Financial Networks

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We Are in a New Era of Decision-Making Characterized by:

- *complex interactions* among decision-makers in organizations;
- *alternative and, at times, conflicting criteria* used in decision-making;
- *constraints on resources*: human, financial, natural, time, etc.;
- *global reach* of many decisions;
- *high impact* of many decisions;
- *increasing risk and uncertainty*;
- the *importance of dynamics* and realizing a timely response to evolving events.

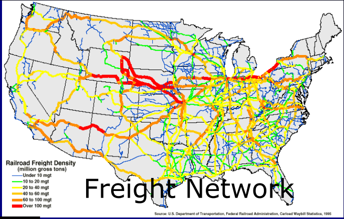
Characteristics of Networks Today

- *large-scale nature* and complexity of network topology;
- *congestion*, which leads to nonlinearities;
- *alternative behavior of users of the networks*, which may lead to paradoxical phenomena;
- *interactions among networks themselves*, such as the Internet with electric power networks, financial networks, and transportation and logistical networks, as well as *social networks with financial networks and supply chains*;
- recognition of *the fragility and vulnerability of network systems*;
- policies surrounding networks today may have major impacts not only economically, but also *socially, politically, and security-wise*.

Networks consist of nodes, links, and flows and one must capture the underlying behavior and interactions of decision-makers and the induced costs, the relevant risks, and prices.

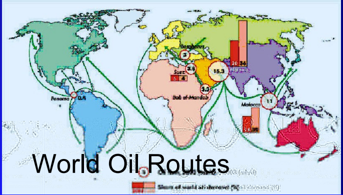
Network methodologies provide a spectrum of tools for financial problem formulation, analysis, and solution.

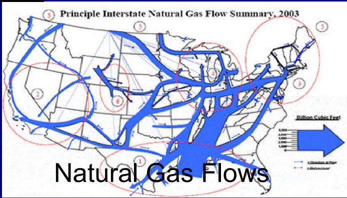
Network System	Nodes	Links	Flows
Transportation	Intersections, Homes, Workplaces, Airports, Railyards	Roads, Airline Routes, Railroad Track	Automobiles, Trains, and Planes,
Manufacturing and logistics	Workstations, Distribution Points	Processing, Shipment	Components, Finished Goods
Communication	Computers, Satellites, Telephone Exchanges	Fiber Optic Cables Radio Links	Voice, Data, Video
Energy	Pumping Stations, Plants	Pipelines, Transmission Lines	Water, Gas, Oil, Electricity



Network

Systems





Interdisciplinary Impact of Networks

Models and Algorithms

Networks

Economics and Finance

Interregional Trade

General Equilibrium

Industrial Organization

Portfolio Optimization

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OR/MS and Engineering

Energy

Manufacturing

Telecommunications

Transportation

Supply Chains

Sociology

Social %et ! or&s

Organizational Theory

Computer Science

#outing "lgorithms

Price of "narchy

Biology

$%" Sequencing

Targeted Cancer Therapy

Brief Early History of the Science of Networks

- 1736 - Euler - the earliest paper on graph theory - Konigsberg bridges problem.
- 1758 - Quesnay in his *Tableau Economique* introduced a network/graph to depict the circular flow of financial funds in an economy.
- 1781 - Monge, who had worked under Napoleon Bonaparte, publishes what is probably the first paper on transportation in minimizing cost.
- 1838 - Cournot states that a competitive price is determined by the intersection of supply and demand curves in the context of spatially separate markets in which transportation costs are included.
- 1841 - Kohl considered a two node, two route transportation network problem.
- 1845 - Kirchhoff wrote Laws of Closed Electric Circuits.

- 1920 - Pigou studied a transportation network system of two routes and noted that the decision-making behavior of the users on the network would result in different flow patterns.

- 1936 - Konig published the first book on graph theory.

- 1939, 1941, 1947 - Kantorovich, Hitchcock, and Koopmans considered the network flow problem associated with the classical minimum cost transportation problem and provided insights into the special network structure of these problems, which yielded special-purpose algorithms.

- 1948, 1951 - Dantzig published the simplex method for linear programming and adapted it for the classical transportation problem.

- 1951 - Enke showed that spatial price equilibrium problems can be solved using electronic circuits

- 1952 - Copeland in his book, *Studies of Moneyflows in the United States*, asked, Does money flow like water or electricity?

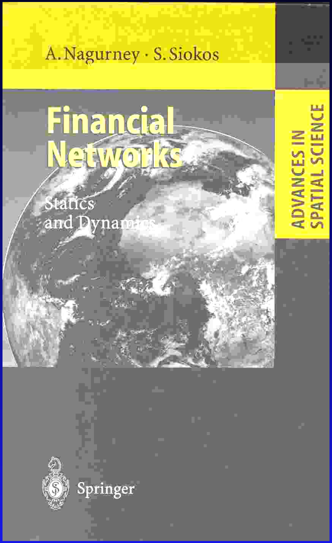
- 1952 - Samuelson gave a rigorous mathematical formulation of spatial price equilibrium and emphasized the network structure.

- 1956 - Beckmann, McGuire, and Winsten in their book, *Studies in the Economics of Transportation*, provided a rigorous treatment of congested urban transportation systems under different behavioral mechanisms due to Wardrop (1952).

- 1962 - Ford and Fulkerson publish *Flows in Networks*.

- 1969 - Dafermos and Sparrow coined the terms user-optimization and system-optimization and develop algorithms for the computation of solutions that exploit the network structure of transportation problems.

Financial Networks



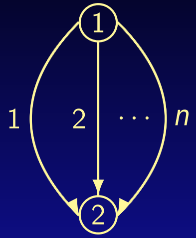


Figure 1: Network Structure of the Classical Markowitz Model

The structure of the classical portfolio optimization problem is that of a network.

Financial Network Models with Multiple Sectors

The need to expand upon the Markowitz and Sharpe frameworks in order to capture interactions among investors / sectors / decision-makers let to financial system network models.

Such models began with the work of Nagurney and Hughes (1992) in the estimation of financial flow of funds accounts.

The book by Nagurney and Siokos (1997) documents the evolution of financial networks models to that date.

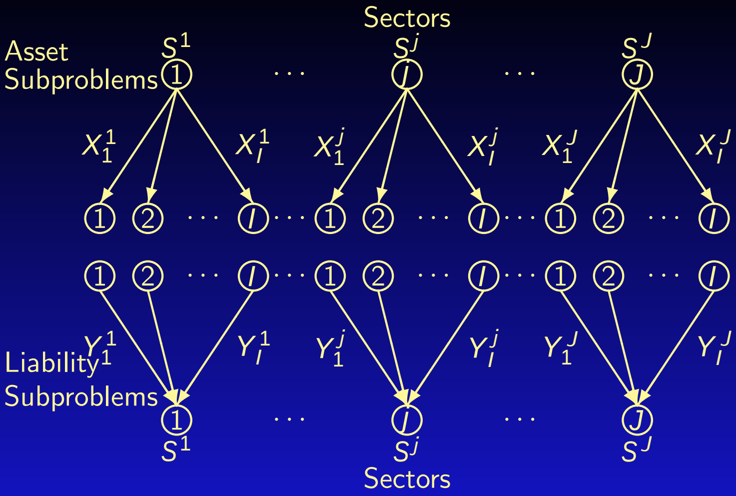


Figure 2: Network Structure of Multiple Financial Sectors' Portfolio Optimization Problems

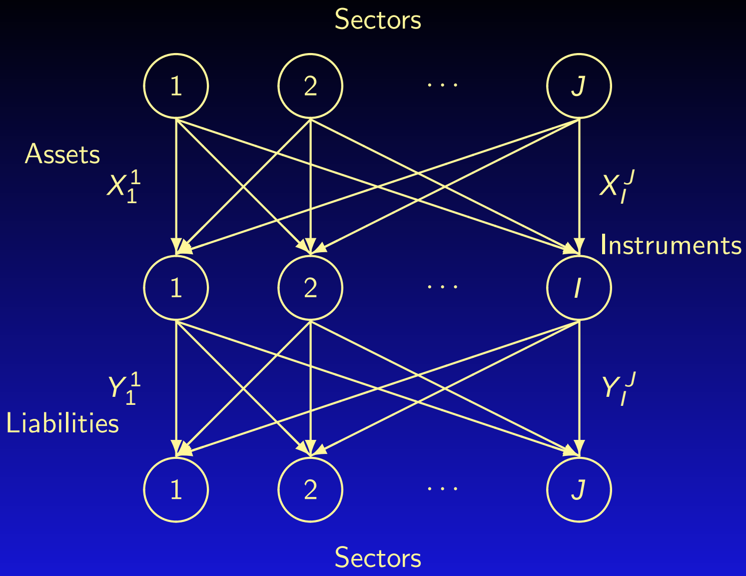


Figure 3: The Network Structure at Equilibrium

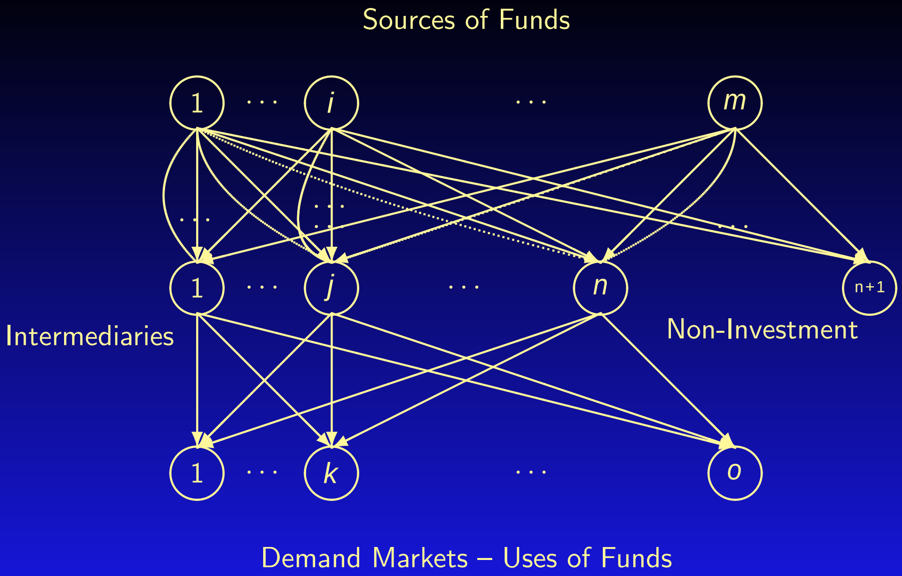


Figure 4: The Network Structure of the Financial Economy with Intermediation and with Non-Investment Allowed

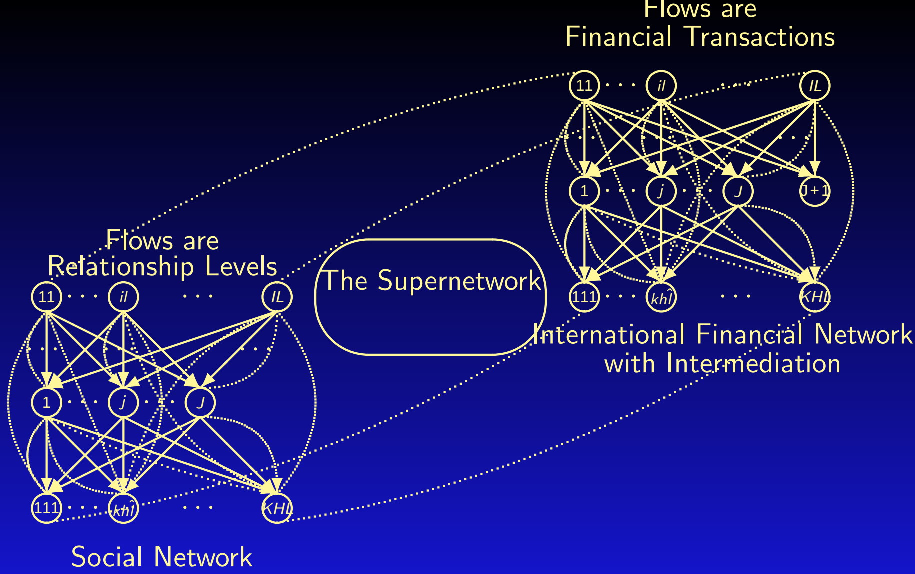
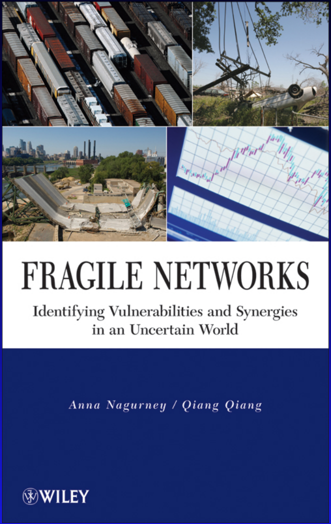


Figure 5: The Multilevel Supernetwork Structure of the Integrated International Financial Network / Social Network System (Nagurney, Cruz, and Wakolbinger (2007))

Fragile Networks



We are living in a world of Fragile Networks.

Because today's financial networks may be *highly interconnected and interdependent*, any disruptions that occur in one part of the network may produce consequences in other parts of the network, which may not only be in the same region but miles away in other countries.

In 2008 and 2009, the world reeled from the effects of the financial credit crisis; leading financial services and banks closed (including the investment bank Lehman Brothers), others merged, and the financial landscape was changed for forever.

The domino e ect of the U.S. economic troubles rippled through overseas markets and pushed countries such as Iceland to the verge of bankruptcy.

It is crucial for the decision-makers in financial systems (managers, executives, and regulators) to be able *to identify a financial network's vulnerable components* to protect the functionality of the network.

Our financial network performance measure (Nagurney and Qiang (2008)) and component importance indicator was published in the edited volume *Computational Methods in Financial Engineering*.

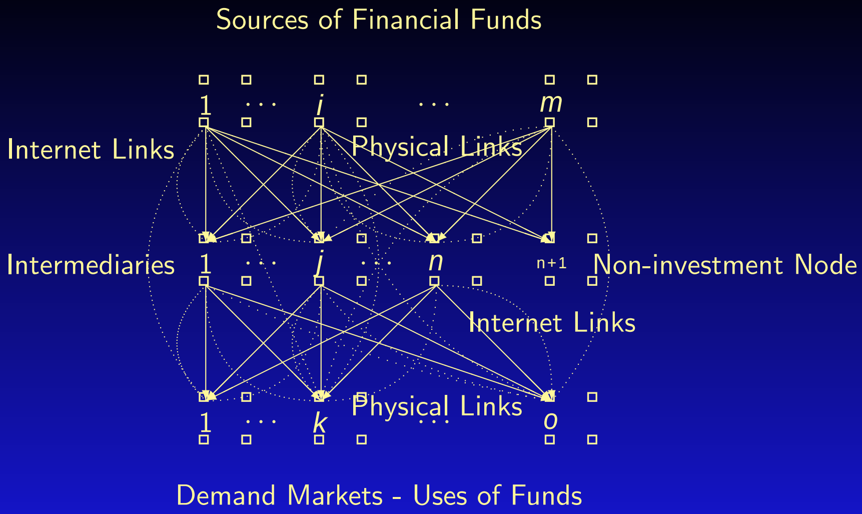


Figure 6: The Structure of the Financial Network with Intermediation and with Electronic Transactions

Definition: The Financial Network Performance Measure

The financial network performance measure, $\mathcal{E}$, for a given network topology G, and demand price functions $\rho_{3k}(d)$ ($k = 1, 2, \ldots, o$), and available funds held by source agents S, is defined as follows:

$$\mathcal{E} = \frac{\sum_{k=1}^{o} \frac{d_k^*}{\rho_{3k}(d^*)}}{o},$$

where o is the number of demand markets in the financial network, and d_k^* and $\rho_{3k}(d^*)$ denote the equilibrium demand and the equilibrium price for demand market k, respectively.

The financial network performance measure $\mathcal{E}$ defined above is actually the average demand to price ratio. It measures the overall (economic) functionality of the financial network.

When the network topology G, the demand price functions, and the available funds held by source agents are given, a financial network is considered performing better if it can satisfy higher demands at lower prices.

Definition: Importance of a Financial Network Component

The importance of a financial network component $g \in G$, $I(g)$, is measured by the relative financial network performance drop after g is removed from the network:

$$I(g) = \frac{\triangle \mathcal{E}}{\mathcal{E}} = \frac{\mathcal{E}(G) - \mathcal{E}(G-g)}{\mathcal{E}(G)}$$

where $G - g$ is the resulting financial network after component g is removed from network G.

It is worth pointing out that the importance of the network components is well-defined even in a financial network with disconnected source agent/demand market pairs.

In our financial network performance measure, the elimination of a transaction link is treated by removing that link from the network while the removal of a node is managed by removing the transaction links entering or exiting that node.

In the case that the removal results in no transaction path connecting a source agent/demand market pair, we simply assign the demand for that source agent/demand market pair to an abstract transaction path with an associated cost of infinity.

We have also been using network methodologies to assess *not only financial performance and vulnerability* but also *synergies* associated with network integration as in mergers and acquisitions

Current Merger & Acquisition Activity

M&As totaled over $2 trillion in 2009, down 32% from full-year 2008 and down 53% from the record high in 2007, according to data from Thomson Reuters.

Mergers announced in October 2010 include Bain Capital / Gymboree, at $1.789 billion and Dynamex / Greenbriar Equity Group ($207 million).

Some of the most visible recent mergers have occurred in the airline industry with Delta and Northwest completing their merger in October 2008 and United and Continental closing on the formation of United Continental Holdings Oct. 1, 2010.

Global 2010 M&A activity is estimated to rise as much as 35% from 2009 figures (Sanford C. Bernstein research firm).

Successful mergers can add tremendous value; however, the failure rate is estimated to be between 74% and 83% (Devero (2004)).

It is worthwhile to develop tools to better predict the associated strategic gains, which include, among others, cost savings.

Mergers and Acquisitions and Network Synergies

A successful merger depends on the ability to measure the anticipated synergy of the proposed merger (cf. Chang (1988)) .

- ◇ Z. Liu and A. Nagurney (2010), "Risk Reduction and Cost Synergy in Mergers and Acquisitions via Supply Chain Network Integration."

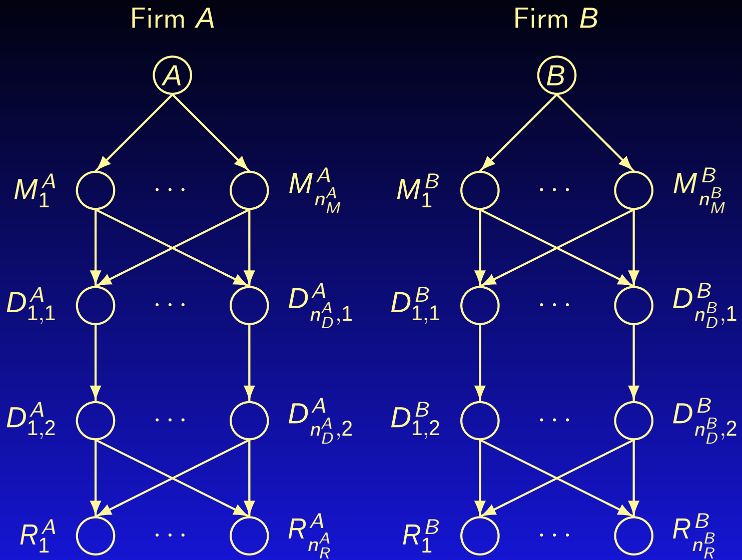


Figure 7: Case 0: Firms A and B Prior to Horizontal Merger

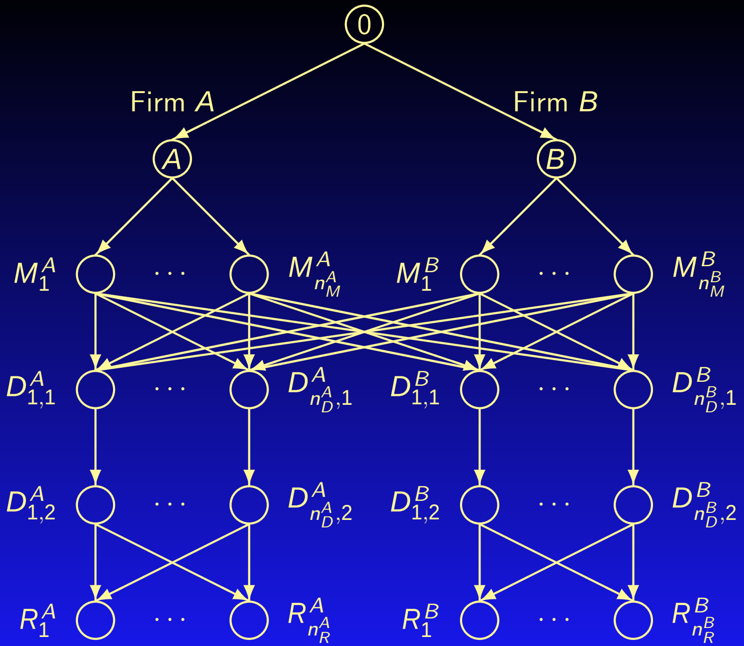


Figure 8: Case 1: Firms A and B Merge

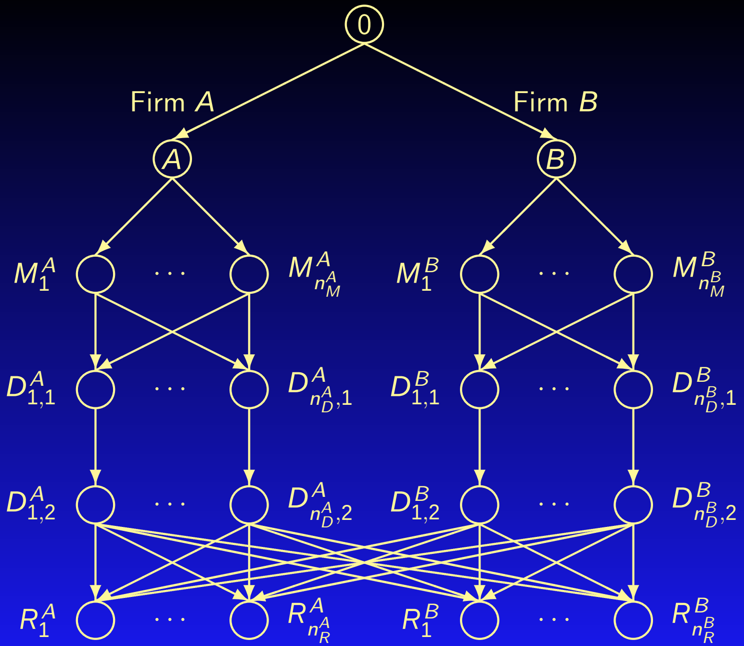


Figure 9: Case 2: Firms A and B Merge

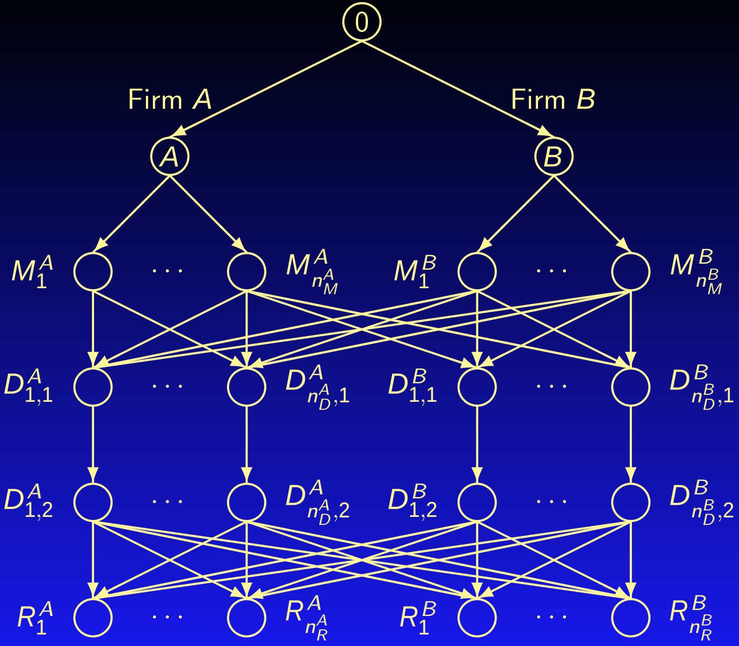


Figure 10: Case 3: Firms A and B Merge

The Expected Total Cost Synergy

$$\mathcal{S}_{TC} \equiv \left[\frac{TC^0 - TC^1}{TC^0}\right] \times 100\%,$$

The Absolute Risk Synergy

$$\mathcal{S}_{TR} \equiv \left[\frac{TR^0 - TR^1}{TR^0}\right] \times 100\%,$$

The Relative Risk Synergy

$$\mathcal{S}_{CV} \equiv \left[\frac{CV^0 - CV^1}{CV^0}\right] \times 100\%,$$

where CV^0 and CV^1 denote the coefficient of variation of the total cost for, respectively, the pre-merger and the post-merger networks:

$$CV^0 \equiv \frac{\sqrt{TR^0}}{TC^0}, \quad CV^1 \equiv \frac{\sqrt{TR^1}}{TC^1}.$$

CV^0 and CV^1 represent the volatilities of the expected total costs of the pre- and post-merger networks, respectively.

The first measure, $\mathcal{S}_{TC}$, quantifies the expected total cost savings obtained by the merger.

The second measure, $\mathcal{S}_{TC}$, represents the reduction of the absolute risk achieved through the merger.

The third measure, $\mathcal{S}_{CV}$, reflects the reduction of the relative risk through the merger.

Some Examples of Oligopolies

- airlines
- freight carriers
- automobile manufacturers
- oil companies
- beer / beverage companies
- wireless communications
- certain financial institutions.

The Network Oligopoly Model

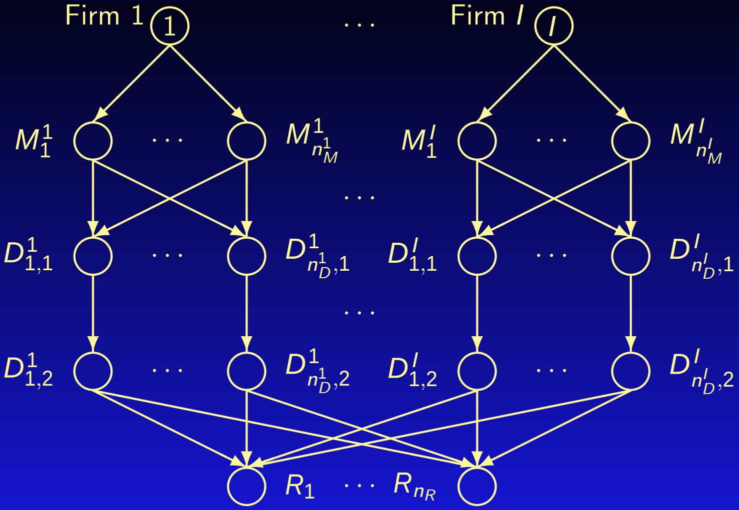


Figure 11: Network Structure of the Oligopoly

Nagurney *Computational Management Science* (2010) **7**, 377-401.

Mergers Through Coalition Formation

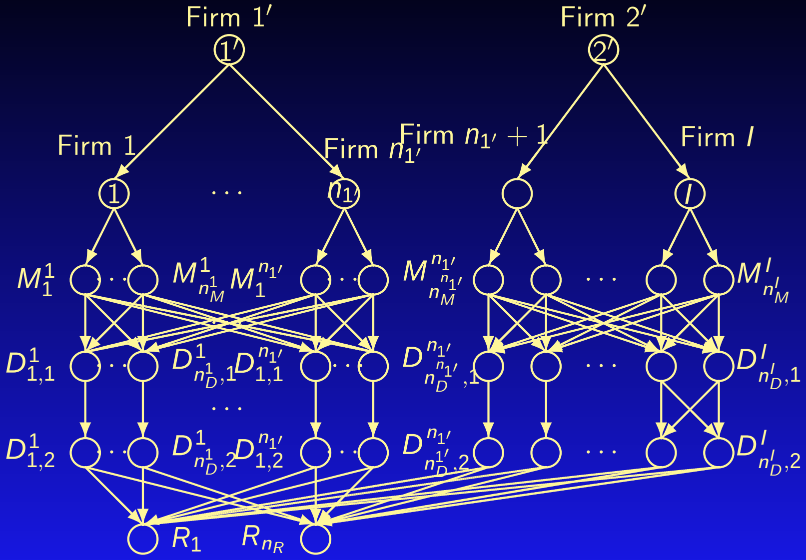


Figure 12: Mergers of the First $n_{1'}$ Firms and the Next $n_{2'}$ Firms

References - for Further Reading

Overview article on Financial Networks:
http://supernet.som.umass.edu/articles/finhandbook.pdf

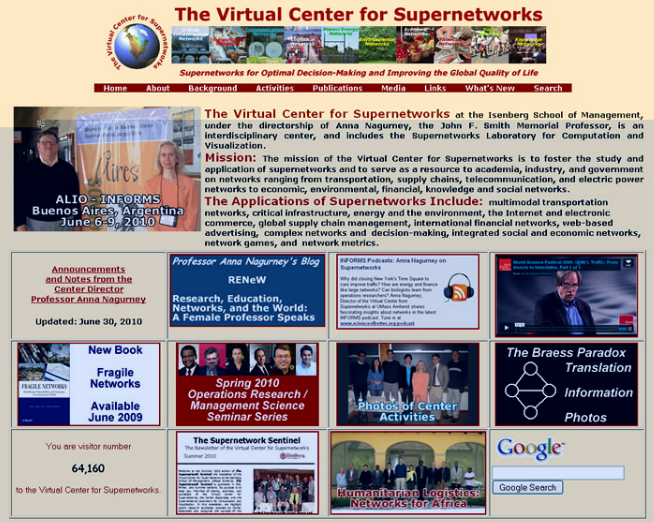
Link to Portfolio Optimization course in Executive Education at Harvard University:
http://supernet.som.umass.edu/courses/Harvard-PortfolioOptimization.pdf

Link to Network Economics course at the World Bank:
http://supernet.som.umass.edu/visuals/nagurney-worldbank-networkeconomics.pdf

Link to numerous articles on network modeling and applications, vulnerability and robustness analysis, as well as network synergy:
http://supernet.som.umass.edu/dart.html

Link to books of interest:
http://supernet.som.umass.edu/bookser.html

THANK YOU!



For more information, see: http://supernet.som.umass.edu