Risk sharing and intermediary asset pricing

- Capital markets enable risk sharing in the society

- Frictions in financial intermediation can disrupt this process (He & Krishnamurthy, 2013; Brunnermeier & Sannikov, 2014)

  → Asset prices reflect intermediaries’ risk exposures rather than those of end-investors

- Testing this prediction is hard due to omitted risk-factor problem (Santos & Veronesi, 2022)
This paper tests theories of risk sharing in a unique setting

1. Studies the pricing of catastrophe bonds
   - Exposed only to natural disaster risk

2. Argues that the relevant intermediary is a specialist hedge fund manager

3. Finds that 71% of security-level variation in the expected returns can be explained by the marginal utility of these intermediaries
   - Inconsistent with omitted risk factor alternatives if natural disasters are independent of marginal value of aggregate wealth (identifying assumption)
Cat bond basics

- Trigger if qualifying natural disasters occur
- Intentionally structured to minimize interest rate and credit risk
  → historical returns virtually uncorrelated with other asset classes
- Issued by (re)insurance companies and government agencies
- Account for around 20% of total reinsurance capital
Risk modeling

Before issuance, sponsor hires a risk modeling company to assess actuarial risk of bond triggering

- AIR, RMS, EQECAT

Modelled loss summarized by three measures

- Attachment probability
- Expected loss (%)
- Exhaustion probability
Fact 1: buying cat bonds has been extremely profitable despite low correlations with other asset classes

\[ R^2_{\text{cat, equity}} = 0.05 \]
\[ \beta_{\text{cat, equity}} = 0.05 \]
\[ R^2_{\text{cat, hy bonds}} = 0.08 \]
\[ \beta_{\text{cat, hy bonds}} = 0.11 \]
Fact 2: historical natural disasters haven’t had significant macroeconomic consequences in developed countries
Fact 3: majority of cat bonds are held by specialist funds

Investor by Category (AON 2018)
Fact 3: majority of cat bonds are held by specialist funds
## Data

**Table: Summary Statistics**

### Panel A: Bond Characteristics (Primary Market)

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Mean</th>
<th>St Dev</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size ($ Million)</td>
<td>675</td>
<td>130.8</td>
<td>119.6</td>
<td>1.8</td>
<td>1500.0</td>
</tr>
<tr>
<td>Time to Maturity (Months)</td>
<td>675</td>
<td>36.9</td>
<td>13.1</td>
<td>5.0</td>
<td>120.0</td>
</tr>
<tr>
<td>Spread (%)</td>
<td>658</td>
<td>7.3</td>
<td>5.1</td>
<td>0.7</td>
<td>49.2</td>
</tr>
<tr>
<td>Attachment Probability (%)</td>
<td>657</td>
<td>3.2</td>
<td>3.2</td>
<td>0.0</td>
<td>23.2</td>
</tr>
<tr>
<td>Expected Loss (%)</td>
<td>661</td>
<td>2.3</td>
<td>2.3</td>
<td>0.0</td>
<td>15.8</td>
</tr>
<tr>
<td>Exhaustion Probability (%)</td>
<td>656</td>
<td>1.8</td>
<td>1.8</td>
<td>0.0</td>
<td>12.0</td>
</tr>
<tr>
<td>Expected excess return (%)</td>
<td>645</td>
<td>5.2</td>
<td>3.8</td>
<td>0.6</td>
<td>43.0</td>
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</table>

### Panel B: Secondary Market

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Mean</th>
<th>St Dev</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turnover (%)</td>
<td>5,969</td>
<td>35.8</td>
<td>79.1</td>
<td>0.0</td>
<td>2000.0</td>
</tr>
<tr>
<td>Discount margin\text{\textit{sheet}} (%)</td>
<td>6,538</td>
<td>6.6</td>
<td>4.8</td>
<td>0.0</td>
<td>39.5</td>
</tr>
<tr>
<td>Discount margin\text{\textit{trace}} (%)</td>
<td>3,994</td>
<td>6.7</td>
<td>4.6</td>
<td>-0.3</td>
<td>36.9</td>
</tr>
</tbody>
</table>
Model

- Simple general equilibrium asset pricing model with financial intermediation similar to Gabaix, Krishnamurthy, and Vigneron (2007)

  - Outside investors can access cat bond markets only through specialized cat funds

  - Intermediation friction: fund manager must have “skin in the game” by having large amount of her own wealth tied to the fund (alternatively, pay is tied to portfolio performance)

  - Key assumption: natural disasters are independent of marginal value of aggregate wealth
Model Predictions

▶ Cross-section:

\[ E_t(R^e_{i,t+1}) = \beta_{i,t}E_t(R^e_{cat,t+1}) \]  \hspace{1cm} (1)

▶ \( R^e_{cat,t+1} \) is excess return on ”cat bond market portfolio”

▶ Time series:

\[ E_t(R^e_{cat,t+1}) = \hat{\rho}\text{Var}_t(R^e_{cat,t+1}) \frac{Size_t}{AUM_t} \]  \hspace{1cm} (2)
Empirical approach

- Prediction of a simple model with intermediation frictions:

\[ E_t(R^e_{i,t+1}) = \beta_{i,t} E_t(R^e_{cat,t+1}) \]

- \[ E_t(R^e_{i,t+1}) = s_{i,t} - e_{i,t} \]
  - Key assumption: actuarial cat models’ loss estimates are a good proxy for investors’ loss estimates

- \( \beta_{i,t} \) cannot be feasibly estimated from historical data
  - Short sample, infrequent trading, highly skewed returns
  - Solution: use actuarial models to model bonds’ return distributions and estimate \( \beta_{i,t} \)’s from simulated data

- Empirically, variation in simulated \( \beta_{i,t} \) is mainly driven by:
  - Bond’s expected loss
  - Relative size of bond’s peril category
Cross-sectional results

\[ R^2 = 0.71 \]

\[ \hat{\beta}_{i,t} E_t(R^e_{cat}) \]

\[ \beta = 1 \]

\[ E(R^e_{cat}) \]

\[ R^2 \text{ decomposition} \]
Cross-sectional results

Table: Pricing of Catastrophe Market Risk

\[
E_t(R_{i,t+1}^e) = \lambda_{0,t} + \lambda_{cat,t} \hat{\beta}_{i,t} + \varepsilon_{i,t+1}
\]
Time series results

Observed premium = \( \frac{E_t(R^e_{cat})}{\text{Var}_t(R^e_{cat})} \),
Time series results

Observed premium = $\frac{E_t(R^e_{cat})}{Vart(R^e_{cat})}$, Predicted premium = $\hat{\rho} \frac{Size_t}{AUM_t}$
Pooled results

- Model predicts:

\[ E_t(R_{i,t+1}^e) = \beta_{i,t}\hat{\rho}\text{Var}_t(R_{cat,t+1}^e)\frac{\text{Size}_t}{\text{AUM}_t} \]

- I estimate this with:

\[ E_t(R_{i,t+1}^e) = \delta \beta_{i,t} F_t + \varepsilon_{i,t} \]

<table>
<thead>
<tr>
<th>$F_t$</th>
<th>$\text{Var}<em>t(R</em>{cat,t+1}^e)$</th>
<th>$\frac{\text{Size}_t}{\text{AUM}_t}$</th>
<th>$\frac{\text{Size}_t}{\text{AUM}_t}$</th>
<th>$E_t(R_{cat,t+1}^e)$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.35***</td>
<td>0.02***</td>
<td>0.96***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.38)</td>
<td>(0.00)</td>
<td>(0.05)</td>
</tr>
<tr>
<td>$R^2$</td>
<td></td>
<td>0.78</td>
<td>0.77</td>
<td>0.87</td>
</tr>
<tr>
<td>$N$</td>
<td></td>
<td>581</td>
<td>581</td>
<td>581</td>
</tr>
</tbody>
</table>
Alternatives

- Froot (2001)
  1. Liquidity
  2. Moral hazard & adverse selection
  3. Inefficient risk transformation
  4. Market power

- Others
  1. Peso problem
  2. Probability weighting
  3. Rare disasters
  4. Climate change risk
Growing climate change concerns unlikely to explain prices

![Graph showing observed premium and its variance over time with shaded areas indicating qualifying disasters.]

- **E_t(R_p^e)**: Observed premium
- **Var_t(R_p^e)**: Variance of observed premium

- **Cyclone portfolio**
- **Earthquake portfolio**
- **Qualifying disaster(s)**

Tuomas Tomunen  
Failure to Share Natural Disaster Risk
What next?

MARKETS

State Farm Halts Home-Insurance Sales in California

State Farm is the nation’s biggest car and home insurer by premium volume. It said it “made this decision due to historic increases in construction costs outpacing inflation, rapidly growing catastrophe exposure, and a challenging reinsurance market.” It posted the statement on its website and referred questions to trade groups.

Source: WSJ May 26, 2023

- Ge and Tomunen (Work-in-progress): to what extent fluctuations in reinsurance premium affect home insurance costs?
Conclusion

- A model with intermediation frictions can explain premium on natural disaster risk
  - Implies a failure in risk sharing

- Potential policy tools
  1. Increase the number of available peril categories
  2. Improve access to the market
  3. Educate investors
Thank you for your attention!
Related literature


**Contribution:** Provide evidence on intermediary pricing mechanism in a clean laboratory
Related literature (cont’d)


**Contribution:** Rule out alternative frictions proposed by Froot (2001), cross-sectional evidence with explicit pricing model
Related literature (cont’d)

**Climate Finance:** Bansal et al. (2017), Barnett et al. (2019), Bolton and Kacperczyk (2019), Daniel et al. (2018), Engle et al. (2019), Hong et al. (2019), Ilhan et al. (2019), Krueger et al. (2019),

**Contribution:** Evidence on intermediation frictions being a major impediment for efficient allocation of natural disaster risk
Froot (2001) assumptions and hypotheses

**Assumptions:**

1. Cat risk is diversifiable
   - No peso problem
2. Actuarial risk models are unbiased

**Hypotheses (supply side):**

1. Insufficient reinsurance capital
2. Reinsurance companies have market power
3. Corporate form for reinsurance is inefficient
4. Poor liquidity & High transaction costs
5. Moral hazard & Adverse selection
Appendix

Typical deal structure

1. Investors
2. Special Purpose Vehicle (SPV)
3. Collateral Account
4. Sponsor (Insuree)

- Sale proceeds to Investors
- Coupons from Investors to SPV
- Principal at maturity from SPV to Investors
- Premiums from Sponsor to SPV
- Reimbursement from SPV to Sponsor
- Returns on collateral from SPV to Collateral Account
- Liquidation value from Collateral Account to SPV

Tuomas Tomunen
Failure to Share Natural Disaster Risk
Market structure

Total Reinsurance Capital ($605B)

Traditional Capital ($507B)

Collateralized Reinsurance ($53B)

Alternative Capital - ILS ($98B)

Catastrophe Bonds ($32B)

Others ($13B)

Source: AON Benfield (2018)
Cat bonds are uncorrelated with major asset classes

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>0.272**</td>
<td>0.258*</td>
<td>0.266*</td>
<td>0.319**</td>
<td>0.268*</td>
</tr>
<tr>
<td></td>
<td>(0.136)</td>
<td>(0.139)</td>
<td>(0.158)</td>
<td>(0.131)</td>
<td>(0.160)</td>
</tr>
<tr>
<td>Equities</td>
<td>0.027</td>
<td></td>
<td></td>
<td>0.005</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.021)</td>
<td></td>
<td></td>
<td>(0.034)</td>
<td></td>
</tr>
<tr>
<td>High-yield bonds</td>
<td>0.057*</td>
<td></td>
<td></td>
<td>0.038</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.031)</td>
<td></td>
<td></td>
<td>(0.051)</td>
<td></td>
</tr>
<tr>
<td>MBS</td>
<td></td>
<td>0.091</td>
<td></td>
<td>0.139</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.173)</td>
<td></td>
<td>(0.165)</td>
<td></td>
</tr>
<tr>
<td>Carry trade</td>
<td></td>
<td></td>
<td>0.031</td>
<td>0.008</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.040)</td>
<td>(0.049)</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>156</td>
<td>156</td>
<td>156</td>
<td>154</td>
<td>154</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.013</td>
<td>0.026</td>
<td>0.005</td>
<td>0.006</td>
<td>0.034</td>
</tr>
</tbody>
</table>

$$R_t^{cat} = a + b R_t^{other} + \epsilon_t$$
Risk modeling

- Before issuance, sponsor hires a risk modeling company to assess actuarial risk of bond triggering
  - AIR, RMS, EQECAT

- Modelled loss summarized by three measures
  - Attachment probability
  - Expected loss (%)
  - Exhaustion probability
Top 10 Peril Categories

- NA Hurricane
- NA Earthquake
- Europe Windstorm
- NA Thunderstorm
- Asia Earthquake
- NA Winterstorm
- NA Wildfire
- NA Other
- Asia Typhoon
- Australia Cyclone

Observations
Risk Model

Hazard Module

Inventory Module

Engineering Module

Financial Module

Modeled Loss Distribution
Market Share of Risk Modeling Companies

- AIR (59.1%)
- EQECAT (21.9%)
- RMS (18.5%)
- Aon Benfield (0.2%)
- KatRisk (0.3%)
Macro effects of natural disasters

Estimate impulse response to natural disasters with Jordà (2005) local projections:

\[ \Delta_h y_{i,t+h} = \gamma_i + \gamma_t + b_1 \text{Small}_{i,t} + b_2 \text{Large}_{i,t} + \varepsilon_{i,t} \]

- 13 countries (\(i\))
- Annual sample from 1950 to 2016 (\(t\))
- \(\text{Small}_{i,t} = 1\) if \(\frac{dmg}{gdp}_{i,t-1} \in [0.2\%, 1\%]\) (8% of obs)
- \(\text{Large}_{i,t} = 1\) if \(\frac{dmg}{gdp}_{i,t-1} > 1\%\) (2% of obs)
Impulse responses to small disasters

- **Consumption growth**
  - 0% to 5% over 3 years

- **GDP growth**
  - 0% to 5% over 3 years

- **House price growth**
  - -10% to 10% over 3 years

- **Stock market return**
  - -25% to 25% over 3 years
Model

- Follows Gabaix, Krishnamurthy, Vigneron (2007)
- Two periods
- Large mass of outside investors
  - Marginal rate of substitution $M_H$ is independent of natural disasters
- Specialized cat bond fund managers
  - Choose a portfolio of cat bonds at $t = 0$
  - Have mean-variance preferences
- Friction: Managers must contribute $\alpha\%$ of funds they manage ("skin in the game")
Model: Assets

- At $t = 0$, $N$ cat bonds are issued at par
- Per-unit coupon of $C_i = r + s_i$ at maturity ($t = 1$)
- Bond can trigger due to natural disaster. Value of principal at maturity is:

$$P_i(x_i) = \begin{cases} 
1 & x_i > \bar{x}_i \\
F_i(x_i) & x_i \leq x_i \leq \bar{x}_i \\
0 & x_i < x_i 
\end{cases}$$

(3)

- Expected loss: $e_{l_i} = 1 - E_0 (P_i)$
- Expected excess return: $E_0 (R_{i}^e) = s_i - e_{l_i}$
Estimating betas

- Assumption: events are uncorrelated across peril categories and perfectly correlated within categories
- Only single-peril bonds are included in the sample
Table: Summary of Simulation Results

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Mean</th>
<th>St Dev</th>
<th>Min</th>
<th>25%</th>
<th>50%</th>
<th>75%</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_{\text{sheet}}$</td>
<td>2,158</td>
<td>1.04</td>
<td>0.71</td>
<td>0.01</td>
<td>0.42</td>
<td>0.92</td>
<td>1.54</td>
<td>3.28</td>
</tr>
<tr>
<td>$\beta_{\text{trace}}$</td>
<td>1,267</td>
<td>0.98</td>
<td>0.69</td>
<td>0.01</td>
<td>0.36</td>
<td>0.86</td>
<td>1.53</td>
<td>2.94</td>
</tr>
<tr>
<td>$N_{\text{trials}}$</td>
<td>500,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$N_{\text{perils}}$</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Examples of estimated betas

<table>
<thead>
<tr>
<th>Bond</th>
<th>Sponsor</th>
<th>Expected Loss</th>
<th>$\hat{\beta}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ursa Re Series 2017-1 Class E</td>
<td>California Earthquake Authority</td>
<td>3.33%</td>
<td>2.24</td>
</tr>
<tr>
<td>Ursa Re Series 2017-1 Class B</td>
<td>California Earthquake Authority</td>
<td>1.11%</td>
<td>1.28</td>
</tr>
<tr>
<td>Bosphorus Ltd. Series 2015-1 Class A</td>
<td>Turkish Catastrophe Insurance Pool</td>
<td>1.47%</td>
<td>0.08</td>
</tr>
</tbody>
</table>
Estimating betas

Let $x_{i,t} \sim U(0, 1)$. Given Attachment probability ($\bar{x}_i$), Expected loss ($el_i$) and Exhaustion probability ($x_i$), I assume the following payoff function for principal:

$$P_i(x_i) = \begin{cases} 
1, & x_i \geq \bar{x}_i \\
\left(\frac{x_i - x_i}{\bar{x}_i - x_i}\right) \phi_i, & x_i < x_i < \bar{x}_i \\
0, & x_i \leq x_i
\end{cases}$$  

(4)

where $\phi_i = \frac{\bar{x}_i - x_i}{\bar{x}_i - el_i} - 1$

Excess return in state $x$ then is:

$$R_{i,t+1}^e(x) = (1 + rt + s_{i,t})P_i(x) - rt$$  

(5)
Illustration of payoff function $P$

$\phi_B < 1$  $\phi_A = 1$  $\phi_C > 1$

Bond A ($e_l_A = 0.02$)
Bond B ($e_l_B = 0.015$)
Bond C ($e_l_C = 0.025$)
Results (TRACE prices)

**Table: Pricing of Catastrophe Market Risk**

<table>
<thead>
<tr>
<th>$t$</th>
<th>$\lambda_{0,t}$</th>
<th>(t-stat)</th>
<th>$\lambda_{cat,t}$</th>
<th>(t-stat)</th>
<th>$\lambda_{cat,t} - E_t(R_{cat,t+1}^e)$</th>
<th>(t-stat)</th>
<th>$R^2$</th>
<th>$N$</th>
<th>$N_{clusters}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>0.76</td>
<td>1.75</td>
<td>1.20</td>
<td>3.39</td>
<td>-0.80</td>
<td>-2.26</td>
<td>0.40</td>
<td>16</td>
<td>12</td>
</tr>
<tr>
<td>2006</td>
<td>-1.93</td>
<td>-2.56</td>
<td>7.57</td>
<td>11.71</td>
<td>1.99</td>
<td>3.08</td>
<td>0.87</td>
<td>29</td>
<td>15</td>
</tr>
<tr>
<td>2007</td>
<td>1.52</td>
<td>5.32</td>
<td>3.59</td>
<td>9.58</td>
<td>-1.32</td>
<td>-3.53</td>
<td>0.87</td>
<td>23</td>
<td>17</td>
</tr>
<tr>
<td>2008</td>
<td>1.82</td>
<td>1.94</td>
<td>2.41</td>
<td>3.38</td>
<td>-1.35</td>
<td>-1.89</td>
<td>0.53</td>
<td>18</td>
<td>15</td>
</tr>
<tr>
<td>2009</td>
<td>4.36</td>
<td>4.21</td>
<td>3.61</td>
<td>3.26</td>
<td>-3.60</td>
<td>-3.24</td>
<td>0.53</td>
<td>19</td>
<td>15</td>
</tr>
<tr>
<td>2010</td>
<td>3.47</td>
<td>7.52</td>
<td>1.40</td>
<td>3.79</td>
<td>-3.23</td>
<td>-8.72</td>
<td>0.38</td>
<td>26</td>
<td>19</td>
</tr>
<tr>
<td>2011</td>
<td>1.29</td>
<td>1.48</td>
<td>2.52</td>
<td>3.51</td>
<td>-1.44</td>
<td>-2.00</td>
<td>0.60</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td>2012</td>
<td>1.97</td>
<td>5.17</td>
<td>4.14</td>
<td>11.72</td>
<td>-2.49</td>
<td>-7.05</td>
<td>0.86</td>
<td>22</td>
<td>20</td>
</tr>
<tr>
<td>2013</td>
<td>0.95</td>
<td>4.98</td>
<td>2.14</td>
<td>8.40</td>
<td>-1.26</td>
<td>-4.95</td>
<td>0.76</td>
<td>30</td>
<td>26</td>
</tr>
<tr>
<td>2014</td>
<td>1.36</td>
<td>9.88</td>
<td>0.96</td>
<td>5.08</td>
<td>-1.63</td>
<td>-8.64</td>
<td>0.47</td>
<td>34</td>
<td>28</td>
</tr>
<tr>
<td>2015</td>
<td>1.37</td>
<td>7.47</td>
<td>0.99</td>
<td>6.37</td>
<td>-1.41</td>
<td>-9.03</td>
<td>0.55</td>
<td>35</td>
<td>27</td>
</tr>
<tr>
<td>2016</td>
<td>0.98</td>
<td>6.34</td>
<td>0.91</td>
<td>4.46</td>
<td>-0.83</td>
<td>-4.04</td>
<td>0.55</td>
<td>29</td>
<td>23</td>
</tr>
<tr>
<td>2017</td>
<td>0.82</td>
<td>3.27</td>
<td>0.77</td>
<td>2.42</td>
<td>-0.41</td>
<td>-1.29</td>
<td>0.14</td>
<td>35</td>
<td>27</td>
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<tr>
<td>2018</td>
<td>0.72</td>
<td>3.30</td>
<td>0.46</td>
<td>2.44</td>
<td>-0.57</td>
<td>-3.02</td>
<td>0.17</td>
<td>31</td>
<td>22</td>
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<tr>
<td>FM</td>
<td>1.51</td>
<td>9.32</td>
<td>1.95</td>
<td>10.02</td>
<td>-1.40</td>
<td>-9.47</td>
<td>0.46</td>
<td>57</td>
<td></td>
</tr>
</tbody>
</table>

$$E_t(R_{i,t+1}^e) = \lambda_{0,t} + \lambda_{cat,t} \hat{\beta}_{i,t} + \varepsilon_{i,t+1}$$
Main results

$R^2 = 0.31$

Predicted premium $\hat{\beta}_{i,t} E_t (R_{cat}^e)$

Observed premium $E_t (R_{i}^e)$
Main results

\[ R^2 = 0.27 \]
Main results

\[ \hat{\beta}_{i,t} E_t (R_{cat}^e) \]

\[ R^2_{\text{overall}} = 0.71 \]
\[ R^2_{\text{within ct}} = 0.63 \]
\[ R^2_{\text{between c, within t}} = 0.62 \]
\[ R^2_{\text{between t}} = 0.97 \]
Realized losses highly consistent with the predictions of the actuarial models
Alternative hypothesis that all premium is due to biased loss estimates inconsistent with the data
Modeled vs. actual losses

- **Expected loss**
- **Interdecile range**
- **Observed loss**

Loss %
0% 1% 2% 3% 4% 5% 10% 50% 90%

Prob(Loss ≤)

Modeled vs. actual losses (biased estimates)

- Expected loss
- Interdecile range
- Observed loss
Measuring Liquidity

I use all feasible measures from Friewald, Jankowitsch, and Subrahmanyam (2012):

- Trading activity variables
  - Turnover
  - Number of trades
  - Trading interval

- Bond characteristics
  - Amount issued
  - Age
  - Time to maturity
Measuring Liquidity (Cont’d)

**Table: Correlation of Beta and Liquidity Measures**

<table>
<thead>
<tr>
<th></th>
<th>( \hat{\beta} )</th>
<th>Turnover</th>
<th>N trades</th>
<th>Trading interval</th>
<th>Amount issued</th>
<th>Age</th>
<th>Maturity</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \hat{\beta} )</td>
<td>1.00</td>
<td>0.06</td>
<td>0.03</td>
<td>-0.04</td>
<td>-0.01</td>
<td>-0.15</td>
<td>-0.14</td>
</tr>
<tr>
<td>Turnover</td>
<td>0.06</td>
<td>1.00</td>
<td>0.65</td>
<td>-0.10</td>
<td>0.04</td>
<td>-0.10</td>
<td>0.13</td>
</tr>
<tr>
<td>N trades</td>
<td>0.03</td>
<td>0.65</td>
<td>1.00</td>
<td>-0.25</td>
<td>0.44</td>
<td>-0.11</td>
<td>0.15</td>
</tr>
<tr>
<td>Trading interval</td>
<td>-0.04</td>
<td>-0.10</td>
<td>-0.25</td>
<td>1.00</td>
<td>-0.21</td>
<td>0.31</td>
<td>-0.18</td>
</tr>
<tr>
<td>Amount issued</td>
<td>-0.01</td>
<td>0.04</td>
<td>0.44</td>
<td>-0.21</td>
<td>1.00</td>
<td>-0.04</td>
<td>0.12</td>
</tr>
<tr>
<td>Age</td>
<td>-0.15</td>
<td>-0.10</td>
<td>-0.11</td>
<td>0.31</td>
<td>-0.04</td>
<td>1.00</td>
<td>-0.57</td>
</tr>
<tr>
<td>Maturity</td>
<td>-0.14</td>
<td>0.13</td>
<td>0.15</td>
<td>-0.18</td>
<td>0.12</td>
<td>-0.57</td>
<td>1.00</td>
</tr>
</tbody>
</table>
## Appendix

### Liquidity: Pricing Results

**Table: Pricing of Catastrophe Market Risk (Liquidity)**

<table>
<thead>
<tr>
<th>Liquidity measure (LIQ)</th>
<th>Turnover</th>
<th>N trades</th>
<th>Trading interval</th>
<th>Amount issued</th>
<th>Age</th>
<th>Maturity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda_0$</td>
<td>1.44</td>
<td>1.47</td>
<td>1.45</td>
<td>1.62</td>
<td>1.61</td>
<td>1.32</td>
</tr>
<tr>
<td>(t-stat)</td>
<td>(9.45)</td>
<td>(9.41)</td>
<td>(9.12)</td>
<td>(8.70)</td>
<td>(9.67)</td>
<td>(5.88)</td>
</tr>
<tr>
<td>$\lambda_{cat}$</td>
<td>2.03</td>
<td>2.06</td>
<td>1.81</td>
<td>2.08</td>
<td>1.99</td>
<td>2.00</td>
</tr>
<tr>
<td>(t-stat)</td>
<td>(10.07)</td>
<td>(10.51)</td>
<td>(10.35)</td>
<td>(10.49)</td>
<td>(10.07)</td>
<td>(10.26)</td>
</tr>
<tr>
<td>$\lambda_{liq}$</td>
<td>-0.27</td>
<td>-0.04</td>
<td>-0.00</td>
<td>-0.00</td>
<td>-0.17</td>
<td>0.03</td>
</tr>
<tr>
<td>(t-stat)</td>
<td>(-2.30)</td>
<td>(-3.69)</td>
<td>(-0.99)</td>
<td>(-3.98)</td>
<td>(-3.18)</td>
<td>(0.54)</td>
</tr>
</tbody>
</table>

$N = 57$  
$R^2 = 0.54$

\[
E_t(R^e_{i,t+1}) = \lambda_{0,t} + \lambda_{cat,t}\hat{\beta}_{i,t} + \lambda_{liq,t}LIQ_{i,t} + \varepsilon_{i,t+1}
\]
## Results (Subsamples)

**Table: Pricing of Catastrophe Market Risk (Subsamples)**

<table>
<thead>
<tr>
<th></th>
<th>Main</th>
<th>Noncallables</th>
<th>Earthquake</th>
<th>Parametric</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda_{0,t}$</td>
<td>1.23</td>
<td>1.20</td>
<td>1.50</td>
<td>1.28</td>
</tr>
<tr>
<td>(t-stat)</td>
<td>(9.41)</td>
<td>(9.53)</td>
<td>(8.50)</td>
<td>(8.82)</td>
</tr>
<tr>
<td>$\lambda_{cat,t}$</td>
<td>2.06</td>
<td>2.11</td>
<td>1.98</td>
<td>1.94</td>
</tr>
<tr>
<td>(t-stat)</td>
<td>(11.67)</td>
<td>(11.56)</td>
<td>(6.52)</td>
<td>(7.62)</td>
</tr>
<tr>
<td>$\lambda_{cat,t} - E_{t} \left(R_{cat,t+1}^{e}\right)$</td>
<td>-1.10</td>
<td>-1.05</td>
<td>-1.18</td>
<td>-1.23</td>
</tr>
<tr>
<td>(t-stat)</td>
<td>(-9.02)</td>
<td>(-8.70)</td>
<td>(-3.94)</td>
<td>(-6.51)</td>
</tr>
<tr>
<td>$N$</td>
<td>63</td>
<td>63</td>
<td>63</td>
<td>63</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.49</td>
<td>0.51</td>
<td>0.43</td>
<td>0.49</td>
</tr>
</tbody>
</table>

\[
E_t(R_{i,t+1}^e) = \lambda_{0,t} + \lambda_{cat,t} \hat{\beta}_{i,t} + \varepsilon_{i,t+1}
\]
Past returns

- Insurance-linked Securities
- High-yield Corporate Bonds
- Stocks
Accounting for Peso Problem

- SDF: $M(x_{t+1}, z_{t+1})$
- Two bonds, $A$ and $B$:

  $$x_A \leq x_B, \quad e_A < e_B$$
Accounting for Peso Problem (cont’d)

Assumption 1: \( M(x_{t+1}, z_{t+1}) = M(z_{t+1}) \), \( x_{t+1} \geq x^* \)
(Small disasters are not priced)

Assumption 2: \( x_A \geq x^* \)
(Safe bond exhausts before ”severe disaster threshold” is hit)

Prediction:
\[ \Delta s_t = \Delta e_{lt} \]

Empirical specification:
\[ \Delta s_{i,j} = \lambda \Delta e_{i,j} + \varepsilon_{i,j} \]

H0: \( \lambda = 1 \)
Results
## Results (cont’d)

### Table: Price of non-extreme cat risk

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda$</td>
<td>1.46***</td>
<td>1.42***</td>
<td>1.48***</td>
<td>1.44***</td>
<td>1.44***</td>
<td>1.49**</td>
</tr>
<tr>
<td></td>
<td>(0.09)</td>
<td>(0.09)</td>
<td>(0.12)</td>
<td>(0.13)</td>
<td>(0.15)</td>
<td>(0.19)</td>
</tr>
<tr>
<td>$N$</td>
<td>151</td>
<td>125</td>
<td>92</td>
<td>57</td>
<td>45</td>
<td>34</td>
</tr>
<tr>
<td>$N$ Clusters</td>
<td>106</td>
<td>89</td>
<td>67</td>
<td>42</td>
<td>33</td>
<td>25</td>
</tr>
<tr>
<td>Largest Cluster (%)</td>
<td>2.65</td>
<td>3.20</td>
<td>4.35</td>
<td>7.02</td>
<td>8.89</td>
<td>11.76</td>
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<tr>
<td>$R^2$</td>
<td>0.82</td>
<td>0.84</td>
<td>0.85</td>
<td>0.86</td>
<td>0.86</td>
<td>0.87</td>
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<tr>
<td>Min($el_A$)</td>
<td>0.00</td>
<td>0.50</td>
<td>1.00</td>
<td>1.50</td>
<td>2.00</td>
<td>2.50</td>
</tr>
</tbody>
</table>

$$\Delta s_{i,j} = \lambda \Delta el_{i,j} + \varepsilon_{i,j}$$
Illustration of Assumptions

Bond Payoff $P(x)$

Priced Catastrophes

$x^*$

$X_A$

$X_B$

Bond A

Bond B
Barberis and Huang (2008) predicts that:

- Assets with negative skewness (not coskewness) have high excess returns
- One group of investors buy all assets, N groups of investors each short one asset

Explains aggregate premium and market structure

But: my beta measure is positively correlated with skewness (0.4)
Probability Weighting: Pricing Results

Table: Pricing of Catastrophe Market Risk (Skewness)

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda_0$</td>
<td>1.23</td>
<td>5.33</td>
<td>1.54</td>
</tr>
<tr>
<td>(t-stat)</td>
<td>(9.41)</td>
<td>(12.38)</td>
<td>(5.42)</td>
</tr>
<tr>
<td>$\lambda_{cat}$</td>
<td>2.06</td>
<td>2.03</td>
<td></td>
</tr>
<tr>
<td>(t-stat)</td>
<td>(11.67)</td>
<td>(10.73)</td>
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<td>$\lambda_{skew}$</td>
<td>0.20</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>(t-stat)</td>
<td>(7.76)</td>
<td>(1.80)</td>
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</tr>
<tr>
<td>$N$</td>
<td>63</td>
<td>63</td>
<td>63</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.49</td>
<td>0.19</td>
<td>0.52</td>
</tr>
</tbody>
</table>

$$E_t(R_{i,t+1}^e) = \lambda_{0,t} + \lambda_{cat,t}\hat{\beta}_{i,t} + \lambda_{skew,t}\text{Skew}_{i,t} + \varepsilon_{i,t+1}$$
## Market Power in Primary Markets

### Table: Catastrophe market risk and investor market power

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Mean</th>
<th>St Dev</th>
<th>Min</th>
<th>25%</th>
<th>50%</th>
<th>75%</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume/Size</td>
<td>148</td>
<td>1.00</td>
<td>0.01</td>
<td>0.96</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.05</td>
</tr>
<tr>
<td>N investors</td>
<td>148</td>
<td>26.48</td>
<td>14.69</td>
<td>1.00</td>
<td>17.75</td>
<td>22.00</td>
<td>30.25</td>
<td>81.00</td>
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<tr>
<td>Ownership HHI</td>
<td>148</td>
<td>0.14</td>
<td>0.10</td>
<td>0.03</td>
<td>0.09</td>
<td>0.12</td>
<td>0.17</td>
<td>1.00</td>
</tr>
</tbody>
</table>

### Panel B: Pricing of catastrophe market risk and market power

<p>| | | | | | | | | |</p>
<table>
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</tr>
</thead>
<tbody>
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<td>( \hat{\beta} )</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \hat{\lambda}_0 )</td>
<td>1.23***</td>
<td>2.17***</td>
<td>1.18***</td>
<td>0.90***</td>
<td>2.56***</td>
<td>0.87***</td>
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<td>(0.68)</td>
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<td>(0.23)</td>
<td>(0.35)</td>
<td>(0.27)</td>
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<tr>
<td>( \hat{\lambda}_{cat} )</td>
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<td>1.10***</td>
<td>1.39***</td>
<td>1.38***</td>
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<td>(0.16)</td>
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<tr>
<td>( \hat{\lambda}_{hhi} )</td>
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<td>0.56</td>
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<td></td>
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<td>(3.26)</td>
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<tr>
<td>( R^2 )</td>
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<td>0.56</td>
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<tr>
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