Financial Engineering of the Integration of Global Supply Chain Networks and Social Networks with Risk Management

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Outline of Presentation

- Motivation
- Presentation of the Supernetwork
- Numerical Examples
- Future Research

Motivation

- “Economic action is embedded in social relations that sometimes facilitate and at other times derail exchange.” (Uzzi, 1996)
- “The network economy is founded on technology but it can only be built on relationships.” (Kelly, 1999)

Motivation

- Global transactions are increasingly exposed to new risks and uncertainties.
- Risk management in global supply chains is very important.
- Relationships in supply chains have the potential to reduce risk and uncertainty.

Relationships in Supply Chains

- Can reduce risk (cf. Baker and Faulkner (2004, p. 92))
  - By reducing “information asymmetry between buyer and seller”
  - By reducing “opportunism due to imposed social obligations and effective sanctions on the seller”
- Can reduce transaction costs
  - By increasing levels of trust (cf. Dyer (2000))

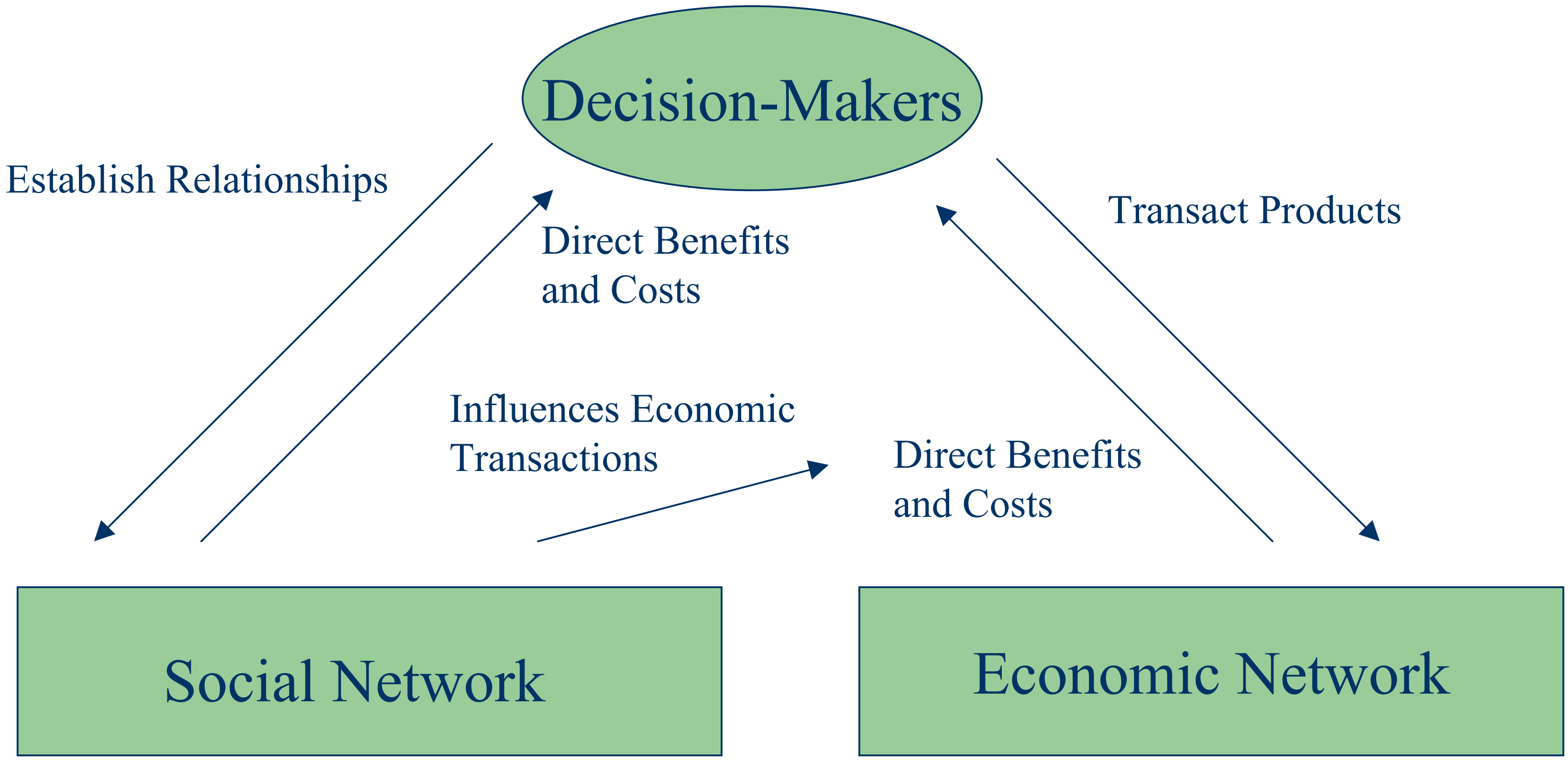
Roles of Social Networks in Economic Transactions

- Examples from Sociology
  - Embeddedness theory
    - Granovetter (1985)
    - Uzzi (1996)
- Examples from Economics
  - Williamson (1983)
  - Joskow (1988)
  - Crawford (1990)
  - Vickers and Waterson (1991)
  - Muthoo (1998)

Roles of Social Networks in Economic Transactions

- Examples from Marketing
  - Relationship marketing
    - Ganesan (1994)
    - Bagozzi (1995)

Research Framework



Supply Chain Network Literature

- Multicriteria decision making
  - Dong, Zhang, and Nagurney (2002)
- Supply chain and e-commerce
  - Nagurney, Loo, Dong, and Zhang (2002b)
- Supply chain, e-commerce, and risk
  - Nagurney, Cruz, Dong, and Zhang (2005)
- Global supply chains
  - Nagurney, Cruz, and Matsypura (2003)
  - Nagurney and Matsypura (2005)

Related Supernetwork Literature

"Dynamic Supernetworks for the Integration of Social Networks and Supply Chains with Electronic Commerce: Modeling and Analysis of Buyer-Seller Relationships with Computations," T. Wakolbinger and A. Nagurney, *Netnomics* **6**: (2004), 153-185.

"The Evolution and Emergence of Integrated Social and Financial Networks with Electronic Transactions: A Dynamic Supernetwork Theory for the Modeling, Analysis, and Computation of Financial Flows and Relationship Levels," A. Nagurney, T. Wakolbinger, and L. Zhao, *Computational Economics* **27**: (2006), 353-393.

Supernetwork Integrating a Global Supply Chain with a Social Network

- Models the interaction of a global supply chain network and a social network
- Captures interactions among individual sectors
- Includes electronic transactions
- Incorporates transaction costs and risk

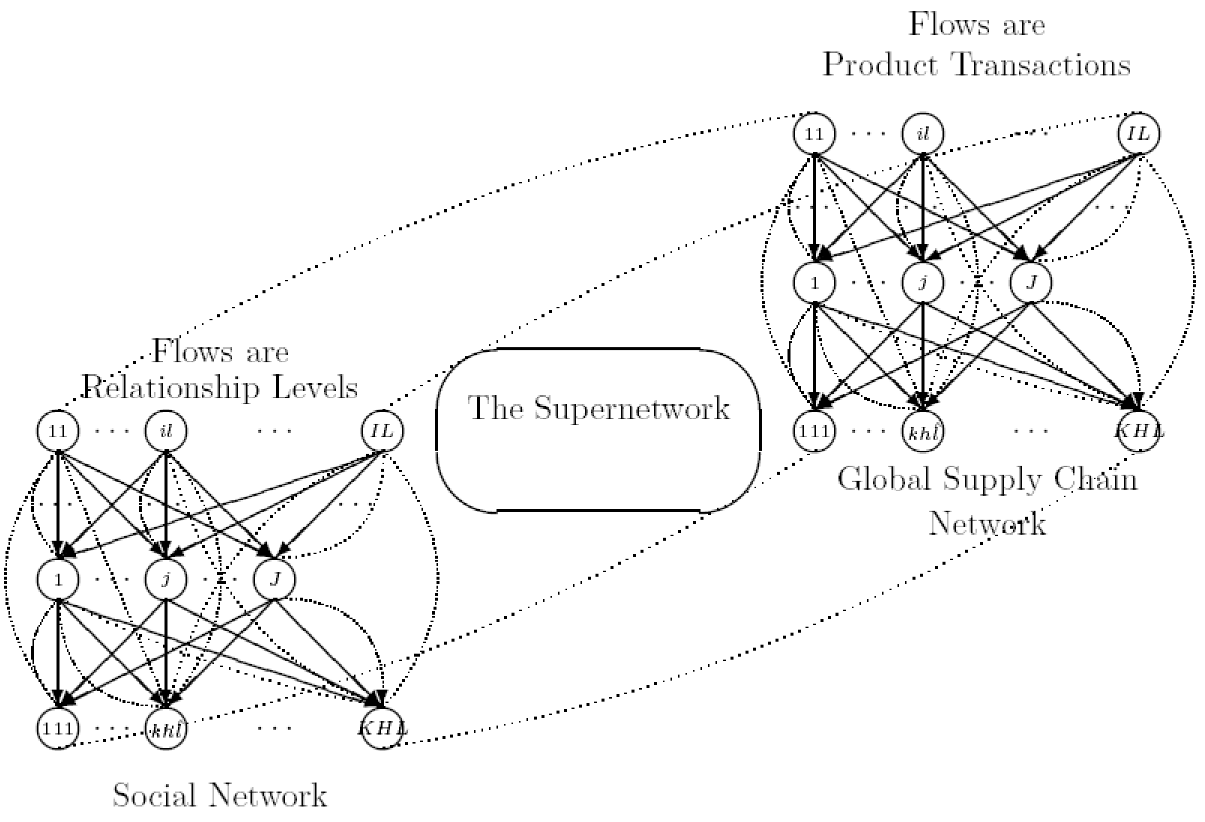
Supernetwork Integrating a Global Supply Chain with a Social Network

- Extends the model by Wakolbinger and Nagurney (2004) to the international domain
  - Introduction of multiple countries and currencies
- Includes more general risk and relationship value functions

Assumptions

- I manufacturers
- J retailers
- K demand markets
- L countries
- H currencies
- The demand for a product in a country can be associated with a particular currency
- Fixed exchange rates
- Transaction costs are measured in the base currency

Network Structure



Assumptions

- Manufacturers and retailers are multicriteria decision-makers
- Manufacturers and retailers try to
  - Maximize profit
  - Minimize risk
  - Maximize relationship value
  - Individual weights assigned to the different criteria
- Nash equilibrium

Supernetwork Integrating a Social with a Supply Chain Network

- Decision-makers in the network can decide about the amount of product they wish to transact and the relationship levels [0,1] they wish to establish
- Establishing relationship levels incurs some costs
- Relationship levels
  - Influence transaction costs
  - Influence risk
  - Have some additional value (“relationship value”)

A Manufacturer’s Multicriteria Decision-Making Problem

$$\text{Maximize} \quad U^{il} = \sum_{j=1}^{J}\sum_{h=1}^{H}\sum_{m=1}^{2}(\rho_{1jhm}^{il*} \times e_h)q_{jhm}^{il} + \sum_{k=1}^{K}\sum_{h=1}^{H}\sum_{\hat{l}=1}^{L}(\rho_{1kh\hat{l}}^{il*} \times e_h)q_{kh\hat{l}}^{il} - f^{il}(Q^1, Q^2)$$

$$-\sum_{j=1}^{J}\sum_{h=1}^{H}\sum_{m=1}^{2} c_{jhm}^{il}(q_{jhm}^{il}, \eta_{jhm}^{il}) - \sum_{k=1}^{K}\sum_{h=1}^{H}\sum_{\hat{l}=1}^{L} c_{kh\hat{l}}^{il}(q_{kh\hat{l}}^{il}, \eta_{kh\hat{l}}^{il}) - \sum_{j=1}^{J}\sum_{h=1}^{H}\sum_{m=1}^{2} b_{jhm}^{il}(\eta_{jhm}^{il})$$

$$-\sum_{k=1}^{K}\sum_{h=1}^{H}\sum_{\hat{l}=1}^{L} b_{kh\hat{l}}^{il}(\eta_{kh\hat{l}}^{il}) - \alpha^{il} r^{il}(Q^1, Q^2, \eta^1, \eta^2) + \beta^{il} v^{il}(\eta^1, \eta^2, Q^1, Q^2)$$

subject to:

$$q_{jhm}^{il} \geq 0, \quad q_{kh\hat{l}}^{il} \geq 0, \quad \forall j, h, m, k, \hat{l},$$

$$0 \leq \eta_{jhm}^{il} \leq 1, \quad 0 \leq \eta_{kh\hat{l}}^{il} \leq 1, \quad \forall j, h, m, k, \hat{l}.$$

A Retailer's Multicriteria Decision-Making Problem

$$\text{Maximize} \quad U^j = \sum_{k=1}^{K}\sum_{h=1}^{H}\sum_{\hat{l}=1}^{L}\sum_{m=1}^{2}(\rho^{j*}_{2kh\hat{l}m} \times e_h)q^j_{kh\hat{l}m} - c_j(Q^1) - \sum_{i=1}^{I}\sum_{l=1}^{L}\sum_{h=1}^{H}\sum_{m=1}^{2}\hat{c}^{il}_{jhm}(q^{il}_{jhm}, \eta^{il}_{jhm})$$

$$-\sum_{k=1}^{K}\sum_{h=1}^{H}\sum_{\hat{l}=1}^{L}\sum_{m=1}^{2}c^j_{kh\hat{l}m}(q^j_{kh\hat{l}m}, \eta^j_{kh\hat{l}m}) - \sum_{i=1}^{I}\sum_{l=1}^{L}\sum_{h=1}^{H}\sum_{m=1}^{2}\hat{b}^{il}_{jhm}(\eta^{il}_{jhm}) - \sum_{k=1}^{K}\sum_{h=1}^{H}\sum_{\hat{l}=1}^{L}\sum_{m=1}^{2}b^j_{kh\hat{l}m}(\eta^j_{kh\hat{l}m})$$

$$-\sum_{i=1}^{I}\sum_{l=1}^{L}\sum_{h=1}^{H}\sum_{m=1}^{2}(\rho^{il*}_{1jhm} \times e_h)q^{il}_{jhm} - \delta^j r^j(Q^1, Q^3, \eta^1, \eta^3) + \gamma^j v^j(Q^1, Q^3, \eta^1, \eta^3)$$

subject to:

$$\sum_{k=1}^{K}\sum_{h=1}^{H}\sum_{\hat{l}=1}^{L}\sum_{m=1}^{2}q^j_{kh\hat{l}m} \leq \sum_{i=1}^{I}\sum_{l=1}^{L}\sum_{h=1}^{H}\sum_{m=1}^{2}q^{il}_{jhm},$$

$$q^{il}_{jhm} \geq 0, \quad q^j_{kh\hat{l}m} \geq 0, \quad \forall i, l, k, h, \hat{l}, m,$$

$$0 \leq \eta^{il}_{jhm} \leq 1, \quad 0 \leq \eta^j_{kh\hat{l}m} \leq 1, \quad \forall i, l, h, m, k, \hat{l}.$$

Equilibrium Conditions for the Demand Markets

$$\rho^{j*}_{2kh\hat{l}m} \times e_h + \hat{c}^{j}_{kh\hat{l}m}(Q^{2*}, Q^{3*}, \eta^{2*}, \eta^{3*}) \begin{cases} = \rho^*_{3kh\hat{l}}, & \text{if} \quad q^{j*}_{kh\hat{l}m} > 0, \\ \geq \rho^*_{3kh\hat{l}}, & \text{if} \quad q^{j*}_{kh\hat{l}m} = 0, \end{cases}$$

$$\rho^{il*}_{1kh\hat{l}} \times e_h + \hat{c}^{il}_{kh\hat{l}}(Q^{2*}, Q^{3*}, \eta^{2*}, \eta^{3*}) \begin{cases} = \rho^*_{3kh\hat{l}}, & \text{if} \quad q^{il*}_{kh\hat{l}} > 0, \\ \geq \rho^*_{3kh\hat{l}}, & \text{if} \quad q^{il*}_{kh\hat{l}} = 0. \end{cases}$$

$$d_{kh\hat{l}}(\rho^*_3) \begin{cases} = \sum_{j=1}^{J} \sum_{m=1}^{2} q^{j*}_{kh\hat{l}m} + \sum_{i=1}^{I} \sum_{l=1}^{L} q^{il*}_{kh\hat{l}}, & \text{if} \quad \rho^*_{3kh\hat{l}} > 0, \\ \leq \sum_{j=1}^{J} \sum_{m=1}^{2} q^{j*}_{kh\hat{l}m} + \sum_{i=1}^{I} \sum_{l=1}^{L} q^{il*}_{kh\hat{l}}, & \text{if} \quad \rho^*_{3kh\hat{l}} = 0. \end{cases}$$

The Equilibrium State

Definition 3.1: The equilibrium state of the supernetwork is one where the flows between the tiers of the supernetwork coincide and the product transactions, relationship levels, and prices satisfy the sum of the optimality conditions and the equilibrium conditions.

The equilibrium state is equivalent to a VI of the form:

$$\text{determine } X^* \in \mathcal{K} \text{ satisfying}$$

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

The Projected Dynamical System

The dynamic model can be formulated as a projected dynamical system (Dupuis and Nagurney (1993) and Nagurney and Zhang (1996a)) defined by the initial value problem:

$$\dot{X} = \Pi_{\mathcal{K}}(X, -F(X)), \quad X(0) = X_0,$$

where $\Pi_{\mathcal{K}}$ denotes the projection of $-F(X)$ onto $\mathcal{K}$ at X and X_0 is equal to the point corresponding to the initial product transactions, relationship levels, shadow prices, and demand market prices.

The set of stationary points of the projected dynamical system coincides with the set of solutions of the variational inequality problem.

The Disequilibrium Dynamics

The trajectory of the PDS describes the dynamic evolution of:

- the product transactions on the global supply chain network
- the relationship levels on the social network,
- the demand market prices, and
- the Lagrange multipliers or shadow prices associated with the retailers.

Euler Method

Step 0: Initialization

Set $X^0 \in \mathcal{K}$.

Let $\mathcal{T} = 1$ and set the sequence $\{\alpha_\mathcal{T}\}$ so that $\sum_{\mathcal{T}=1}^{\infty} \alpha_\mathcal{T} = \infty$, $\alpha_\mathcal{T} > 0$ for all $\mathcal{T}$, and $\alpha_\mathcal{T} \to 0$ as $\mathcal{T} \to \infty$.

Step 1: Computation

Compute $X^\mathcal{T} \in \mathcal{K}$ by solving the variational inequality subproblem:

$$\langle X^\mathcal{T} + \alpha_\mathcal{T} F(X^{\mathcal{T}-1}) - X^{\mathcal{T}-1}, X - X^\mathcal{T} \rangle \geq 0, \qquad \forall X \in \mathcal{K} \tag{2.27}$$

Step 2: Convergence Verification

If $|X^\mathcal{T} - X^{\mathcal{T}-1}| \leq \epsilon$, with $\epsilon > 0$, a pre-specified tolerance, then stop; otherwise, set $\mathcal{T} := \mathcal{T} + 1$, and go to Step 1.

Qualitative Properties

We have established

- Existence of a solution to the VI
- Uniqueness of a solution to the VI
- Conditions for the existence of a unique trajectory to the projected dynamical system
- Convergence of the Euler method

Numerical Examples

- Two countries with two manufacturers in each country
- Two currencies
- Two retailers and two demand markets
- Only physical transactions between manufacturers and retailers and retailers and demand markets.
- Electronic transactions are allowed between manufacturers and demand markets.
- Variance-covariance matrices associated with risk functions are identity matrices.
- Relationship levels only between manufacturers and retailers and between retailers and demand markets

Table 1: Functions for Numerical Examples 1 - 2

Notation	**Definition**
$f^{il}(Q^1, Q^3) = .5(\sum_{j=1}^{2}\sum_{h=1}^{2} q^{il}_{jh1})^2$	Production costs faced by manufacturers
$c_j(Q^1) = .5(\sum_{i=1}^{2}\sum_{h=1}^{2} q^{i1}_{jh1})^2$	Handling costs faced by retailers
$d_{111}(\rho_3) = -2\rho_{3111} - 1.5\rho_{3121} + 1000$	Demand functions
$d_{121}(\rho_3) = -2\rho_{3121} - 1.5\rho_{3111} + 1000$	Demand functions
$d_{211}(\rho_3) = -2\rho_{3211} - 1.5\rho_{3221} + 1000$	Demand functions
$d_{221}(\rho_3) = -2\rho_{3221} - 1.5\rho_{3211} + 1000$	Demand functions
$d_{112}(\rho_3) = -2\rho_{3112} - 1.5\rho_{3122} + 1000$	Demand functions
$d_{122}(\rho_3) = -2\rho_{3122} - 1.5\rho_{3112} + 1000$	Demand functions
$d_{212}(\rho_3) = -2\rho_{3212} - 1.5\rho_{3222} + 1000$	Demand functions
$d_{222}(\rho_3) = -2\rho_{3222} - 1.5\rho_{3212} + 1000$	Demand functions
$c^{il}_{jhm}(q^{il}_{jhm}, \eta^{il}_{jhm}) = .5(q^{il}_{jhm})^2 + 3.5q^{il}_{jhm} - \eta^{il}_{jhm}$	Transaction costs faced by manufacturers transacting with retailers
$c^{il}_{kh\hat{l}}(q^{il}_{kh\hat{l}}, \eta^{il}_{kh\hat{l}}) = .5(q^{il}_{kh\hat{l}})^2 + q^{il}_{kh\hat{l}}$	Transaction costs faced by manufacturers transacting with consumers
$\hat{c}^{il}_{jhm}(q^{il}_{jhm}, \eta^{il}_{jhm}) = 1.5{q^{il}_{jhm}}^2 + 3q^{il}_{jhm}$	Transaction costs faced by retailers transacting with manufacturers
$\hat{c}^{j}_{kh\hat{l}m}(Q^2, Q^3, \eta^2, \eta^3) = q^{j}_{khlm} - \eta^{j}_{kh\hat{l}m} + 5$	Transaction costs faced by consumers transacting with retailers
$\hat{c}^{il}_{kh\hat{l}}(Q^2, Q^3, \eta^2, \eta^3) = .1q^{il}_{kh\hat{l}} + 1$	Transaction costs faced by consumers transacting with manufacturers
$v^{il}_{jhm}(\eta^1, \eta^2, Q^1, Q^2) = \eta^{il}_{jhm}$	Relationship value functions for manufacturers
$v^{j}_{kh\hat{l}m}(\eta^1, \eta^3, Q^1, Q^3) = \eta^{j}_{kh\hat{l}m}$	Relationship value functions for retailers
$b^{il}_{jhm}(\eta^{il}_{jhm}) = 2\eta^{il}_{jhm}$	Relationship cost functions for manufacturers
$b^{j}_{kh\hat{l}m}(\eta^{j}_{kh\hat{l}m}) = \eta^{j}_{kh\hat{l}m}$	Relationship cost functions for retailers

Numerical Examples

- Example 1
  - Weights for all criteria are 1.
- Example 2
  - Weights for relationship value for both manufacturers and retailers increased from 1 to 20.
- Example 3
  - Intercept for demand function of demand market 1, currency 1, and country 1 increased by 100.

Table 2: Results of Numerical Examples 1 - 3

Variable	**Example 1**	**Example 2**	**Example 3**
q^{il*}_{jh1}	2.160	2.160	2.192
$q^{j*}_{kh\hat{l}} : q^{1*}_{111}, q^{2*}_{111}$	2.160	2.160	4.631
$q^{j*}_{kh\hat{l}} : q^{1*}_{121}, q^{2*}_{121}$	2.160	2.160	0.861
all remaining $q^{j*}_{kh\hat{l}}$	2.160	2.160	2.007
$q^{il*}_{kh\hat{l}}$	22.376	22.376	22.376
λ^*	224.322	224.322	227.126
$\rho^*_{3khl} : \rho^*_{3111}$	258.917	258.917	295.570
$\rho^*_{3khl} : \rho^*_{3121}$	258.917	258.917	243.925
all remaining ρ^*_{3khl}	258.917	258.917	259.619
η^{il}_{jhm}	0	1	1
$\eta^{j}_{kh\hat{l}m}$	0	0	0

Novelty of Our Research

- Supernetworks show the dynamic co-evolution of product and price flows and the social network structure
- Product flows and social network structure are interrelated
- Network of relationships has a measurable economic value

Summary

- We model the behavior of the decision-makers, their interactions, and the dynamic evolution of the associated variables.
- We study the problems qualitatively as well as computationally.
- We develop algorithms, implement them, and establish conditions for convergence.

Future Research

- We will simulate changes in
  - Transaction and handling costs
  - Risk and demand functions
  - Weights for relationship value and risk
  - Costs for establishing relationships
  - Exchange rates
- We will analyze effects of these changes on manufacturers’ and retailers’ profits and the evolution of the social network structure.

The full text of the related papers can be found under Downloadable Articles at:

http://supernet.som.umass.edu

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