Statics and Dynamics of Complex Network Systems: Supply Chain Analysis and Financial Networks with Intermediation

Dissertation Defense

by

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June 21, 2004

- Complex network systems
  - Financial networks with intermediation
  - Supply chains
- In
  - Static setting
  - Dynamic setting

Dissertation Structure

- Introduction
  - Literature survey
  - Research motivation
- Methodologies
  - Variational inequality theory
  - Projected dynamical systems
- Multilevel network perspective for supply chain
- Financial networks with intermediation
  - Statics
  - Dynamics
  - Electronic transaction
  - Risk management with variable weights

Literature Survey for Supply Chain Analysis

- Interdisciplinary topic that received great attention
  - Theoretical challenges
  - Practical importance
- Conceptual in nature
  - Cohen and Huchzermeier (1997), Bramel and Simchi-Levi (1997), Poirier (1996, 1999), Miller (2001)
- Analytical study
  - Federgruen and Zipkin (1986), Federgruen (1993), Chan, Muriel and Simchi-Levi (1998), Ganeshan et al. (1998)

- Development of supply chain network models
  - Study of interactions among decision-makers
    - Compete within a tier
    - Cooperate between tiers
  - Nagurney, Dong, and Zhang (2002)
    - First multitiered model studying the supply chains in a unified manner in network equilibrium context
  - Nagurney and Dong (2002b)
    - For further background
  - Nagurney, Loo, Dong, and Zhang (2002)
    - Static models over a single network
  - Nagurney and Dong (2002a) and Nagurney, Dong, and Mokhtarian (2001, 2003)
    - Unified treatment of complex network systems
      - Teleshopping vs shopping
      - Telecommuting vs commuting

Research Motivation for Supply Chain Analysis

- To capture distinct flows
  - Logistical
  - Informational
  - Financial

  within the *same* supply chain network system
- Observe *evolution* of
  - Prices
  - Commodity shipments

  through a discrete-time process

Novelty of My Research

- Nagurney, Ke, Cruz, Hancock and Southworth (2002)
  - *Environment and Planning B*
  - First proposed the multilevel (Logistical/Informational/Financial) network perspective to study the supply chain problem in network equilibrium context.
  - In the supply chain model, the financial and informational networks are made explicit.
  - The multilevel network was widely used thereafter and inspired the idea of supernetworks (http://supernet.som.umass.edu/).

Literature Survey for Financial Networks with Intermediation

- Intermediation
  - Banks, savings institutions, investment and insurance companies
- Quesnay (1758)
  - Origin use of networks to represent financial system
  - Depict the circular flow of funds
- Thore (1969, 1980)
  - Study systems of linked portfolios in credit networks
  - Decentralization/decomposition theory
  - Basic intertemporal models

Literature Survey for Financial Networks with Intermediation

- Nagurney, Dong, and Hughes (1992)
  - Multi-sector, multi-instrument
- Dong, Zhang, and Nagurney (1996)
  - Dynamic model
- Nagurney and Dong (1995, 1996a, b)
  - Inclusion of transaction costs

Literature Survey for Electronic Finance

- A growing area of study
  - Increasing impact on
    - Financial markets
    - Financial intermediation
    - Related regulatory issues and governance
  - Claessens, Glaessner, and Klingebiel (2000, 2001), Long (2000), Banks (2001), Turner (2001)
- Particular emphasis
  - Conceptualization
  - Role of networks in the transformations
  - McAndrews and Stefanidis (2000), Allen, Hawkins, and Seto (2001), Economides (2001), and Nagurney and Dong (2002)

Literature Survey for Risk Management with Variable Weights

- Behavior of investors
  - Maximize the expected return
  - Minimize the risk
- Markowitz (1952, 1959)
  - Mean and variance
- Numerous extension (Sharpe (1971), Stone (1973), Young (1998))
  - Equal trade-off between two criteria
- Dong and Nagurney (2001) and Nagurney, Dong, and Mokhtarian (2002)
  - Variable weights

Research Motivation for Financial Networks with Intermediation

- The financial economy explicitly includes
  - Financial intermediaries
  - Source agents
  - Uses of financial funds
- Advances of telecommunications have enormous effect
  - Financial services
  - Options available for financial transactions
  - Distribution channels
  - New types of products
  - Role of financial intermediaries
- Construction of a unified, quantifiable framework
- Variable weights to catch the risk attitudes of investors

Novelty of My Research

- Nagurney and Ke (2001a)
  - Published in *Quantitative Finance*
  - First publication that modeled the financial network with intermediation quantifiably.
- Nagurney and Ke (2001b)
  - Disequilibrium dynamics
  - Foundation for further study
- Nagurney and Ke (2003)
  - Published in *Quantitative Finance*
  - First considered the impact of electronic transaction
  - Capture competition within a tier of nodes and cooperation between tiers.
- Nagurney and Ke (2004)
  - First studied the bicriteria decision-making problem in multitiered financial networks.

Chapter 2: Overview of Methodologies

- Introduction
- Methodologies
  - Variational inequality theory
  - Projected dynamical systems
- Multilevel network perspective for supply chain
- Financial networks with intermediation
- Conclusion

- Definition of variational inequality problem:

To determine a vector $X^* \in \mathcal{K} \subset \mathcal{R}^n$ such that

$$F(X^*)^T \cdot (X - X^*) \geq 0, \quad \forall X \in \mathcal{K}$$

- Qualitative properties
  - Existence
  - Monotonicity
  - Lipschitz continuity
  - Uniqueness

Chapter 2: Overview of Methodologies

- Introduction
- Methodologies
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- Financial networks with intermediation
- Conclusion

- Algorithms
  - Projection method
    - Initialization
    - Computation

$$\left[X^{\tau} + \alpha G^{-1} F(X^{\tau-1}) - X^{\tau-1}\right]^{T}$$

$$\cdot \left[X - X^{\tau}\right] \geq 0, \quad \forall X \in \mathcal{K}$$

    - Convergence verification

Chapter 2: Overview of Methodologies

- Introduction
- Methodologies
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- Conclusion

- Modified projection method
  - Initialization
  - Computation

$$[\bar{X}^{\tau} + \alpha F(X^{\tau-1}) - X^{\tau-1}]^T$$

$$\cdot [X - \bar{X}^{\tau}] \geq 0, \quad \forall X \in \mathcal{K}.$$

  - Adaptation

$$[X^{\tau} + \alpha F(\bar{X}^{\tau}) - X^{\tau-1}]^T$$

$$\cdot [X - X^{\tau}] \geq 0, \quad \forall X \in \mathcal{K}$$

  - Convergence verification

Chapter 2: Overview of Methodologies

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- Definition of Projected Dynamical Systems

Given $X \in \mathcal{K}$ and $v \in F^n$, define the projection of *v* at X (with respect to *K*) by

$$\pi_{\mathcal{K}}(X, v) = \lim_{\delta \to 0} \frac{P_{\mathcal{K}}(X + \delta v) - X}{\delta}$$

And $P_{\mathcal{K}}(X) = argmin_{X' \in \mathcal{K}} \|X' - X\|.$

Definition: *The projected dynamical system (PDS) is defined as map:* $\Phi : \mathcal{K} \times \mathcal{R} \mapsto \mathcal{K}$

where: $\Phi(X, t) = \phi_X(t)$ *solves the initial value problem:*

$$\dot{\phi}_X(t) = \pi_{\mathcal{K}}(\phi_X(t), -F(\phi_X(t))),$$

$$\phi_X(0) = X$$

Chapter 2: Overview of Methodologies

- Introduction
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- Qualitative properties
  - Existence, uniqueness, and continuous dependence (Theorem 2.8)
  - Lipschitz continuity (Theorem 2.9)
  - Stability analysis

Chapter 2: Overview of Methodologies

- Introduction
- Methodologies
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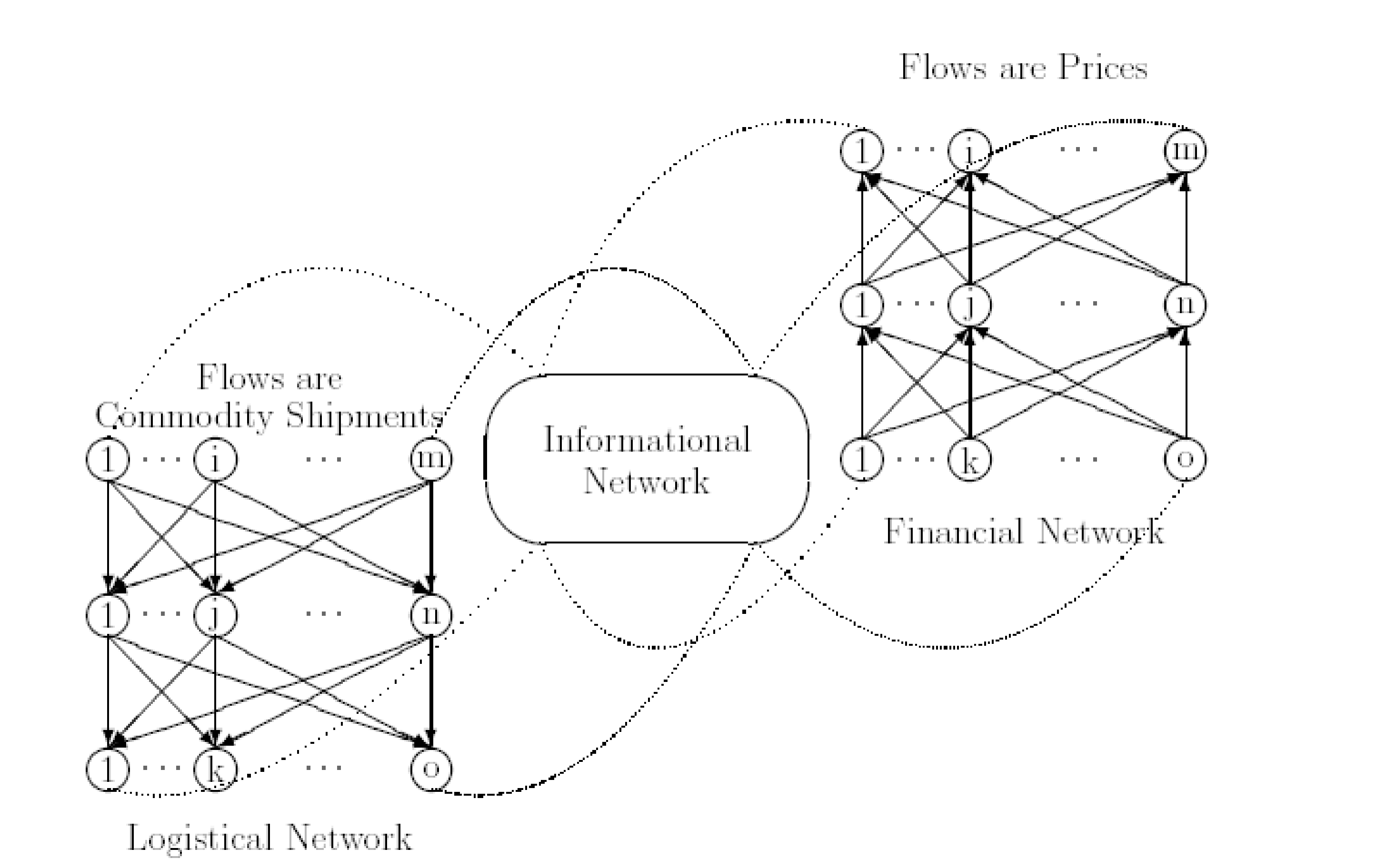
- Conclusion

- Algorithm (the Euler method)
  - Initialization
    - Set the sequence $\{\alpha_\tau\}$
  - Computation

$$X^\tau = P_{\mathcal{K}}(X^{\tau-1} - \alpha_{\tau-1} F(X^{\tau-1}))$$

  - Convergence verification

Chapter 3: Dynamics of Supply Chains: A Multilevel Network Perspective



Notable Features

- Within the same network:
- Logistical network
  - Depict the physical flows of products
  - Examine the relationships of various individual entities
- Informational network
  - Processing information
  - Demand forecasting information
  - Management information
  - Price information
- Financial network
  - Prices

The Dynamics

- The quantity flows over logistical network
  - The firms adjust commodity shipment
  - The consumers adjust consumption based on prices
  - The retailers operating between them
- The prices over financial network

The Projected Dynamical System

- The equilibrium point (the variational inequality formulation)
- Qualitative properties
  - Monotonicity
  - Lipschitz continuity
  - Existence and uniqueness
  - Stability of the system
- A discrete-time adjustment process
  - The Euler method
  - Computation of the commodity shipments at each iteration
  - Computation of the prices at each iteration

Numerical Examples

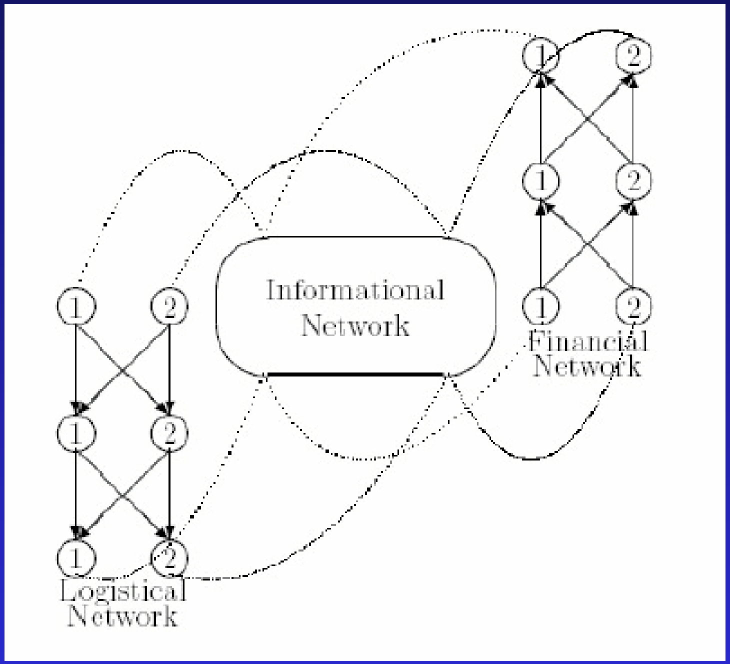


Figure 3.2: Multilevel Network for Examples 3.1 and 3.2

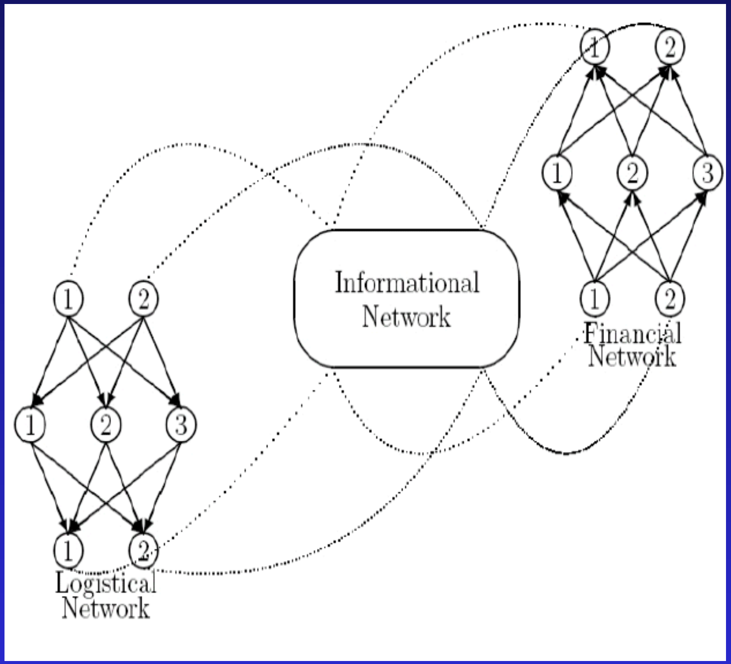


Figure 3.3: Multilevel Network for Example 3.3

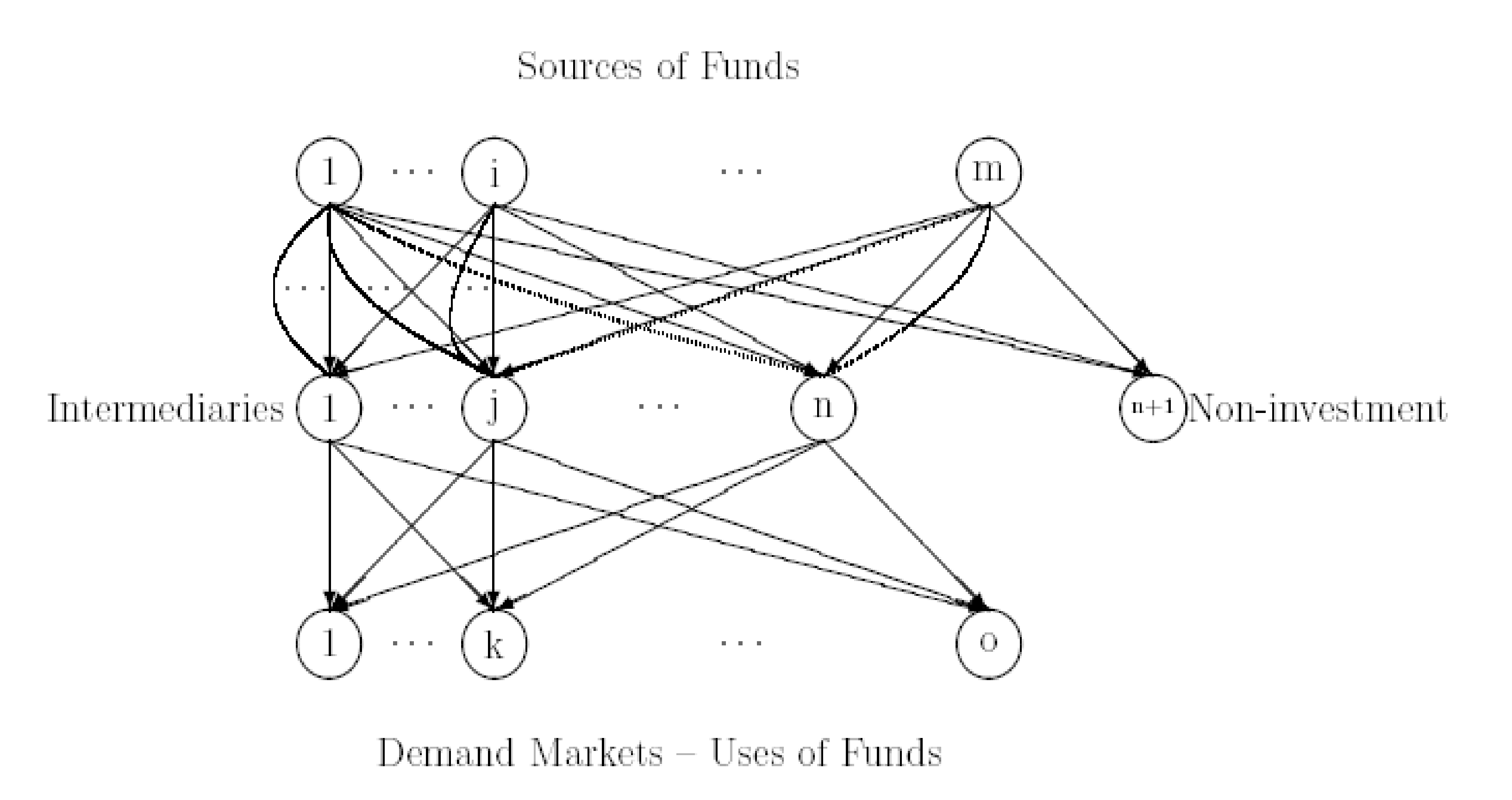
Input Data for Examples

The production cost functions of the manufacturers	Example 3.1: $f_i(q)=2.5q_i^2+q_1q_2+2q_i$ Example 3.2: $f_1(q)=2.5q_1^2+q_1q_2+12q_1$ Example 3.3: $f_2(q)=2.5q_2^2+q_1q_2+12q_2$
The transaction cost functions faced by the manufacturers and associated with retailers	Example 3.1: $c_{ij}(Q^1)=.5 {q_{ij}^{1}}^{2}+3.5q_{ij}^{1}$ Example 3.2: $c_{1j}(Q^1)={q_{1j}^{1}}^{2}+3.5q_{1j}^{1}$ Example 3.3: $c_{i3}(Q^1)=.5{q_{i3}^{1}}^{2}+5q_{i3}^{1}$
The handling costs of the retailers	$c_j(Q^1)=.5(\sum_{i=1}^{2} q_{ij}^{1})^2$
The demand functions	$d_1(\rho^3)=-2\rho_1^3-1.5\rho_2^3+1000$ $d_2(\rho^3)=-2\rho_2^3-1.5\rho_1^3+1000$.
The transaction costs between the retailers and the consumers	$c_{jk}(Q^2)=q_{jk}^{2}+5$

Equilibrium Patterns of the Numerical Examples

			Example 3.1	Example 3.2	Example 3.3
Flows Q^*	Q^{1*} (q_{ij}^{1*})	q_{11}^{1*}	16.608	14.507	9.243
		q_{12}^{1*}	16.608	14.507	9.243
		q_{21}^{1*}	16.608	17.230	13.567
		q_{22}^{1*}	16.608	17.230	13.567
		q_{13}^{1*}			14.645
		q_{23}^{1*}			9.726
	Q^{2*} (q_{jk}^{2*})	q_{11}^{2*}	16.608	15.869	11.404
		q_{12}^{2*}	16.608	15.869	11.404
		q_{21}^{2*}	16.608	15.869	11.404
		q_{22}^{2*}	16.608	15.869	11.404
		q_{31}^{2*}			12.184
		q_{32}^{2*}			12.184
prices ρ^{3*}	ρ_k^{3*}	ρ_1^{3*}	276.224	276.646	275.717
		ρ_2^{3*}	276.224	276.646	275.717

Chapter 4: Financial Networks with Intermediation



Notable Features

- Financial systems in disequilibrium or in equilibrium
- Interactions
  - Among individual sectors
    - Each facing own objective function
- Emphasize the advantage of network modeling and computation
- Allowing non-investment
- Consideration of transaction costs

- The behavior and optimality conditions
  - Agents with sources of funds

$$\text{Maximize } U^i(q_i^1) = \sum_{j=1}^{n}\sum_{l=1}^{L} \rho_{ijl}^1 q_{ijl}^1 - \sum_{j=1}^{n}\sum_{l=1}^{L} c_{ijl}(q_{ijl}^1) - q_i^{1^T} V^i q_i^1,$$

$$\sum_{j=1}^{n}\sum_{l=1}^{L} q_{ijl}^1 \leq S^i$$

  - Intermediaries

$$\text{Maximize } U^j(q_j^2) = \sum_{k=1}^{o}(\rho_{jk}^2 q_{jk}^2 - c_{jk}(q_{jk}^2)) - c_j(Q^1) - \sum_{i=1}^{m}\sum_{l=1}^{L}(\hat{c}_{ijl}(q_{ijl}^1) + \rho_{ijl}^1 q_{ijl}^1) - q_j^{2^T} V^j q_j^2$$

Subject to: $$\sum_{k=1}^{o} q_{jk}^2 \leq \sum_{i=1}^{m}\sum_{l=1}^{L} q_{ijl}^1$$

  - Demand markets

$$\rho_{jk}^{2*} + \hat{c}_{jk}(Q^{2*}) \begin{cases} = \rho_k^{3*}, & \text{if} \quad q_{jk}^{2*} > 0 \\ \geq \rho_k^{3*}, & \text{if} \quad q_{jk}^{2*} = 0. \end{cases}$$

$$d_k(\rho^{3*}) \begin{cases} = \sum_{j=1}^{n} q_{jk}^{2*}, & \text{if} \quad \rho_k^{3*} > 0 \\ \leq \sum_{j=1}^{n} q_{jk}^{2*}, & \text{if} \quad \rho_k^{3*} = 0 \end{cases}$$

- Variational inequality formulation

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{l=1}^{L}\left[2V_{z_{jl}}^{i}\cdot q_i^{1*}+2V_{z_{il}}^{j}\cdot q_j^{2*}+\frac{\partial c_{ijl}(q_{ijl}^{1*})}{\partial q_{ijl}^{1}}+\frac{\partial c_j(Q^{1*})}{\partial q_{ijl}^{1}}\right.$$
$$\left.+\frac{\partial \hat{c}_{ijl}(q_{ijl}^{1*})}{\partial q_{ijl}^{1}}-\gamma_j^{*}\right]\times\left[q_{ijl}^{1}-q_{ijl}^{1*}\right]$$
$$+\sum_{j=1}^{n}\sum_{k=1}^{o}\left[2V_{z_{mL+k}}^{j}\cdot q_j^{2*}+\frac{\partial c_{jk}(q_{jk}^{2*})}{\partial q_{jk}^{2}}+\hat{c}_{jk}(Q^{2*})+\gamma_j^{*}-\rho_k^{3*}\right]\times\left[q_{jk}^{2}-q_{jk}^{2*}\right]$$
$$+\sum_{j=1}^{n}\left[\sum_{i=1}^{m}\sum_{l=1}^{L}q_{ijl}^{1*}-\sum_{k=1}^{o}q_{jk}^{2*}\right]\times\left[\gamma_j-\gamma_j^{*}\right]$$
$$+\sum_{k=1}^{o}\left[\sum_{j=1}^{n}q_{jk}^{2*}-d_k(\rho^{3*})\right]\times\left[\rho_k^{3}-\rho_k^{3*}\right]\geq 0,\quad \forall (Q^1,Q^2,\gamma,\rho^3)\in\mathcal{K},$$

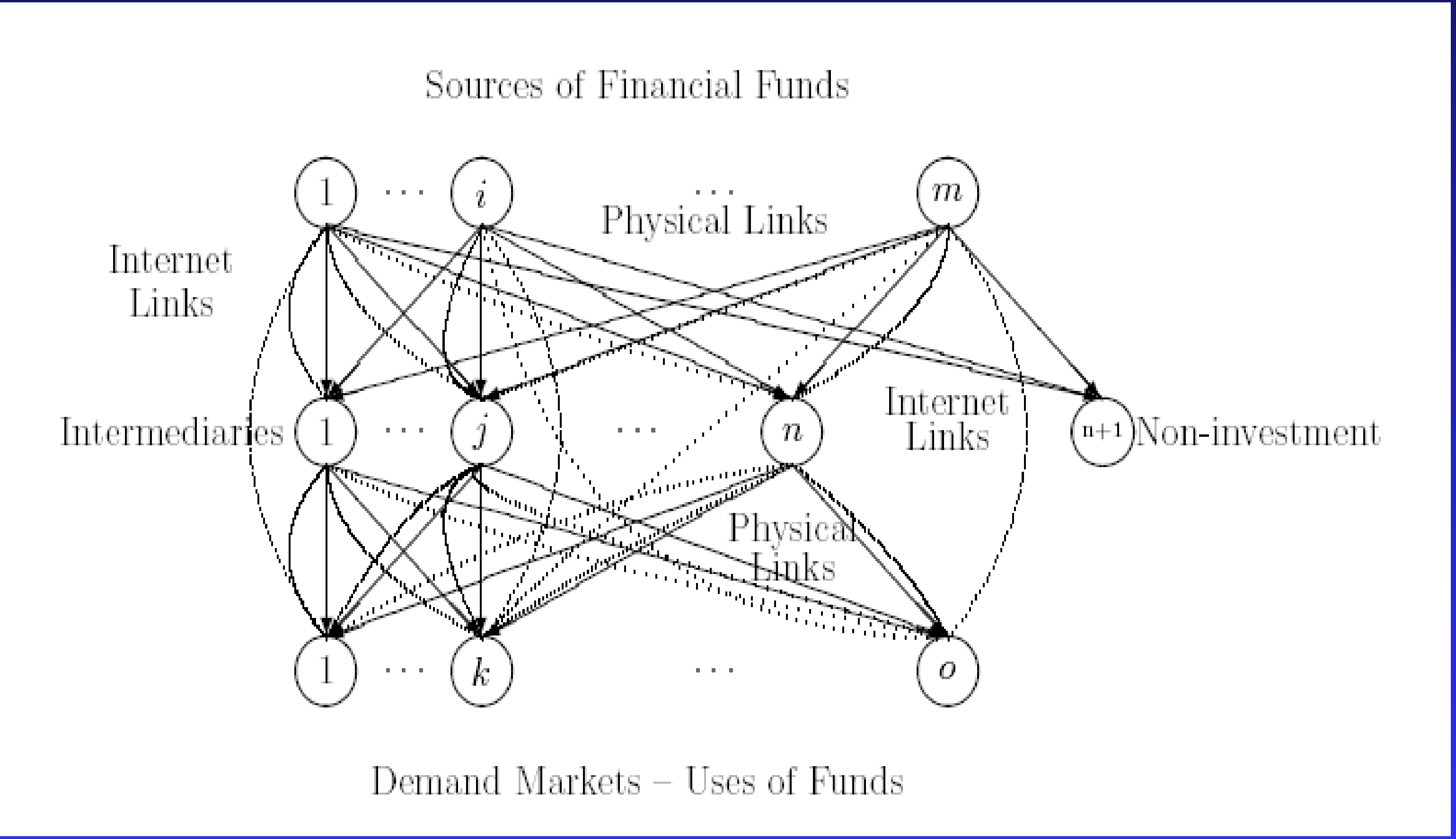
- Qualitative properties
  - Uniqueness
  - Existence
- The algorithm
  - Modified projection method
  - Computation of financial flow of products and prices
- Numerical examples

Chapter 5: Dynamics of Financial Networks with Intermediation

- Network structure
- The dynamics
  - Financial flows
    - Source agents adjust investment in various instruments
    - Intermediaries adjust transactions
    - Consumers obtain the financial products
  - Prices over time

- The projected dynamical system
- The equilibrium point (the variational inequality formulation)
- Qualitative properties
  - Existence and uniqueness
  - Stability of the system
- A discrete-time adjustment process
  - The Euler method
  - Computation of financial flows and prices at each iteration
- Numerical examples
  - Verify that the set of stationary points of PDS coincides with the set of solutions to the VI problem

Chapter 6: Dynamics of Financial Networks with Electronic Transactions



Notable Features

- Electronic transactions
- Source agents can transact:
  - With the intermediaries either physically or electronically
  - With the consumers in an electronic manner
- Intermediaries transact with the consumers
  - Physically
  - Electronically

- The behavior and optimality conditions
  - Agents with sources of funds
    - Maximize the net revenue
    - Minimize the risk
  - Intermediaries
    - Maximize the net revenue
    - Minimize the risk
  - Demand markets
- Variational inequality formulation
- The dynamics
  - The projected dynamical system

- Qualitative properties
  - Uniqueness
  - Existence
  - Lipschitz continuity
  - Stability of the system
- The algorithm
  - The Euler method
  - Computation of financial flows and prices
- Numerical examples

Numerical Examples

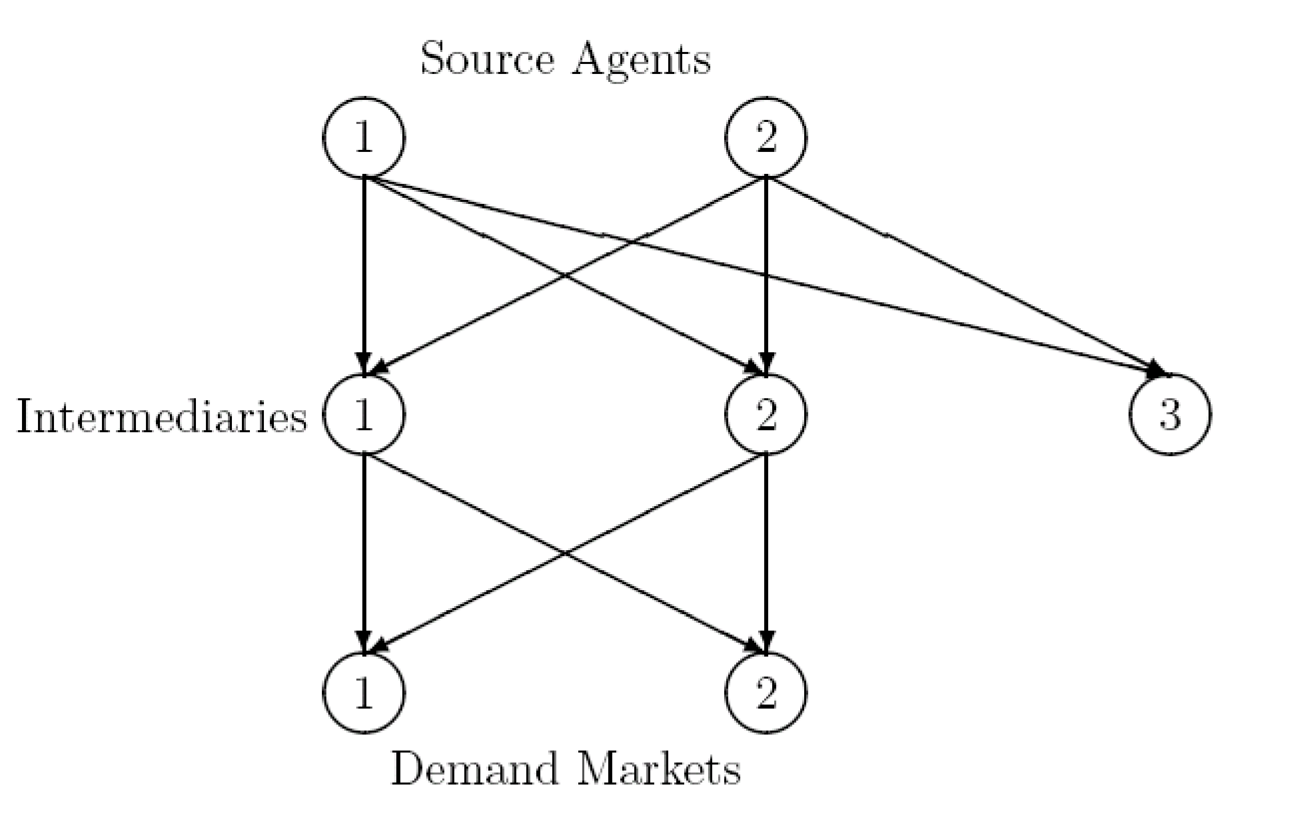


Figure: The Financial Network Structure of Example 6.1

Numerical Examples (Cont.)

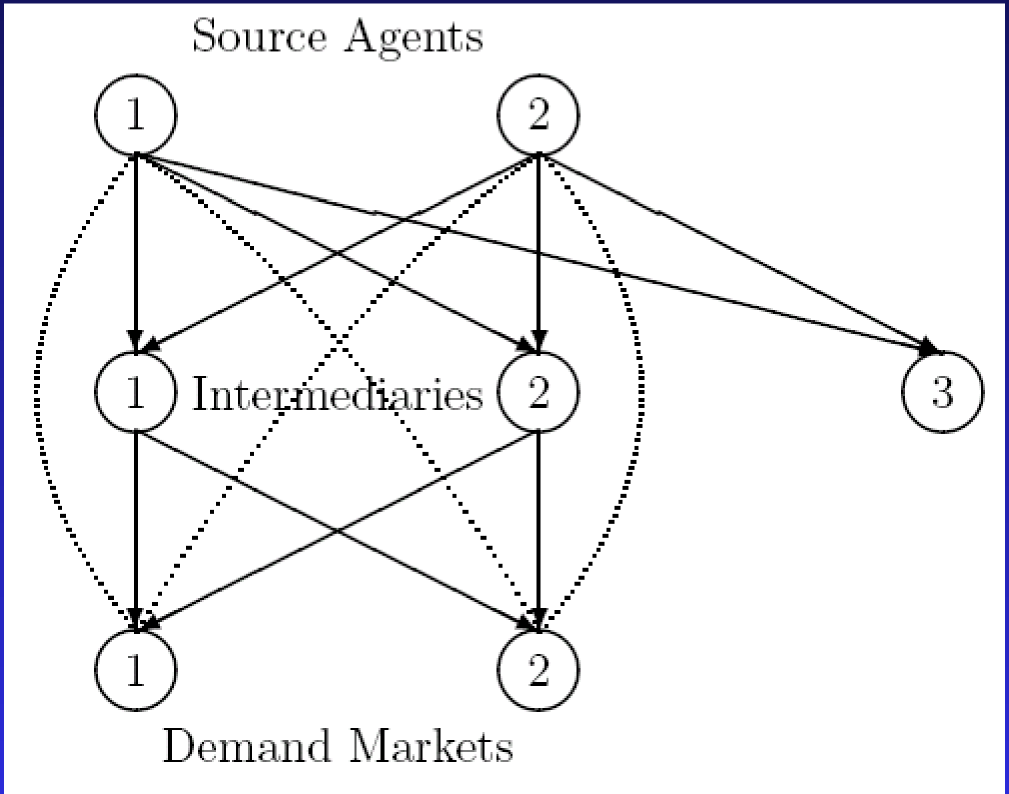


Figure: The Financial Network Structure of Example 6.2

Numerical Examples (Cont.)

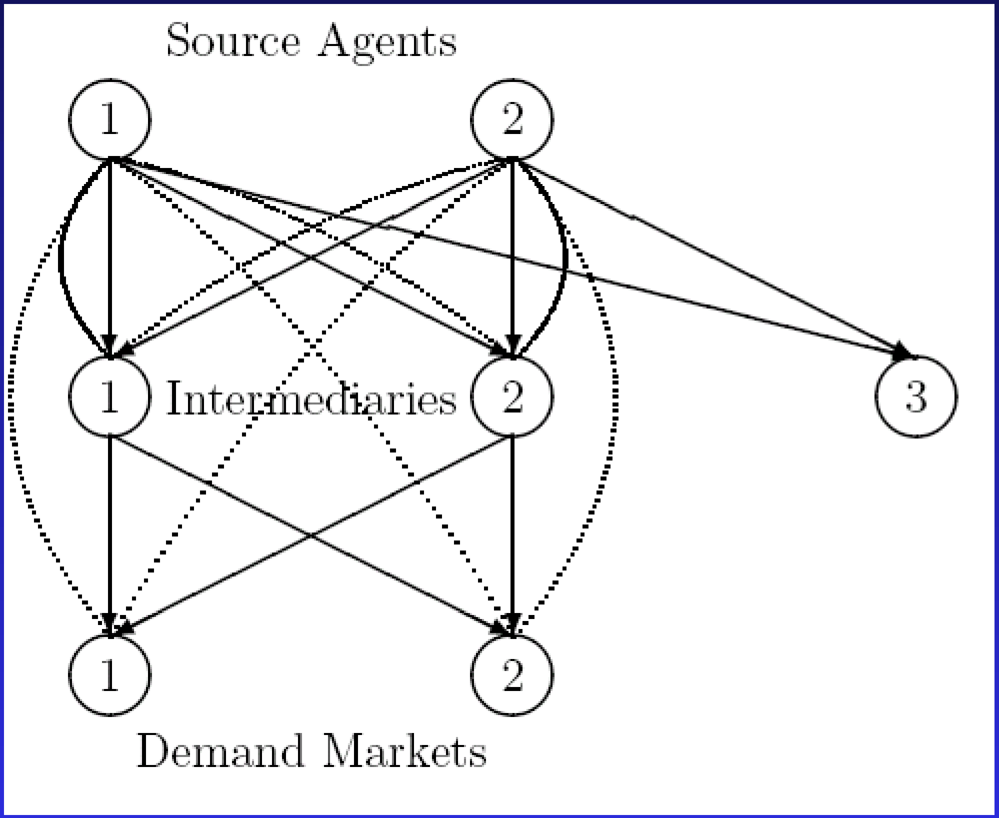


Figure: The Financial Network Structure of Example 6.3

Input Data for Examples 6.1-6.3

The transaction cost functions of the source agents	$c_{ijl}(q^1_{ijl}) = 0.5(q^1_{ijl})^2 + 3.5q^1_{ijl}$
The handling costs of the intermediaries	$c_j(Q^1) = 0.5\left(\sum_{i=1}^{2} q^1_{ij1}\right)^2$
The transaction costs of the intermediaries associated with transacting with source agents	$\hat{c}_{ijl}(q^1_{ijl}) = 1.5(q^1_{ijl})^2 + 3q^1_{ijl}$
The transaction costs of the consumers transacting with the intermediaries	$\hat{c}_{jkl}(q^2_{jkl}) = q^2_{jkl} + 5$
The demand functions at the demand markets	$d_1(\rho^3) = -2\rho^3_1 - 1.5\rho^3_2 + 1000$ $d_2(\rho^3) = -2\rho^3_2 - 1.5\rho^3_1 + 1000$

Additional transaction costs for Example 6.2 and 6.3:

The transaction cost functions of the source agents for dealing with demand markets:	$c_{ik}(q_{ik}^3) = 0.5(q_{ik}^3)^2 + q_{ik}^3$
Transaction cost functions from the demand markets:	$\hat{c}_{ik}(Q^2, Q^3) = q_{ik}^3 + 1$

Based on Example 6.2, the additional transaction costs for Example 6.3 are:

The transaction costs of the source agents transacting with the financial intermediaries electronically:	$c_{ij2}(q_{ij2}^1) = 0.5(q_{ij2}^1)^2 + 0.5q_{ij2}^1$
Transaction costs of the intermediaries transacting with sources electronically:	$\hat{c}_{ij2}(q_{ij2}^1) = 0.5(q_{ij2}^1)^2 + 0.5q_{ij2}^1$

Table 6.1: Equilibrium Patterns of the Numerical Examples

			Example 6.1	Example 6.2	Example 6.3
Flows Q^*	Q^{1*}	q^{1*}_{111}	10	4.8	3.09
	(q^{1*}_{ijl})	q^{1*}_{121}	10	4.8	3.09
		q^{1*}_{211}	10	4.8	3.09
		q^{1*}_{221}	10	4.8	3.09
		q^{1*}_{112}			3.33
		q^{1*}_{122}			3.33
		q^{1*}_{212}			3.33
		q^{1*}_{222}			3.33
	Q^{2*}	q^{2*}_{111}	10	4.8	6.42
	(q^{2*}_{jkl})	q^{2*}_{121}	10	4.8	6.42
		q^{2*}_{211}	10	4.8	6.42
		q^{2*}_{221}	10	4.8	6.42
	Q^{3*}	q^{3*}_{11}		5.2	3.57
	(q^{3*}_{ik})	q^{3*}_{12}		5.2	3.57
		q^{3*}_{21}		5.2	3.57
		q^{3*}_{22}		5.2	3.57
Lagrange Multipliers	γ^*_j	γ^*_1	245.02	260.59	255.72
γ^*		γ^*_2	245.02	260.59	255.72
Prices ρ^{3*}	ρ^{3*}_k	ρ^{3*}_1	280	280	280
		ρ^{3*}_2	280	280	280

Chapter 7: Financial Networks with Intermediation: Risk Management with Variable Weights

Why variable weights?

In decision-making under uncertainty,

Risk attitude → Decisions → Expected monetary payoffs

To reveal a sector's preference over the return and the risk, we reconstruct the objective functions to include the variable weights.

Notable Features

- Each source agent
  - Maximize net revenue z_{1i}^{1}
  - Minimize risk z_{2i}^{1}
- Each intermediary
  - Maximize net revenue z_{1j}^{2}
  - Minimize risk z_{2j}^{2}
- Essence: "How much achievement on one objective is the decision-maker willing to give up in order to improve achievement on another objective?"
- Criterion-dependent weight w_{2I}^{t}
  - For source agents: I=i; i=1,…,m, and t=1
  - For intermediaries: I=j; j=1,…,n, and t=2

- Risk-penalizing value function
  - Source Agents

$$\text{Maximize } U^i(q_i^1) = \sum_{j=1}^{n}\sum_{l=1}^{L}(\rho_{ijl}^1 q_{ijl}^1 - c_{ijl}(q_{ijl}^1)) - w_{2i}^1(r^i(q_i^1))r^i(q_i^1)$$

  - Intermediaries

$$\text{Maximize } U^j(q_j^2) = \sum_{k=1}^{o}(\rho_{jk}^2 q_{jk}^2 - c_{jk}(q_{jk}^2)) - c_j(Q^1) - \sum_{i=1}^{m}\sum_{l=1}^{L}(\hat{c}_{ijl}(q_{ijl}^1) + \rho_{ijl}^1 q_{ijl}^1)$$
$$-w_{2j}^2(r^j(q_j^2))r^j(q_j^2), \qquad (7.16)$$

Subject to: $$\sum_{k=1}^{o} q_{jk}^2 \leq \sum_{i=1}^{m}\sum_{l=1}^{L} q_{ijl}^1$$

  - Demand Markets

- Variational inequality formulation
- Qualitative properties
  - Uniqueness
  - Existence
- The algorithm
  - Modified projection method
  - Computation of financial flow of products and prices
- Numerical examples

Input Data for Examples 7.1-7.3

The transaction cost functions of the source agents	$c_{ijl}(q_{ijl}^1) = 0.5(q_{ijl}^1)^2 + 3.5q_{ijl}^1$
The handling costs of the intermediaries	$c_j(Q^1) = 0.5\left(\sum_{i=1}^{2} q_{ij1}^1\right)^2$
The transaction costs of the intermediaries associated with transacting with source agents	$\hat{c}_{ijl}(q_{ijl}^1) = 1.5(q_{ijl}^1)^2 + 3q_{ijl}^1$
The transaction costs of the consumers associated with transacting with the intermediaries	$\hat{c}_{jkl}(q_{jkl}^2) = q_{jkl}^2 + 5$
The demand functions at the demand markets	$d_1(\rho^3) = -2\rho_1^3 - 1.5\rho_2^3 + 1000$ $d_2(\rho^3) = -2\rho_2^3 - 1.5\rho_1^3 + 1000$

Weights in Examples 7.2 and 7.3

- Example 7.2: weights associated with the source agents transacting with the first financial intermediary were doubled
- Example 7.3: $w^1_{2i} = z^1_{2i}$ for $i =$ 1, 2.

Table 7.1: Equilibrium Patterns of the Numerical Examples

			Example 7.1	Example 7.2	Example 7.3
Flows Q^*	Q^{1*}	q^{1*}_{111}	10	9.29	3.10
	(q^{1*}_{ijl})	q^{1*}_{121}	10	10.71	3.10
		q^{1*}_{211}	10	9.29	3.10
		q^{1*}_{221}	10	10.71	3.10
	Q^{2*}	q^{2*}_{11}	10	9.29	3.10
	(q^{2*}_{jk})	q^{2*}_{12}	10	9.29	3.10
		q^{2*}_{21}	10	10.71	3.10
		q^{2*}_{22}	10	10.71	3.10
Lagrange Multipliers	γ^*_j	γ^*_1	245.00	247.14	269.63
γ^*		γ^*_2	245.00	242.86	269.63
Prices ρ^{3*}	ρ^{3*}_k	ρ^{3*}_1	280	280	283.94
		ρ^{3*}_2	280	280	283.94

Comparison of the Two Areas

- Similarities
  - Network structure
  - Variables
  - Cost structure
  - Methodology
- Differences
  - Construction
  - Flows on the links
  - Direction of flows
  - Behavior of top two tiers
  - Role of middle tier
  - Constraints

Contributions

- First dynamic multilevel supply chain model within context of network equilibrium (Nagurney, Ke, Cruz, Hancock, and Southworth (2002))
- First financial network study to explicitly include the financial intermediaries quantifiably (Nagurney and Ke (2001a))
- First financial network study to consider the impact of electronic transactions quantifiably (Nagurney and Ke (2003))
- Incorporate the dimension of the explicit dynamic behavior of the various financial agents as well as the price dynamics
- Inclusion of variable weights brings the model closer to the "reality" of financial transactions

Future Research

- Empirical study
  - Multilevel supply chain network model
  - Theoretical models of financial networks
- Informational Networks
  - Vary with respect to
    - Timelines
    - Quality of information
  - Different costs
- Introduction of variable weights into current
  - Supply chain network models
  - International financial network models
- Additional criteria

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