Supply Chain Network Structure and Risk Propagation

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Supply chain relationships create direct and indirect effects on firms.

Correlation and reliability issues in particular create nonlinear effects on the value of supplier connections.

Including nonlinear effects leads to a wide variety of equilibrium network configurations.

New databases (e.g., Bloomberg SPLC) provide opportunities to investigate financial and operational supply chain network interactions.

Empirical results on firm returns show significant supplier and customer effects, lagged effects from supplier shocks, and differences in the second-order risk impact of centrality depending on the firm’s chain level.
Outline

- Basic network configurations
- Impact of nonlinearity on supply chain structure and risk propagation
- Empirical data set
- Analysis
Correlation among business interests and suppliers may create opportunities for increasing or decreasing risk.
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Network Implications

1. Correlation among business interests and suppliers may create opportunities for increasing or decreasing risk

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2. A distributor may have incentives to add similar suppliers to build on existing capabilities

Result: Increasing connections may have different effects at different levels of the chain

Effects from connections are then nonlinear (e.g., from interactions)

Nonlinear (joint firm) effects may be critical in the formation of supply chain links
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3. Nonlinear (joint firm) effects may be critical in the formation of supply chain links.
Previous work: Jackson and Wolinsky (1996): Firm $i$ maximizes utility $u_i$ by creating connections $ij$ in graph $G$ (distance $d_{ij}$) where

$$u_i = w_{ii} + \sum_{j \neq i} \delta^{d_{ij}} w_{ij} - \sum_{(ij) \in G} c_{ij}.$$
Network Model

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2. Results: For symmetric networks, either $G$ is complete, a star graph, or linkless.

3. Innovation: allow nonlinear effects $w_i, jk x_{ij} x_{ik}$ where $x_{ij} = 1$ for $(ij) \in G$.

$w_i, jk$ may be positive or negative depending on correlation of $j$ and $k$ interests and their reliability.

Hypothesis: negative correlation yields negative $w_i, jk$.
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Birge (Chicago Booth)
Implications for Supply Chain Structure

- Even symmetric networks with this cost structure may have widely varying equilibrium structure
- With a single parameter $\alpha$ for the correlation, a full range of degree distributions exist
- Examples:
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Supply Chain Risk Propagation

Example framework: Suppliers $A$, $B$; manufacturer $M$; distributor/wholesaler $W$

- Shocks: probability $p$ of individual survival of each without considering the effects of these nodes
Systematic risk: volatility of survival probability conditional on not having an idiosyncratic bad shock.

- For each node in simple network: conditional survival probability $p^3$.
- Volatility $= p^3(1 - p^3)$: decreases as $p$ increases for $p > 0.5$. 
Expanded Network

Example framework: Suppliers $A_i$, $B_i$; manufacturer $M_i$; distributor/wholesaler $W_i$
Propogation in Expanded Network

- Manufacturer $M_1$ can survive if one of the wholesaler nodes is wiped out; Wholesaler $W_1$ cannot survive either manufacturer’s loss (due to lower margin/market power).
- **Implications:**
  - More-connected $M_1$’s conditional survival probability:
    
    $$ (1 - (1 - p)^2)^3 = p^3(2 - p)^3 > p^3, \quad (1) $$
    
    where $p^3$ is the conditional survival of the singly-connected $M_2$.
  - Wholesaler $W_1$’s conditional survival probability:
    
    $$ (1 - (1 - p)^2)^2 p = p^3(2 - p)^2. \quad (2) $$
  - $W_2$’s conditional survival probability:
    
    $$ p^4(2 - p)^2 < p^3(2 - p)^2. \quad (3) $$
    
    Also, because $p(2 - p)^2 < 1$,

    $$ p^4(2 - p)^2 < p^3, \text{ conditional survival in simple tree.} \quad (4) $$

- **Result:** Wholesaler/distributor with more connections faces higher risk while the opposite is true for manufacturers.
Verifying Hypotheses Empirically

- New database: Bloomberg SPLC, 25000×25000 supply chain connections
- With effort can be fully collected (so far, 8000×8000)
- Size distribution:
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![Histogram of log sales distribution](image)
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Verifying Hypotheses Empirically

- New database: Bloomberg SPLC, $25000 \times 25000$ supply chain connections
- With effort can be fully collected (so far, $8000 \times 8000$)
- Size distribution:

![logsales distribution chart](image-url)
Degree distributions

- Date for $8000 \times 8000$ firms
- In- and out-degree follows exponential distributions
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Supply Chain Relationship Hypotheses

- Performance metric: stock return (proxy for direct shock effects and systematic risk)
- First-order effects
  - Suppliers’ and customers’ concurrent performance relates to the firm
  - Supplier momentum (one-month lag) may be related to firm performance
  - Customer momentum (following Cohen and Frazzini (2008) not related to firm performance
- Second-order (systematic risk) effects
  - Centrality influences firm risk and return performance
  - More central manufacturing firms have lower returns (lower risk)
  - More central logistics (transportation, wholesale, retail) firms have higher returns (higher risk)
First-Order Effects

- Model:
  \[ r_{i,t} = \alpha + \beta_1 r_{i,t-1} + \beta_2 \sum_j w_{ij}^{in} r_{j,t-1} + \beta_3 \sum_j w_{ij}^{out} r_{j,t-1} + \beta_4 \sum_j w_{ij}^{in} r_{j,t} + \beta_5 \sum_j w_{ij}^{out} r_{j,t} + \epsilon_{i,t}. \]

- Coefficients \( \alpha \) and \( \beta_k, \ k = 1, \ldots, 5 \) (estimated); \( \sum_j w_{ij}^{in} r_{j,t-1} \) - one-month supplier momentum, \( \sum_j w_{ij}^{out} r_{j,t-1} \) - one-month customer momentum, \( \sum_j w_{ij}^{in} r_{j,t} \) - concurrent supplier return, and \( \sum_j w_{ij}^{out} r_{j,t} \) - the concurrent customer return.

- Use US firms in SPLC.
- Monthly returns over 2010-2012.
- Include common risk factors (MKT, SMB, HML, MOM).
Table: Fama-Macbeth Regression of Concurrent Returns and Momentum.

<table>
<thead>
<tr>
<th></th>
<th>$\alpha$</th>
<th>$r_{i,t-1}$</th>
<th>$\sum_j w_{ij}^{in} r_{j,t-1}$</th>
<th>$\sum_j w_{ij}^{out} r_{j,t-1}$</th>
<th>$\sum_j w_{ij}^{in} r_{j,t}$</th>
<th>$\sum_j w_{ij}^{out} r_{j,t}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ave. Coef</td>
<td>-0.001</td>
<td>-0.088***</td>
<td>0.036**</td>
<td>0.024</td>
<td>0.399***</td>
<td>0.755***</td>
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<td>(T-Stat)</td>
<td>(-0.96)</td>
<td>(-11.06)</td>
<td>(2.17)</td>
<td>(0.95)</td>
<td>(20.90)</td>
<td>(3.12)</td>
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<td>Ave. Coef</td>
<td>0.009***</td>
<td>-0.090***</td>
<td>0.057***</td>
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<td>(T-Stat)</td>
<td>(10.38)</td>
<td>(-9.08)</td>
<td>(2.96)</td>
<td>(0.09)</td>
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<tr>
<td>Ave. Coef</td>
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<td>-0.047***</td>
<td></td>
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<td></td>
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<tr>
<td>(T-Stat)</td>
<td>(10.53)</td>
<td>(-6.96)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ave. Coef</td>
<td>0.008***</td>
<td></td>
<td>0.022**</td>
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<tr>
<td>(T-Stat)</td>
<td>(11.09)</td>
<td></td>
<td>(1.83)</td>
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<tr>
<td>Ave. Coef</td>
<td>0.008***</td>
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<td></td>
<td>-0.040</td>
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<td>(T-Stat)</td>
<td>(10.92)</td>
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<td>Ave. Coef</td>
<td>0.003***</td>
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<td>0.619***</td>
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<td>(T-Stat)</td>
<td>(3.61)</td>
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<td>(37.25)</td>
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<tr>
<td>Ave. Coef</td>
<td>-0.002**</td>
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<td></td>
<td></td>
<td>0.992***</td>
<td>(4.54)</td>
</tr>
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<td>(T-Stat)</td>
<td>(-2.26)</td>
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<tr>
<td>Ave. Coef</td>
<td>0.004***</td>
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<td>0.018*</td>
<td>0.625***</td>
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<td>(T-Stat)</td>
<td>(4.51)</td>
<td></td>
<td>(1.57)</td>
<td>(36.44)</td>
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<tr>
<td>Ave. Coef</td>
<td>-0.002*</td>
<td></td>
<td></td>
<td>0.001</td>
<td>1.001***</td>
<td>(4.51)</td>
</tr>
<tr>
<td>(T-Stat)</td>
<td>(-1.92)</td>
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<td></td>
<td>(0.0274)</td>
<td></td>
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<tr>
<td>Ave. Coef</td>
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<td></td>
<td></td>
<td>0.393***</td>
<td>0.744***</td>
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<td>(T-Stat)</td>
<td>(-1.80)</td>
<td></td>
<td></td>
<td>(22.48)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p-value<10%, **p-value<5%, ***p-value<1%
Second-Order Effects

- Model:
  - Characterize centrality by eigenvector centrality and in- and out-degree centrality
  - Use average of industry if no relationship in dataset
  - Split by NAICS code (3 for manufacturing, 4 for logistics)

- Split into quintiles of centrality.

- Observe trends and significance in returns across quintiles.
## Second-Order Results: Manufacturing

<table>
<thead>
<tr>
<th>N3 Portfolio</th>
<th>Alpha(%)</th>
<th>$R_{mt} - R_{ft}$</th>
<th>Factor Loadings</th>
<th>Adj. $R^2$(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1(Low)</td>
<td>0.340</td>
<td>1.250***</td>
<td>SMB 0.327</td>
<td>92.13</td>
</tr>
<tr>
<td></td>
<td>(0.99)</td>
<td>(15.71)</td>
<td>HML -0.366</td>
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<tr>
<td></td>
<td>0.630*</td>
<td>(9.90)</td>
<td>MOM -0.145</td>
<td>93.25</td>
</tr>
<tr>
<td></td>
<td>(1.81)</td>
<td></td>
<td>Adj -1.27</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.077</td>
<td>1.220***</td>
<td>SMB 0.491</td>
<td>91.10</td>
</tr>
<tr>
<td></td>
<td>(0.22)</td>
<td>(14.70)</td>
<td>HML -0.594**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.414</td>
<td>(10.07)</td>
<td>MOM 0.025</td>
<td>93.63</td>
</tr>
<tr>
<td></td>
<td>(1.25)</td>
<td></td>
<td>Adj (0.23)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.430</td>
<td>0.902***</td>
<td>SMB -0.561*</td>
<td>86.05</td>
</tr>
<tr>
<td></td>
<td>(1.26)</td>
<td>(11.43)</td>
<td>HML -0.205</td>
<td></td>
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<tr>
<td></td>
<td>0.175</td>
<td>(9.61)</td>
<td>MOM 0.079</td>
<td>87.74</td>
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<tr>
<td></td>
<td>(0.50)</td>
<td></td>
<td>Adj (0.69)</td>
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</tr>
<tr>
<td>4</td>
<td>0.105</td>
<td>1.066***</td>
<td>SMB -0.079</td>
<td>92.44</td>
</tr>
<tr>
<td></td>
<td>(0.37)</td>
<td>(16.05)</td>
<td>HML -0.338</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.127</td>
<td>(10.83)</td>
<td>MOM 0.022</td>
<td>92.51</td>
</tr>
<tr>
<td></td>
<td>(0.41)</td>
<td></td>
<td>Adj (0.22)</td>
<td></td>
</tr>
<tr>
<td>5(High)</td>
<td>0.053</td>
<td>0.804***</td>
<td>SMB -0.659***</td>
<td>84.67</td>
</tr>
<tr>
<td></td>
<td>(0.16)</td>
<td>(10.81)</td>
<td>HML -0.431**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.170</td>
<td>(11.52)</td>
<td>MOM 0.009</td>
<td>91.00</td>
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<tr>
<td></td>
<td>(-0.63)</td>
<td></td>
<td>Adj (0.10)</td>
<td></td>
</tr>
<tr>
<td>High-Low</td>
<td>-0.287***</td>
<td>-0.446***</td>
<td>SMB -0.986***</td>
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</tr>
<tr>
<td></td>
<td>(-2.87)</td>
<td>(-19.21)</td>
<td>HML -0.065</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.800***</td>
<td>(-3.71)</td>
<td>MOM 0.153***</td>
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</tr>
<tr>
<td></td>
<td>(-8.52)</td>
<td></td>
<td>Adj (5.03)</td>
<td></td>
</tr>
</tbody>
</table>

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## Second-Order Results: Logistics

### Table: Factor Sensitivities by In-degree Centrality for Logistics Firms.

<table>
<thead>
<tr>
<th>N4</th>
<th>Portfolio</th>
<th>Alpha(%)&lt;sup&gt;*&lt;sub&gt;1&lt;/sub&gt;</th>
<th>( R_{mt} - R_{ft} )</th>
<th>Factor Loadings</th>
<th>\textit{Adj. } ( R^2(%) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1(Low)</td>
<td>0.061 (0.12)</td>
<td>1.072***</td>
<td>1.072***</td>
<td>( \text{SMB} )</td>
<td>0.061 (0.12)</td>
</tr>
<tr>
<td>2</td>
<td>0.327 (0.72)</td>
<td>1.078***</td>
<td>1.078***</td>
<td>( \text{SMB} )</td>
<td>0.327 (0.78)</td>
</tr>
<tr>
<td>3</td>
<td>0.493 (1.01)</td>
<td>0.973***</td>
<td>0.973***</td>
<td>( \text{SMB} )</td>
<td>0.242 (0.44)</td>
</tr>
<tr>
<td>4</td>
<td>0.703* (1.73)</td>
<td>0.893***</td>
<td>0.893***</td>
<td>( \text{SMB} )</td>
<td>0.741 (1.67)</td>
</tr>
<tr>
<td>5(High)</td>
<td>0.922** (2.71)</td>
<td>0.638***</td>
<td>0.638***</td>
<td>( \text{SMB} )</td>
<td>0.878** (2.81)</td>
</tr>
<tr>
<td>High-Low</td>
<td>0.861*** (6.60)</td>
<td>-0.434***</td>
<td>-0.434***</td>
<td>( \text{SMB} )</td>
<td>1.202*** (8.80)</td>
</tr>
</tbody>
</table>

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Conclusions

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2. Nonlinear effects can allow for wide variation in topology.

3. Risk propagation from connections varies depending on chain level.

4. Data indicates wide range of degree distributions (that seem to imply some nonlinear relationships).

5. Evidence of concurrent supplier and customer effects plus supplier momentum effects on returns.

6. Evidence of decreasing returns to centrality in manufacturing and increasing returns to centrality in logistics.
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Thank you! Any questions?