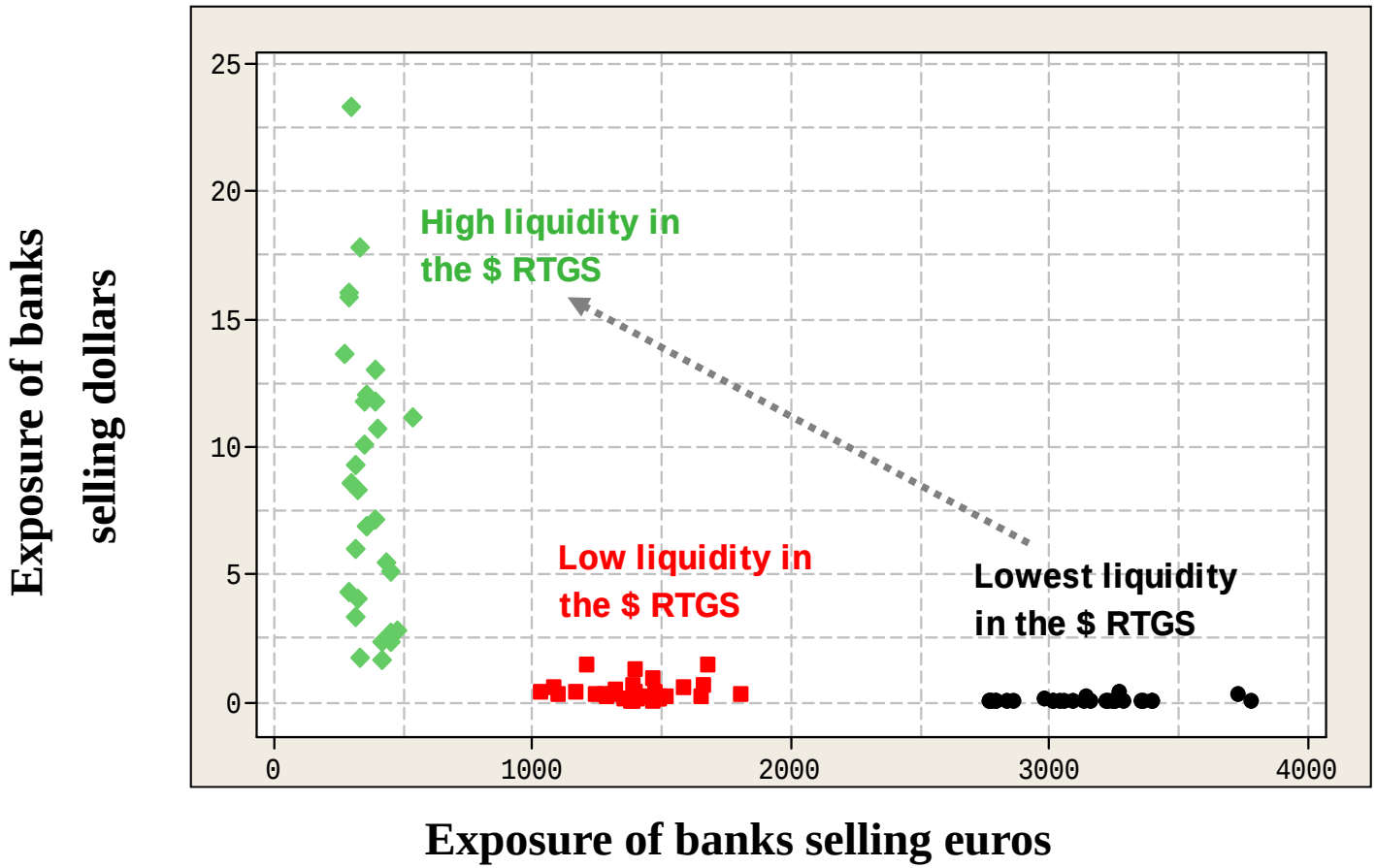


Settlement times may differ due to:

- 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

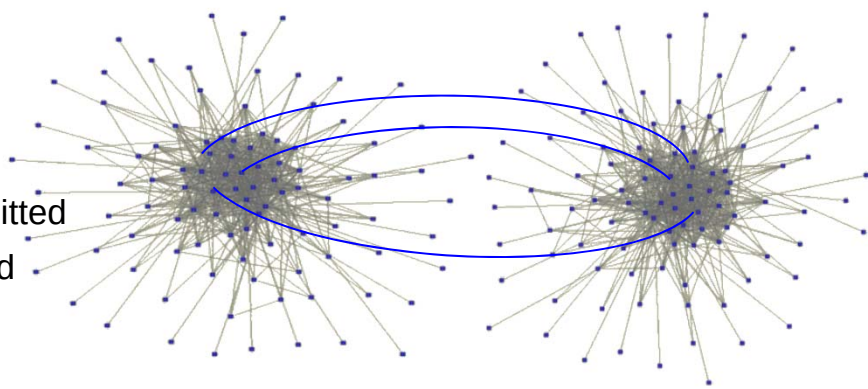
Joint Banque de France / European Central Bank conference on
"Liquidity in interdependent transfer systems"
Paris, 9 June 2008

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

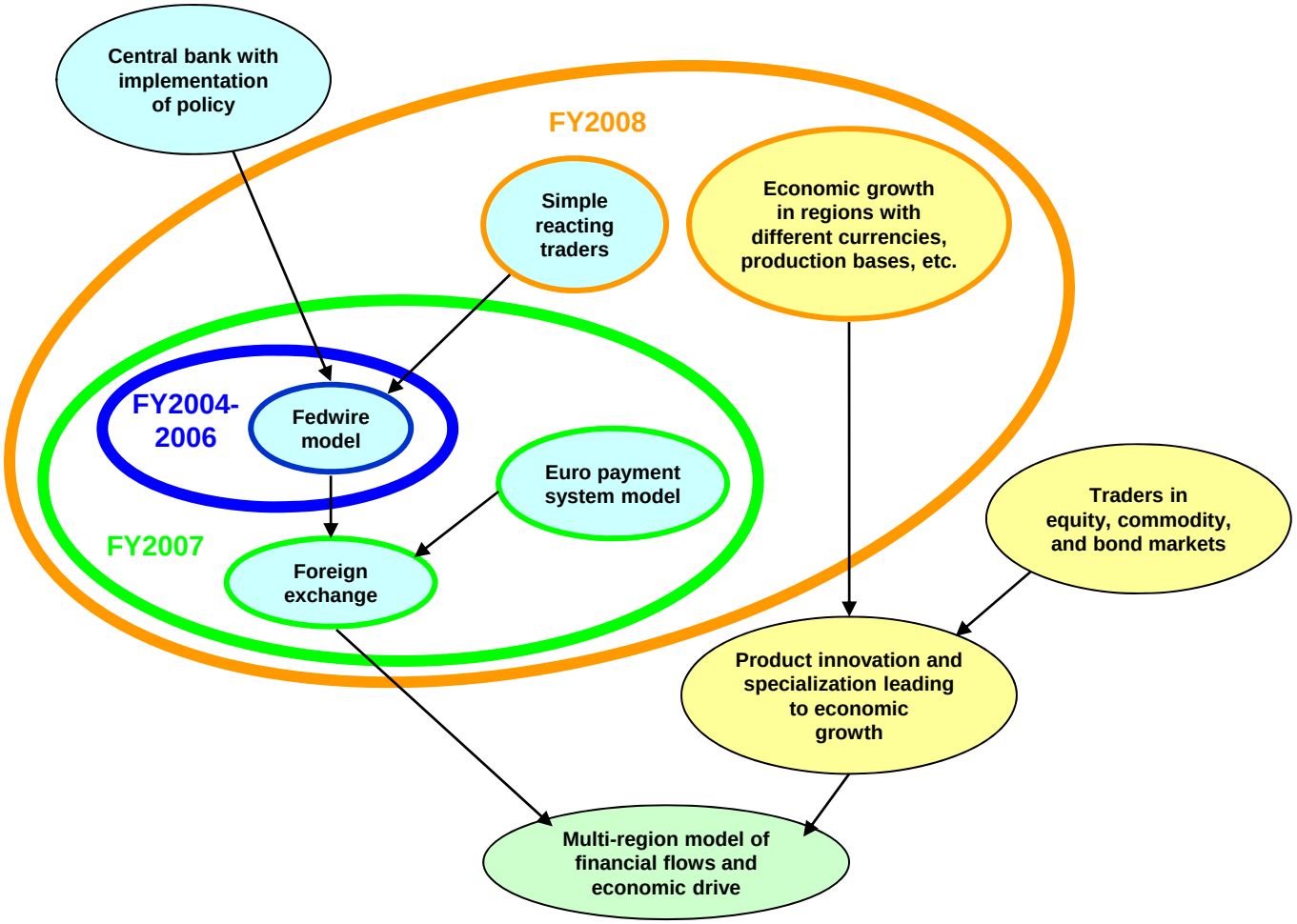
[1]Banque de France, [2]Federal Reserve Bank of New York, [3]Sandia National Laboratories, [4]Helsinki University of Technology

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



Enlarging scope to study bigger risks



Institutions and Technologies for Moving Money (pale blue)

Economic Drives (yellow)

- **Expansion from money transfer into money creation was planned for some time**
- **Motivated by prevalence of innovative finance with no performance history**
- **Focus on disruptions in credit flows rather than payment flows**

Causes of instability

- **Typical pattern of financial crises:**
  - Displacement followed by asset inflation
  - Credit expansion
  - Asset price leveling and collapse
  - Default

"Details proliferate; structure abides"
- Charles P. Kindleberger

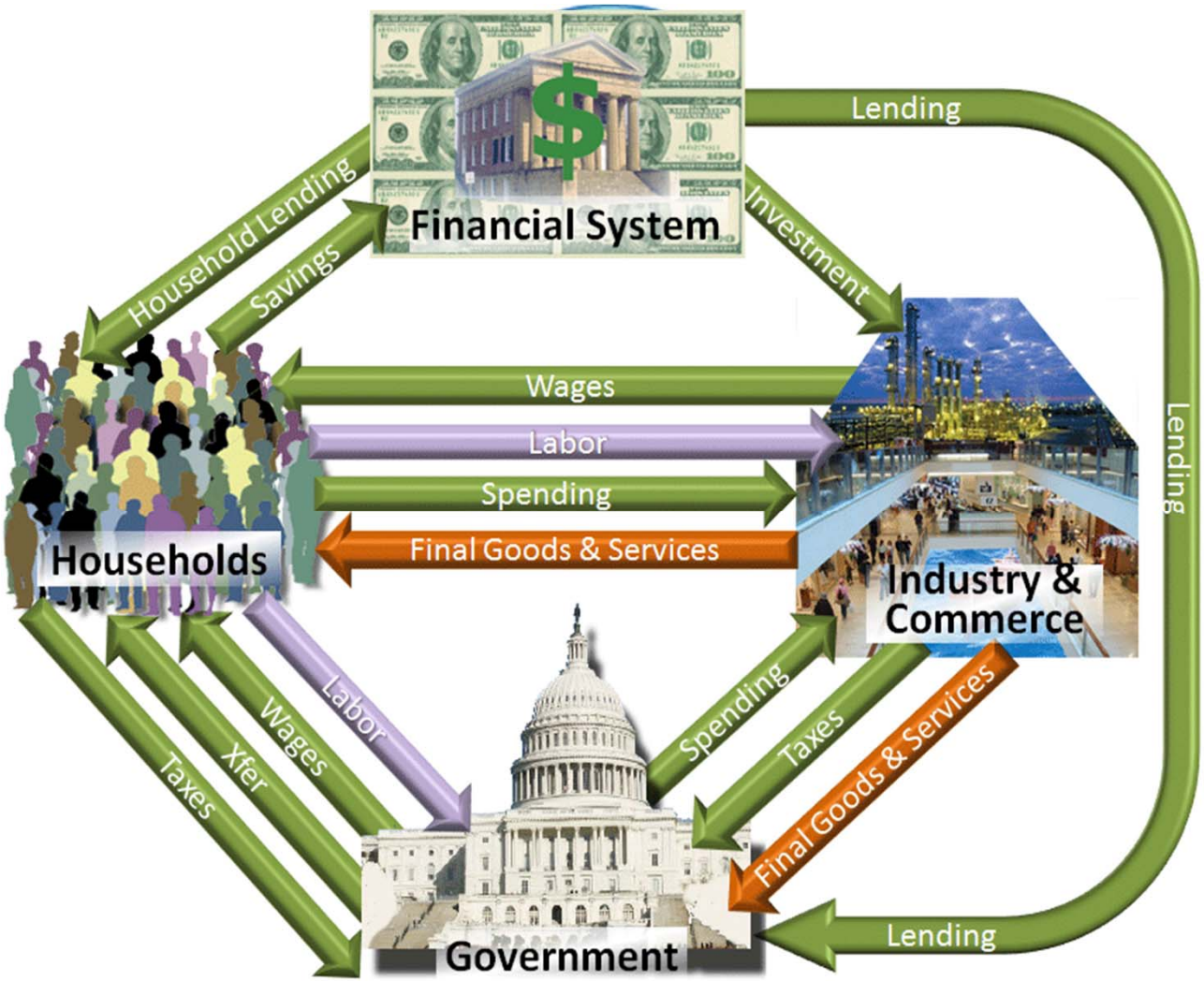
- **Most markets at most times are dominated by negative feedbacks**
- **Sometime *reinforcing* feedbacks predominate**
- **Basic feature: price movements change expectations in a way that fosters stronger movements in the same direction**
- **Financial systems are rife with such structures**

Modeling global financial instability

- **Details of global finance are fiendishly complicated and dynamic, and there will always be destabilizing feedbacks in financial systems. Models are unlikely to be able to predict the next collapse.**

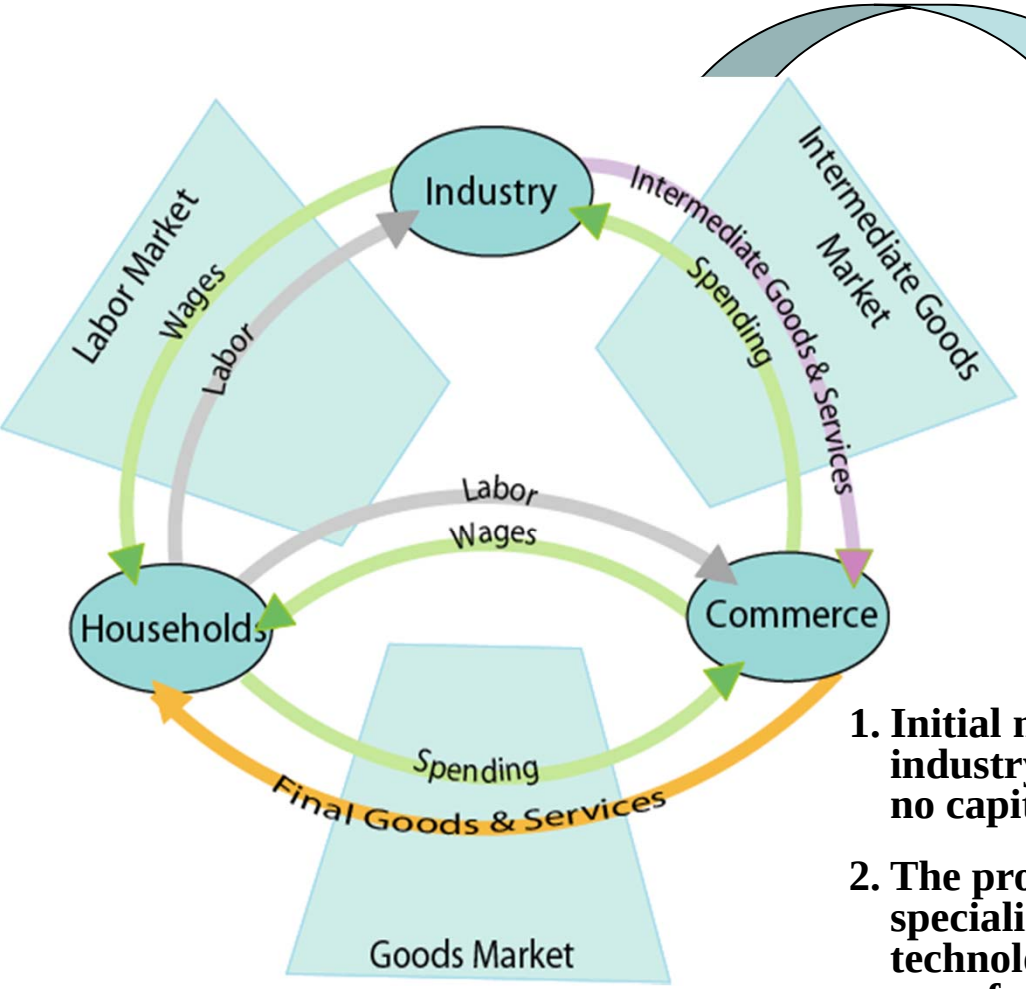
- **CASoS engineering framework leads to appropriately focused analyses:**
  - Goals: Moderate the episodic crises that occur in financial systems, as measured by
    - Production
    - Employment
  - Controls:
    - Countercyclical policies (asset prices, spreads,…)
    - Adaptive capital requirements
    - Exchanges for new financial instruments
    - …

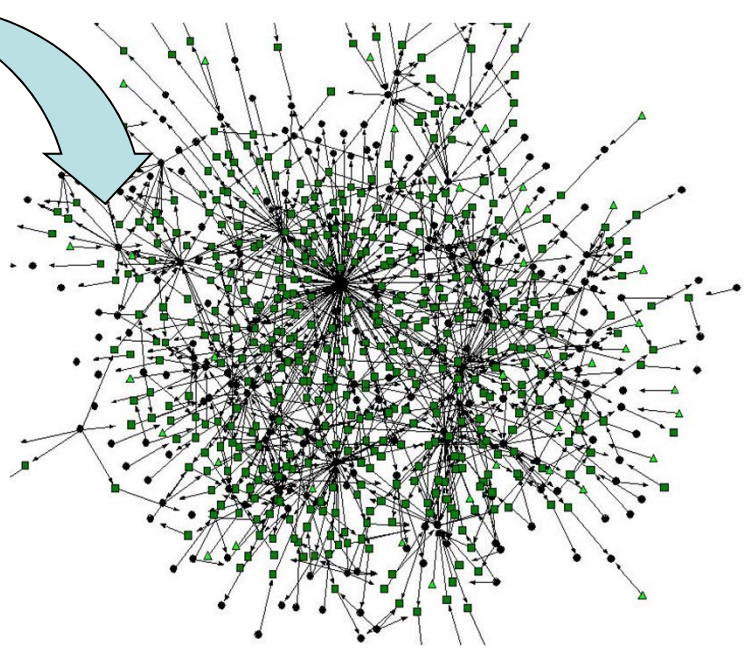
Economic context of finance



- **Intermediation is the key role of finance**
- **Risk perception is essential:**
  - Anticipated performance of allocation to different sectors
  - Counterparty reliability
- **Innovation is essential:**
  - Creates new investment opportunities with uncertain prospects
  - Financial innovation is a feature of many crises.

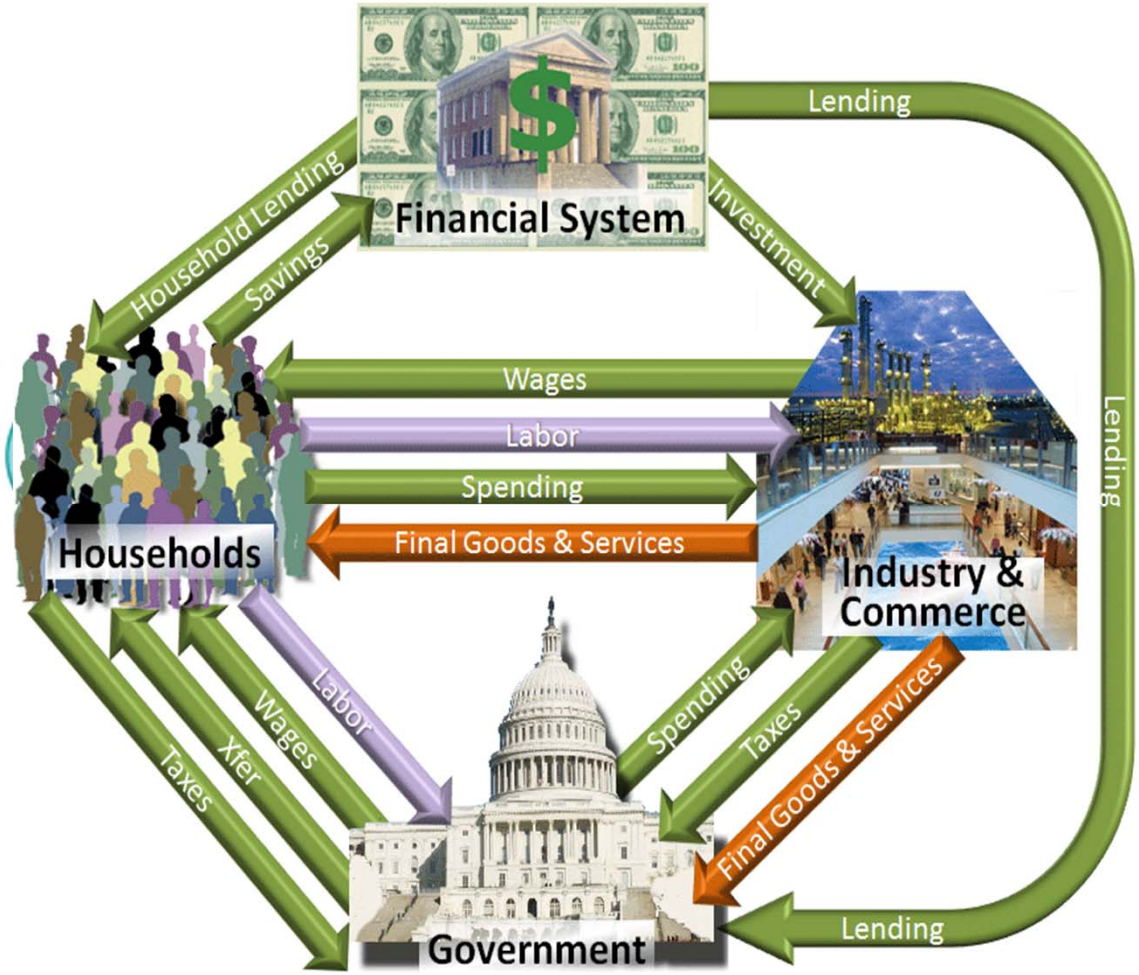
Staged implementation I





1. **Initial model includes only essential economic pieces: households, industry, and commerce, with no differentiation of products and no capital investments by firms.**
2. **The productive sector (commerce and industry) is allowed to specialize by implementing one of a set of randomly-generated technologies. Each technology will employ one or more inputs, one of which will be labor, and produce one or more outputs.**
3. **Technological improvement (via drift in the coefficients of firms' technology reactions) and disruption (via mutations in firms' reactions to include newly-created resources as inputs or catalysts) is added. Expansion is funded only from retained earnings.**

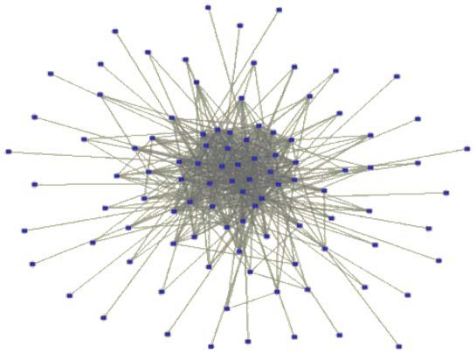
Staged implementation II



4. A government sector is added as employer and consumer, funded by taxes on transactions. By including this sector, demand and production patterns should shift because the services provided by government (for example, infrastructure, defense and law enforcement) are implicit in the operation of the economy.

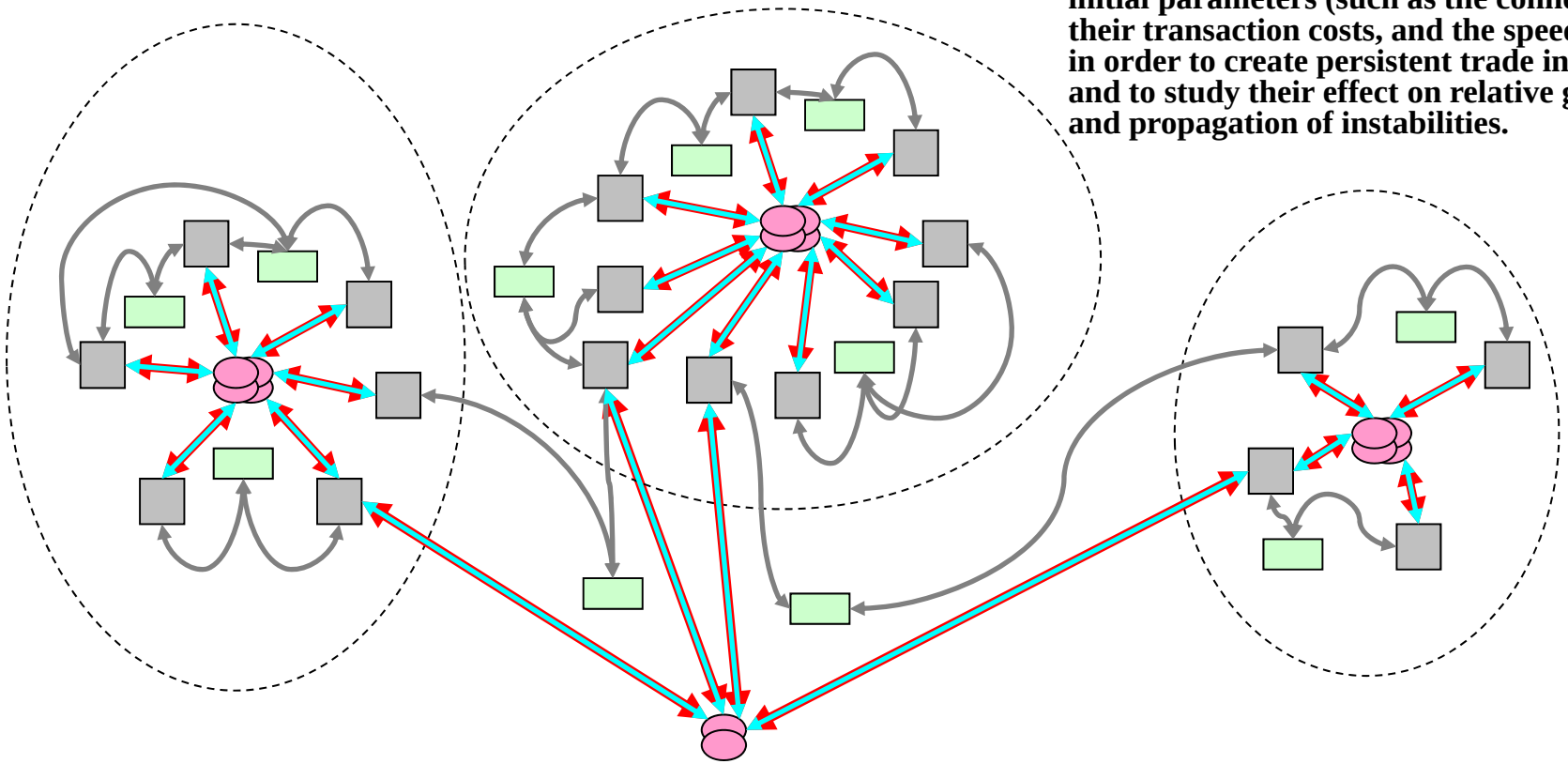
5. A basic financial layer is added in which firms, governments, and households can become indebted. Initially only lending is implemented because, unlike equity, debt is available to all entities (households, firms of any size)

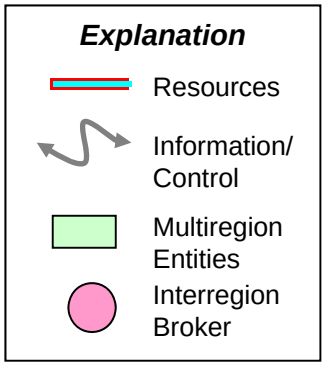
6. Add equity markets, allowing firms of a certain size to issue publicly-traded stock. This introduces the second major mechanism for firms to raise capital. Equity shares are another kind of contract, in which the initial purchase gives the buyer a claim on a future revenue stream from dividends.



Staged implementation III

7. Replicate for multiple regions which can exchange goods. These regions will have different endowments of basic resources (that is resources requiring only labor to produce), and may be assigned different values for other important initial parameters (such as the connectivity of markets and their transaction costs, and the speed of technological change) in order to create persistent trade incentives among regions and to study their effect on relative growth rates, stability, and propagation of instabilities.





8. Allow regions to exchange financial instruments as well, allowing for investment to flow among regions. Including global financial markets will give the model all significant processes characteristic of modern finance. The full model will allow NISAC to evaluate the stability characteristics of the system, and effectiveness of mitigations in controlling financial crises and on general economic growth.

Summary

- **Financial systems are driven by perceptions of risk and value**
- **These perceptions are shaped by experience with the performance of the system**
- **The resulting feedback is often destabilizing**
- **Specific predictions are impossible, but the CASoS framework allows us to use models to inform decisions**

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- 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
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- Bank of Finland 5th Payment and Settlement Simulation Seminar and Workshop. Helsinki, Finland, August 2007
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Contact Information

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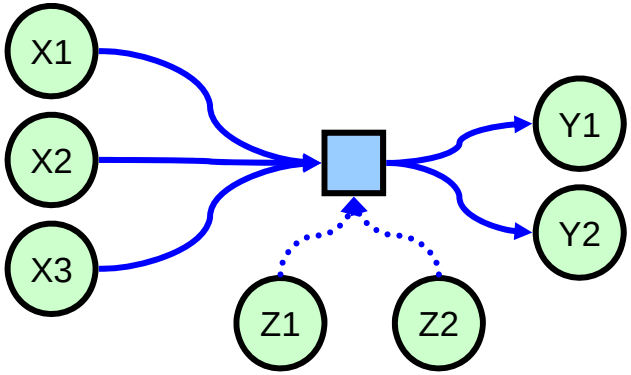
  - Robert J. Glass rjglass@sandia.gov, 505-844-5606

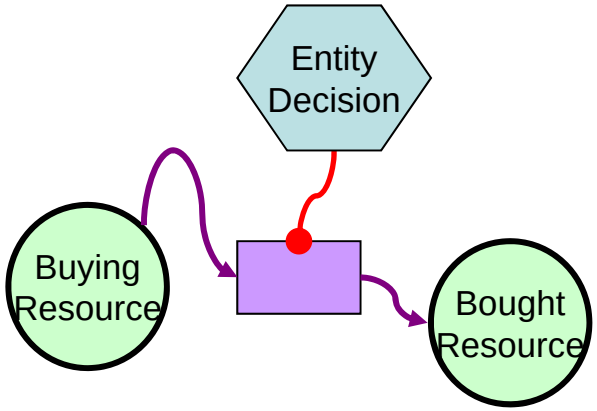
Details

Production and exchange processes

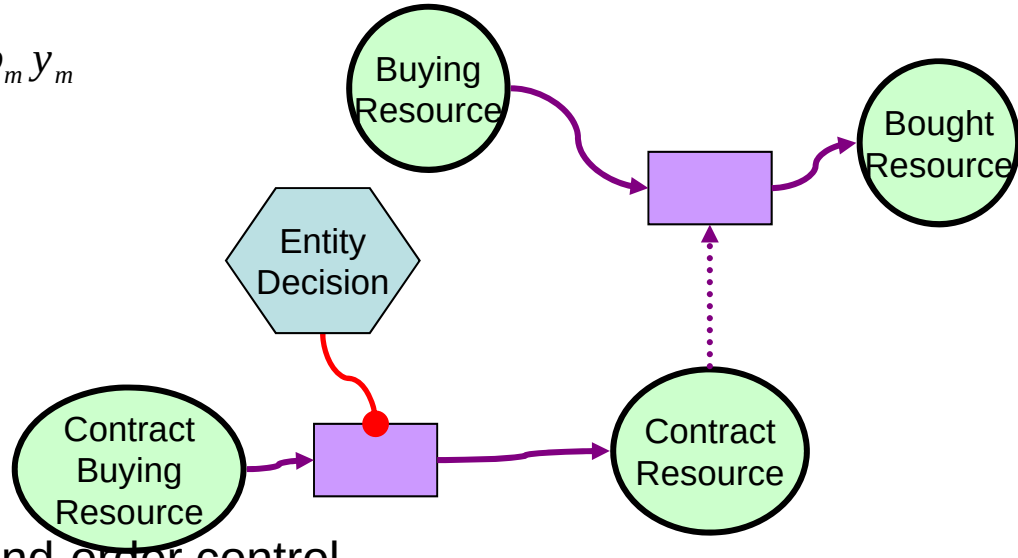


$$a_1x_1 + a_2x_2 + \ldots + a_nx_n \xrightarrow[c_1z_1, c_2z_2, \ldots c_lz_l]{r} b_1y_1 + b_2y_2 + \ldots + b_my_m$$

All processes are modeled on chemical transformations. Rates may be limited by inputs or catalysts



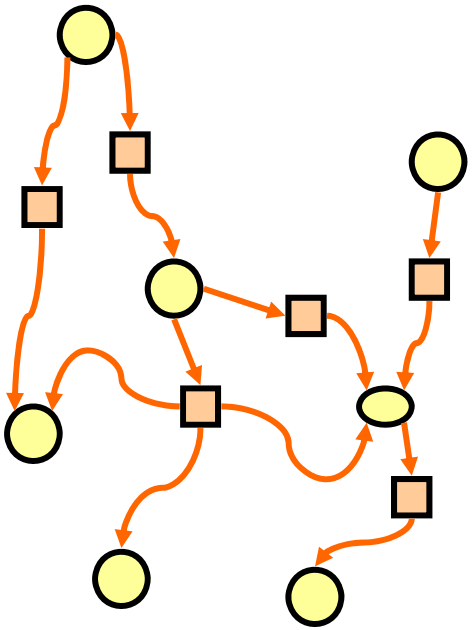
Basic structure of a Immediate Exchange process.



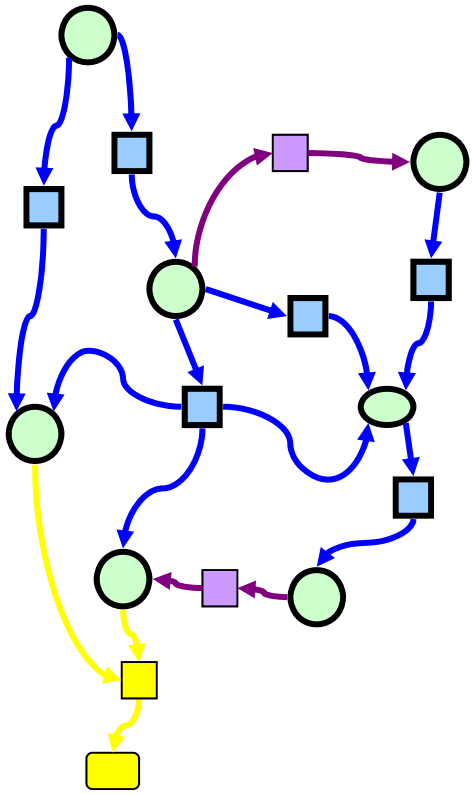
Basic structure of a Contracted Exchange process. The decision to contract is a kind of second-order control, analogous to changing catalyst amounts. Variants include adding decisions to the primary exchange, having no Contract Buying Resource, etc.

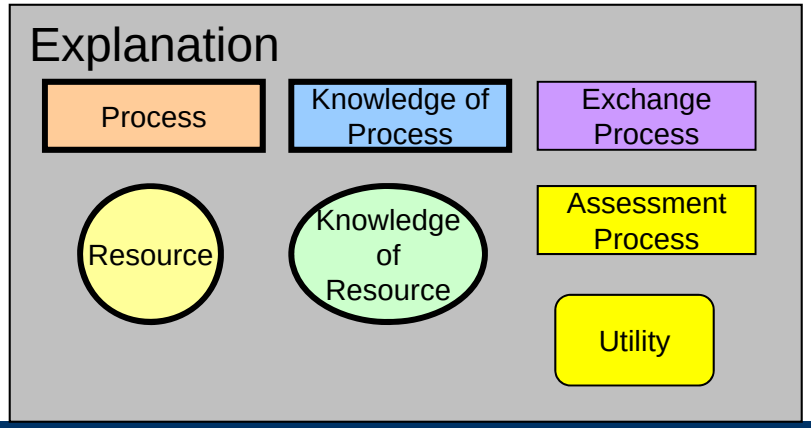
Process networks

Transformation Network

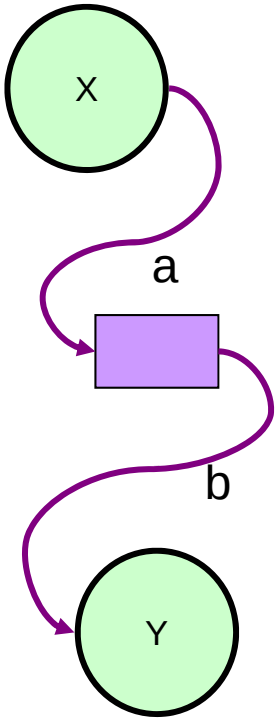


Process Knowledge Network

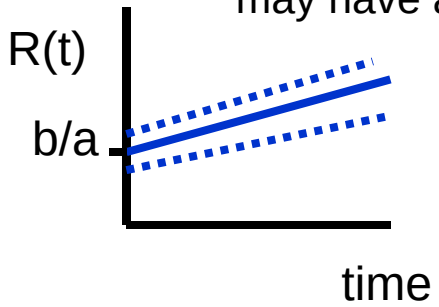




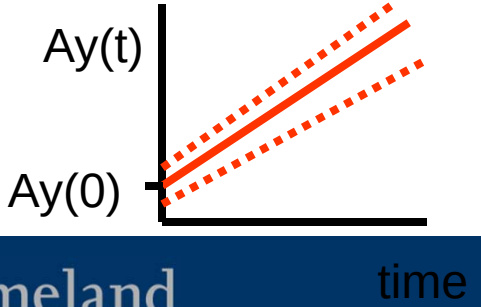
Exchange evaluation model



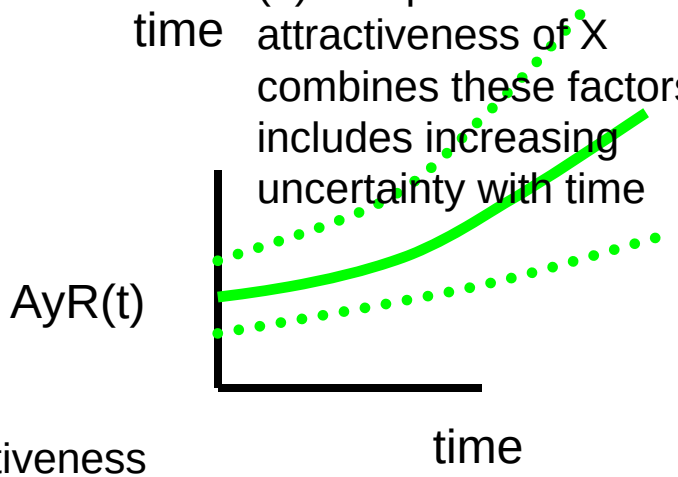
(1) Exchange rates are uncertain and may have a trend



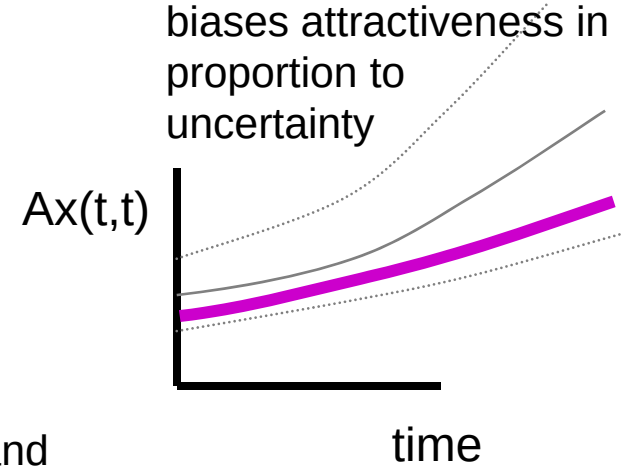
(2) Attractiveness of the output is also uncertain and may have a trend



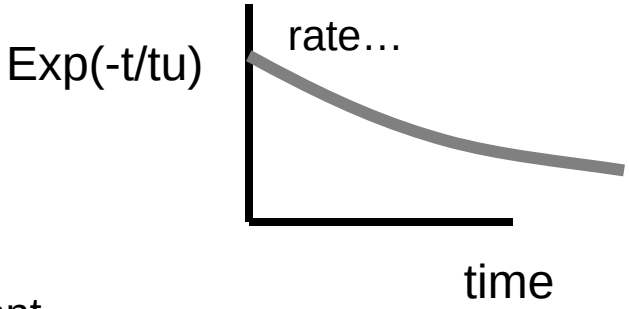
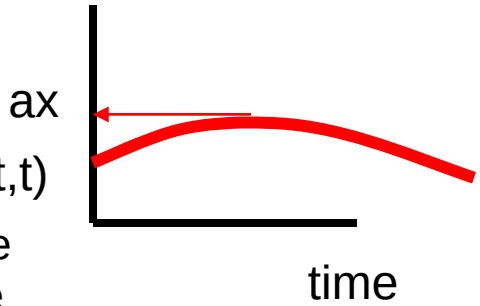
(3) The possible attractiveness of X combines these factors, and includes increasing uncertainty with time



(4) Risk aversion biases attractiveness in proportion to uncertainty



(5) Future values are discounted at some rate…



(5) The current attractiveness is the best current value of all possible exchanges. It is associated with some envisioned exchange time