INTER-FIRM RELATIONSHIPS AND ASSET PRICES

Carlos Ramírez

Tepper School of Business
Carnegie Mellon University

January, 2016
Alcoa Gets $1.5 Billion Supply Contract From GE

Aluminum producer will announce quarterly results amid industry slump

Alcoa will disclose fourth-quarter earnings after the market close. Shown, an Alcoa aluminum plant in Alcoa, Tenn., in 2014. PHOTO: REUTERS

By JOHN W. MILLER
Research Question

To what extent does the transmission of shocks across firms in a network economy explain asset market phenomena?
What I do

- Develop a parsimonious equilibrium model in which:
  - shocks to individual firms spread from one firm to another via long-term inter-firm relationships
  - propensity of relationships to transmit firm-level shocks varies over time

- Calibrate the model to explore whether the transmission of shocks across firms in a network economy has quantitative implications on asset market phenomena
What do we learn from my paper?

The transmission of shocks across firms in customer supplier networks is important to quantitatively understand asset prices.

- Calibrated model generates dynamics of consumption and dividend growth rates similar to long-run risk models.

- Firms that are more central in the network command a higher risk premium than firms that are less central.

- Firm-level return volatilities exhibit high degree of comovement.
Model
Environment

- Dynamic endowment economy. Infinite time horizon.

- One perishable good. $n$ infinitely-lived firms. $n \gg 1$.

- Inter-firm relationships are exogenously determined and fixed.

- Infinitely-lived representative investor with Epstein-Zin-Weil preferences.
Firms’ cash-flows

• Relationships generate interdependencies among firms’ cash-flows,

\[ \log \left( \frac{y_{i,t+1}}{Y_t} \right) \equiv \alpha_0 + \alpha_1 d_i - \alpha_2 \sqrt{n} \tilde{\varepsilon}_{i,t+1}, \quad i \in \{1, \cdots, n\} \]

• \(y_{i,t+1}\) ≡ cash-flow of firm \(i\) at \(t + 1\)

• \(d_i\) ≡ # of connections of firm \(i\)

• \(Y_t\) ≡ aggregate output at \(t\)
Shocks propagate via relationships

- At the beginning of $t$, each firm:
  - faces a negative (firm-specific) shock with probability $q$
  - does not face a negative shock with probability $1 - q$

- At $t$, each relationship:
  - transmits shocks with probability $p_t$
  - does not transmit shocks with probability $1 - p_t$

- A shock to firm $i$ at $t$ also affects firm $j$ if:
  - there exists a sequence of relationships that connects firms $i$ and $j$
  - each relationship in the sequence transmits shocks at $t$
Shocks propagate via relationships
Dynamics of $p_t$

- $p_t$ is time-varying and follows a 2-states Markov chain

- $p_t \in \{p_L, p_H\}, \; p_L < p_H$

- $\psi \equiv \mathbb{P}[p_t = p_H]$

- $\phi$ measures the persistence in $p_t$
Equilibrium Asset Pricing
\[ \mathbb{E}_t \left( \tilde{M}_{t+1} \tilde{R}_{i,t+1} \right) = 1 \]

- \( \tilde{M}_{t+1} \) is the pricing kernel at \( t+1 \),
  
  \[ \tilde{M}_{t+1} \equiv \left[ \beta \left( e^{\Delta \tilde{c}_{t+1}} \right)^{-\rho} \right]^{\frac{1-\gamma}{1-\rho}} \left[ \tilde{R}_{a,t+1} \right]^{\frac{1-\gamma}{1-\rho} - 1} \]

- \( \Delta \tilde{c}_{t+1} \equiv \log \left( \frac{C_{t+1}}{C_t} \right) \) and \( \tilde{R}_{a,t+1} \) is the gross return on aggregate wealth
Shock Propagation and the Pricing Kernel
Shock Propagation and $\Delta \tilde{c}_{t+1}$

\[
\Delta \tilde{c}_{t+1} \equiv \log \left( \frac{Y_{t+1}}{Y_t} \right) \\
= \alpha_0 + \alpha_1 \left( \frac{1}{n} \sum_{i=1}^{n} d_i \right) - \alpha_2 \sqrt{n} \left( \frac{1}{n} \sum_{i=1}^{n} \tilde{\varepsilon}_{i,t+1} \right) \\
= \alpha_0 + \alpha_1 \bar{d} - \alpha_2 \sqrt{n} \tilde{W}_{n,t+1}
\]
Shock Propagation and $\Delta \tilde{c}_{t+1}$

(a) Link structure

(b) $\sqrt{n\tilde{W}_n}$, $q = 0.1$
Shock Propagation if $p_t = 0.2$
Shock Propagation if $p_t = 0.8$
Calibration
Calibration
Uncovering the link structure

- Customer-supplier relationships among U.S. firms
  - 6,500 different firms with common stocks,
  - 27,000 unique annual customer-supplier relationships from 1980 to 2005
  - Relationships last about 3 years on average
  - Size distribution resembles size distribution of CRSP universe
Customer-Supplier Network Dynamics. Year: 1981
Customer-Supplier Network Dynamics. Year: 1999
## Characteristics of Customer-Supplier Networks

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of firms per customer-supplier network</td>
<td>388</td>
<td>178</td>
</tr>
<tr>
<td>Number of relationships per customer-supplier network</td>
<td>281</td>
<td>154</td>
</tr>
<tr>
<td>Number of clusters per network</td>
<td>122</td>
<td>47</td>
</tr>
<tr>
<td>Size of the largest cluster</td>
<td>30</td>
<td>13</td>
</tr>
<tr>
<td>Size of the second largest cluster</td>
<td>24</td>
<td>11</td>
</tr>
<tr>
<td>Size of the third largest cluster</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>Size of the fourth largest cluster</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>Size of the fifth largest cluster</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Exponent of power law degree distribution</td>
<td>3.06</td>
<td>0.28</td>
</tr>
</tbody>
</table>
Calibration

Uncovering dynamics of $p_t$
## Benchmark Parameterization

<table>
<thead>
<tr>
<th>Firms’ Cash-flows</th>
<th>Propagation of shocks</th>
<th>Preferences</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_0$ 0.30</td>
<td>$p_L$ 0.38</td>
<td>$\beta$ 0.99</td>
</tr>
<tr>
<td>$\alpha_1$ 0.10</td>
<td>$p_H$ 0.43</td>
<td>$\gamma$ 10</td>
</tr>
<tr>
<td>$\alpha_2$ 0.07</td>
<td>$q$ 0.20</td>
<td>$\rho$ 0.65</td>
</tr>
<tr>
<td></td>
<td>$\psi$ 0.50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\phi$ 0.92</td>
<td></td>
</tr>
</tbody>
</table>
## Moments under the Benchmark Parameterization

<table>
<thead>
<tr>
<th>Moments</th>
<th>Data</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average annual log of consumption growth rate</td>
<td>1.9%</td>
<td>1.8%</td>
</tr>
<tr>
<td>Annual volatility of log consumption rate</td>
<td>3.5%</td>
<td>4.9%</td>
</tr>
<tr>
<td>Average annual log dividend growth rate</td>
<td>3.8%</td>
<td>3.7%</td>
</tr>
<tr>
<td>Annual volatility of the log dividend growth rate</td>
<td>11.6%</td>
<td>14.9%</td>
</tr>
<tr>
<td>Average annual market return (S&amp;P 500)</td>
<td>11.5%</td>
<td>12%</td>
</tr>
<tr>
<td>Annual volatility of the market return</td>
<td>19%</td>
<td>18.9%</td>
</tr>
<tr>
<td>Average annual risk-free rate (3 month T-Bill)</td>
<td>3.5%</td>
<td>2.0%</td>
</tr>
<tr>
<td>Annual volatility of risk-free rate</td>
<td>3%</td>
<td>0.7%</td>
</tr>
<tr>
<td>Average annual equity risk premium</td>
<td>8%</td>
<td>10%</td>
</tr>
<tr>
<td>Average annual Sharpe ratio</td>
<td>0.4</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Implications of the Calibrated Model
Similarities between the calibrated model and the LRR model

<table>
<thead>
<tr>
<th>Similarity measure</th>
<th>( \mathbb{E}<em>t [\Delta \tilde{c}</em>{t+1}] )</th>
<th>Vol_\text{t} [\Delta \tilde{c}_{t+1}]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean  SD</td>
<td>Mean  SD</td>
</tr>
<tr>
<td>ED</td>
<td>0.958  0.012</td>
<td>0.974  0.008</td>
</tr>
<tr>
<td>DTW</td>
<td>0.758  0.091</td>
<td>0.723  0.105</td>
</tr>
<tr>
<td>PACF</td>
<td>0.736  0.043</td>
<td>0.743  0.043</td>
</tr>
<tr>
<td>ED in AR</td>
<td>0.908  0.100</td>
<td>0.910  0.097</td>
</tr>
<tr>
<td>Linear predictive in ARIMA</td>
<td>0.726  0.325</td>
<td>0.729  0.313</td>
</tr>
<tr>
<td>Spectral distance</td>
<td>1.0   0.000</td>
<td>1.0   0.000</td>
</tr>
</tbody>
</table>

\[
\text{score} = \frac{1}{1 + \text{distance}}
\]
Cross sectional Implications
Cross-Section of Risk Premia

Risk premia vs. diffusion centrality

Firms centrality

$E[R_{i,t} - R_{f,t}]$
Cross sectional Implications
Firm-level Return Volatility

Total Volatility by Size Quintile

Years
Related literature
- Economic linkages and asset pricing properties
  - Buraschi and Porchia (2012)
  - Ahern (2013)
  - Birge and Wu (2014)
  - Herskovic (2015)

- Granular shocks and aggregate fluctuations
Final Remarks
What do we learn from my paper?

The propagation of shocks within customer supplier networks is important to understanding equilibrium asset prices.

- A calibrated model generates dynamics of consumption and dividend growth rates similar to long-run risk models.

- Firms that are more central in the network command a higher risk premium than firms that are less central.

- Firm-level return volatilities exhibit high degree of comovement.
Final Remarks
Caveats and Limitations

- The network that underlies the aggregate economy is only partially observed.

- Better proxies for input specificity?

- Propensity of relationships to transmit shocks may vary across firms, sectors or industries.

- Does strategic network formation temper the quantitative impact of shock propagation on asset prices?
APPENDIX
Why is this important?

Relationships serve as propagation mechanisms of firm-level shocks:

- Hertzel, Li, Officer and Rodgers (JFE, 2008): Within supply chains, distress related to bankruptcy generates negative and significant wealth effects for suppliers.

- Boone and Ivanov (JFE, 2012): Within strategic alliances and joint ventures, distress related to bankruptcy generates negative and significant wealth effects for non-bankrupt strategic partners.

- Barrot and Sauvagnat (2014): Suppliers affected by natural disasters impose substantial losses on their customers, especially when they produce specific inputs.
Impact of $G_n$ and $p_t$ on $\tilde{R}_{a,t+1}$

- $\tilde{R}_{a,t+1} \equiv \frac{P_{a,t+1} + C_{t+1}}{P_{a,t}}$

- If $P_a(c, s) = w_s^a c$, then $\tilde{R}_{a,t+1} = \frac{w_{s'}^a + 1}{w_s^a} e^{\Delta \tilde{c}_{t+1}}$

\[
w_s^a = \beta \left( \sum_{s' \in \{H,L\}} \omega_{s,s'} \mathbb{E} \left( e^{(1-\gamma)\Delta \tilde{c}_{t+1}} \left| p_{s'} \right. \right) \left( w_{s'}^a + 1 \right) \frac{1-\gamma}{1-\rho} \right)^{\frac{1-\rho}{1-\gamma}}\]
Impact of $G_n$ and $p_t$ on $\tilde{R}_{i,t+1}$

If $P_i(y,s) = v_i(s)y$, then

$$v_i(s) = \beta \frac{1-\gamma}{1-\rho} e^{\bar{x} + \frac{\sigma^2}{2}} \left( \sum_{s' \in \{H,L\}} \omega_{s,s'} \left( \frac{w_{s'}^a + 1}{w_s^a} \right)^{\frac{\rho-\gamma}{1-\rho}} \mathbb{E} \left( e^{(\tau-\gamma)\Delta \tilde{c}_{t+1} \mid p_{s'}} v_i(s') \right) \right)$$

$$+ \beta \frac{1-\gamma}{1-\rho} e^{\alpha_0 + \alpha_1 d_i} \left( \sum_{s' \in \{H,L\}} \omega_{s,s'} \left( \frac{w_{s'}^a + 1}{w_s^a} \right)^{\frac{\rho-\gamma}{1-\rho}} \mathbb{E} \left( e^{-\gamma \Delta \tilde{c}_{t+1} \mid p_{s'}} [1 - \pi_i(p_{s'})] \right) \right)$$

and

$$\mathbb{E} \left( \tilde{R}_{i,t+1} \mid s \right) = \frac{1}{v_i(s)} \left( \sum_{s' \in \{H,L\}} \omega_{s,s'} \left\{ v_i(s') \mathbb{E} \left( e^{\bar{x}_{t+1} \mid p_{s'}} \right) + e^{\alpha_0 + \alpha_1 d_i} (1 - \pi_i(p_{s'})) \right\} \right)$$
Risk free rate and Price of Risk

\[
\mathbb{E}(\tilde{R}_{i,t+1} | s) = R_f(s) + \left( \frac{\text{Cov}(\tilde{R}_{i,t+1}, \tilde{M}_{t+1} | s)}{\text{Var}(\tilde{M}_{t+1} | s)} \right) \left( \frac{-\text{Var}(\tilde{M}_{t+1} | s)}{\mathbb{E}(\tilde{M}_{t+1} | s)} \right)
\]

with

\[
\frac{1}{R_f(s)} = \beta^{1-\gamma} \left( \sum_{s' \in \{H,L\}} \omega_{s,s'} \mathbb{E}(e^{-\gamma \Delta \tilde{c}_{t+1} | p_{s'}}) \left( \frac{w_{s'}^{a} + 1}{w_s^{a}} \right)^{\frac{\rho - \gamma}{1-\rho}} \right), \quad s = \{H, L\}
\]

\[
\lambda_{\tilde{M}}(s) = \frac{1}{R_f(s)} - R_f(s) \left( \beta^{2 \left( \frac{1-\gamma}{1-\rho} \right)} \sum_{s' \in \{H,L\}} \omega_{s,s'} \left( \frac{w_{s'}^{a} + 1}{w_s^{a}} \right)^{2 \left( \frac{\rho - \gamma}{1-\rho} \right)} \mathbb{E}(e^{-2\gamma \Delta \tilde{c}_{t+1} | p_{s'}}) \right)
\]
Impact of $G_n$ and $p_t$ on $R_f$

Varying $p_t$. $\psi = 0.1$, $\phi = 0.25$
SHOCK PROPAGATION AND CROSS-SECTIONAL ASSET PRICING
Shock Propagation and $\mathbb{E}\left(\tilde{R}_{i,t} | p_t\right)$

Varying $p_t$. $\psi = 0.1$, $\phi = 0.25$

Difference in expected returns: $E(R_{1,t} | p_t) - E(R_{i,t} | p_t)$
Impact of $G_n$ and $p_t$ on $\lambda \tilde{M}$

Varying $p_t$. $\psi = 0.1$, $\phi = 0.25$

Price of risk: $\lambda \tilde{M}(p_t)$
## Eigenvector Centrality Summary Statistics

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Inter-sectoral Networks</th>
<th>Customer Supplier Networks (10%)</th>
<th>Customer Supplier Networks (20%)</th>
<th>Calibrated Network</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of sectors/firms</td>
<td>474</td>
<td>750</td>
<td>382</td>
<td>400</td>
</tr>
<tr>
<td>Mean</td>
<td>−6.68</td>
<td>−6.74</td>
<td>−6.62</td>
<td>−6.09</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>1.48</td>
<td>1.07</td>
<td>1.31</td>
<td>1.71</td>
</tr>
<tr>
<td>Skewness</td>
<td>0.87</td>
<td>4.04</td>
<td>3.28</td>
<td>1.54</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>4.45</td>
<td>18.50</td>
<td>12.38</td>
<td>3.70</td>
</tr>
<tr>
<td>Minimum</td>
<td>−10.21</td>
<td>−7.01</td>
<td>−7.01</td>
<td>−7.01</td>
</tr>
<tr>
<td>1st Percentile</td>
<td>−9.39</td>
<td>−7.01</td>
<td>−7.01</td>
<td>−7.01</td>
</tr>
<tr>
<td>25th Percentile</td>
<td>−7.71</td>
<td>−7.01</td>
<td>−7.01</td>
<td>−7.01</td>
</tr>
<tr>
<td>Median</td>
<td>−6.85</td>
<td>−7.01</td>
<td>−7.01</td>
<td>−6.09</td>
</tr>
<tr>
<td>75th Percentile</td>
<td>−5.90</td>
<td>−7.01</td>
<td>−7.01</td>
<td>−6.42</td>
</tr>
<tr>
<td>99th</td>
<td>−2.27</td>
<td>−1.83</td>
<td>−1.67</td>
<td>−2.30</td>
</tr>
<tr>
<td>Maximum</td>
<td>−0.17</td>
<td>−0.46</td>
<td>−0.34</td>
<td>−0.74</td>
</tr>
</tbody>
</table>
Calibration

Uncovering dynamics of $\tilde{\rho}_t$
Calibration
Estimates of \( \alpha \)'s

### Annual estimates of \( \alpha_0 \)

![Graph of \( \alpha_0 \)]

### Annual estimates of \( \alpha_1 \)

![Graph of \( \alpha_1 \)]

### Annual estimates of \( \alpha_2 \)

![Graph of \( \alpha_2 \)]
Aggregate Implications

Dynamics of $p_t$

Dynamics of propensity $\tilde{p}_t$
Aggregate Implications

Dynamics of $E_t[\Delta \tilde{c}_{t+1}]$

Dynamics of expected log consumption growth

$LRR$

$Network$

Periods

$E_t[\Delta \tilde{c}_{t+1}]$

$10^{-3}$

$E_t[\Delta \tilde{c}_{t+1}]$ $x 10^{-3}$

Periods

0 20 40 60 80 100 120 140 160 180 200

−5

−4

−3

−2

−1

0

1

2

3

4

$10^{-3}$
Aggregate Implications

Dynamics of $V_t[\Delta \tilde{c}_{t+1}]$

Dynamics of vol of log consumption growth

LRR

Network

$V_{\text{vol}}[\Delta \tilde{c}_{t+1}]$

Periods

$10^{-3}$
(a) Network in 1980  
(b) Network in 1986