An Analysis of the Market Price of Cat Bonds

Neil Bodoff, FCAS and Yunbo Gan, PhD
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Agenda

- Brief introduction to cat bonds
- Description of problem
- Some current models of cat risk pricing
- Motivation for new model
- Proposed model
- Results
- Summary
- Caveats
- Areas for future research
Brief Intro to Cat Bonds

- (Re)insurance company wants to hedge its cat exposure
- Buys reinsurance from SPV
- SPV holds capital equal to the coverage limit ("fully collateralized")
- SPV raises this capital from investors by selling cat bonds
  - often in several layers or "tranches"
- Investors earn coupon rate on the contributed money
- Coupon rate usually defined as LIBOR + "spread" %
Description of Problem

- If the bonds had no exposure to cat loss, then coupon rate should equal LIBOR
- With cat exposure, coupon rate is LIBOR + spread
- Implies that “spread” is the “price of cat risk”
  - thus spread can be considered similar to the RoL of traditional reinsurance contracts
- Problem:
  - how can we describe the price of cat risk in the cat bond market?
  - how can we model the spreads on various cat bonds?
Current Models of Spreads

- Model #1
- Spread % = (expected loss %) x (multiple)
  - practitioner model
  - used to describe, predict, and benchmark various cat bond spreads
  - key parameter is the “multiple”
  - problem: multiple tends to vary
    - when expected loss is large, multiple is small
    - when expected loss is small, multiple is large
  - therefore the model is not complete for describing spreads
Current Models of Spreads

- Model #2
- Spread = function of (probability of loss, conditional severity)
- Example: Spread % = a * probability^b * conditional severity^c
- Suggested by Morton Lane, ASTIN Bulletin 2000
  - winner of CAS Hachemeister Prize, 2001
- Problems
  - no variation of parameters for different perils and/or correlation
  - Gatumel (ASTIN Colloquium, 2008) notes that not all of Lane’s parameters are statistically significant
Current Models of Spreads

- Model #3
  - Spread = function of expected loss and standard deviation
  - Example: spread % = expected loss % + alpha * standard deviation
  - Popular in the traditional reinsurance market
  - Often attributed to paper by Kreps
    - but Kreps explicitly states:
      - standalone standard deviation is only upper bound
    - true price depends on the risk within a portfolio, not standalone

- Other problems
  - reality: loading as a % of sd is not constant, so the sd loading itself tends to vary from low layers to high layers
    - need a “model” of a parameter of a model?
  - skewness matters (PCAS paper by Kozik and Larson)
  - violates Venter’s “no arbitrage” criterion
    - unhelpful when structuring, layering, and tranching
Current Models of Spreads

- Model #4
  - Spread = expected loss % + margin %
  - Used in the corporate bond market
    - “spread over risk free” = expected default loss + margin
      - “Credit Spread Puzzle”
        - market pricing: spreads are higher than needed to cover the expected default loss; why need margin?
        - puzzle even more pronounced for corporate bonds with higher expected default

- Problems
  - cat bond data not consistent with this model
  - rather, when cat bond expected loss increases, so does margin
  - conjecture: increase in expected loss leads to increase in margin because of uncertainty in the estimated expected loss
    - conversely, other explanations of the “credit spread puzzle”, such as correlation with equities, do not work well for cat bonds
Motivation for New Model

- Unlike existing models, we seek a model that
  - does not violate portfolio theory
    - riskiness must be measured within a portfolio, not standalone
  - is consistent with the empirical data
  - is practical and easy to explain to others
  - does not violate Venter’s principle (ASTIN, 1991) of “reinsurance without arbitrage”
    - use the pricing model to calculate the price of the cat cover (all layers combined)
    - then slice the cat cover into various layers ("tranches")
    - use the model to price the layers; add up the prices of the layers
    - does sum of the prices for the various layers equal the price of the total program in one large layer?
    - if not, the formula violates “no arbitrage"
Proposed Model

- Spread % depends upon the covered peril

- Spread % =
  
  peril specific flat margin %
  
  + expected loss % * peril specific loss multiplier

- For each peril, we have a linear function:
  
  - Spread % = constant % + loss multiplier * expected loss %
Data

- Years ending June 30, 1998 – 2008

- Example: “2008 Year” = July 1, 2007 through June 30, 2008

- Single peril bonds only
  - can use multi peril bonds as well
    - but need granular data about the various perils that contribute to the expected loss

- Perils classified based on broadly defined buckets
  - USA Wind
  - Europe Wind
  - California EQ
  - Japan EQ
  - etc.
Results: USA Wind

Parameters are statistically significant

<table>
<thead>
<tr>
<th>Peril</th>
<th>Zone</th>
<th>Years</th>
<th>Market Condition</th>
<th>Parameter Name</th>
<th>Parameter Value</th>
<th>Standard Error</th>
<th>Confidence Interval (95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>USA</td>
<td>All years</td>
<td>Full cycle</td>
<td>Constant %</td>
<td>3.33%</td>
<td>0.45%</td>
<td>2.38% - 4.27%</td>
</tr>
<tr>
<td>Wind</td>
<td>USA</td>
<td>All years</td>
<td>Full cycle</td>
<td>Loss Multiplier</td>
<td>2.40</td>
<td>0.17</td>
<td>2.05 - 2.76</td>
</tr>
</tbody>
</table>
Wind: USA vs. Europe

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<td>2.05</td>
<td>2.76</td>
</tr>
<tr>
<td>Wind</td>
<td>Europe</td>
<td>All years</td>
<td>Full cycle</td>
<td>Constant %</td>
<td>1.61%</td>
<td>0.33%</td>
<td>0.88%</td>
<td>2.33%</td>
</tr>
<tr>
<td>Wind</td>
<td>Europe</td>
<td>All years</td>
<td>Full cycle</td>
<td>Loss Multiplier</td>
<td>2.49</td>
<td>0.14</td>
<td>2.17</td>
<td>2.81</td>
</tr>
</tbody>
</table>

Intercept for Europe is lower than USA; slope is similar.
## Wind: All Years vs Hard Market

### Intercept for USA Wind using hard market data is higher than using all years; slope is similar.

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<td>2.76</td>
</tr>
<tr>
<td>Wind</td>
<td>USA</td>
<td>2006 - 2007</td>
<td>Hard Market</td>
<td>Constant %</td>
<td>4.28%</td>
<td>0.37%</td>
<td>3.47%</td>
<td>5.09%</td>
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<tr>
<td>Wind</td>
<td>USA</td>
<td>2006 - 2007</td>
<td>Hard Market</td>
<td>Loss Multiplier</td>
<td>2.33</td>
<td>0.12</td>
<td>2.07</td>
<td>2.58</td>
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</table>
## EQ: California vs Japan

<table>
<thead>
<tr>
<th>Peril</th>
<th>Zone</th>
<th>Years</th>
<th>Market Condition</th>
<th>Parameter Name</th>
<th>Parameter Value</th>
<th>Standard Error</th>
<th>Confidence Interval (95%)</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Earthquake</td>
<td>California</td>
<td>All years</td>
<td>Full cycle</td>
<td>Constant %</td>
<td>3.78%</td>
<td>0.29%</td>
<td>3.19% to 4.36%</td>
<td></td>
</tr>
<tr>
<td>Earthquake</td>
<td>California</td>
<td>All years</td>
<td>Full cycle</td>
<td>Loss Multiplier</td>
<td>1.48</td>
<td>0.16</td>
<td>1.16 to 1.79</td>
<td></td>
</tr>
<tr>
<td>Earthquake</td>
<td>Japan</td>
<td>All years</td>
<td>Full cycle</td>
<td>Constant %</td>
<td>2.28%</td>
<td>0.20%</td>
<td>1.85% to 2.70%</td>
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</tr>
<tr>
<td>Earthquake</td>
<td>Japan</td>
<td>All years</td>
<td>Full cycle</td>
<td>Loss Multiplier</td>
<td>1.85</td>
<td>0.12</td>
<td>1.60 to 2.10</td>
<td></td>
</tr>
</tbody>
</table>

Intercept for Japan EQ is lower than California; slope for Japan EQ is somewhat higher.
**EQ: All Years vs Hard Market**

Intercept for California EQ is higher using hard market data; slope is higher as well.
Tables of Fitted Parameters

<table>
<thead>
<tr>
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<td>Full Cycle</td>
<td>Constant %</td>
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<td>0.20%</td>
<td>1.85%</td>
<td>2.70%</td>
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</tbody>
</table>

Intercept is similar based on whether exposure is “peak” (USA Wind, California EQ) or “non-peak” (Europe Wind, Japan EQ).

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</tr>
<tr>
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<td>Japan</td>
<td>All Years</td>
<td>Full Cycle</td>
<td>Loss Multiplier</td>
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<td>0.12</td>
<td>1.60</td>
<td>2.10</td>
</tr>
</tbody>
</table>

Slope is similar based on whether physical peril is Wind or EQ, but not based on “peak” versus “non-peak”.


Enhancing Parsimony

- Currently we have used 8 parameters
  - 4 equations with 2 parameters each

- Similarity of some parameters suggests opportunity for enhancing parsimony

- Create “combined multiperil model”
Combined Multiperil Model

Spread % =

\[\text{constant}_{\text{All}} \ % + \text{constant}_{\text{Peak}} \ % \times \text{peak peril indicator variable} + \text{loss multiplier}_{\text{EQ}} \times \text{expected loss}_{\text{EQ}} \ % + \text{loss multiplier}_{\text{Wind}} \times \text{expected loss}_{\text{Wind}} \ %\]
**Multiperil Model Results**

Using Data from All Years

<table>
<thead>
<tr>
<th>Peril</th>
<th>Zone</th>
<th>Years</th>
<th>Condition</th>
<th># of Observations</th>
<th>Market Condition</th>
<th>Parameter Name</th>
<th>Value</th>
<th>Standard Error</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple</td>
<td>Multiple</td>
<td>All years</td>
<td>Full cycle</td>
<td>93</td>
<td>87.3%</td>
<td>86.9%</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</table>

All parameters are significant

Healthy R Square
## Multiperil Model Results

**Using Data from Hard Market 2006 - 2007**

<table>
<thead>
<tr>
<th>Peril Zone</th>
<th>Years</th>
<th>Market Condition</th>
<th># of Observations</th>
<th>Adjusted R Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple</td>
<td>Multiple</td>
<td>2006 - 2007</td>
<td>Hard Market</td>
<td>32</td>
</tr>
</tbody>
</table>

More homogenous data, higher R Square

<table>
<thead>
<tr>
<th>Peril Zone</th>
<th>Years</th>
<th>Market Condition</th>
<th>Parameter Name</th>
<th>Parameter Value</th>
<th>Standard Error</th>
<th>Confidence Interval (95%)</th>
<th>Confidence Interval (95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple</td>
<td>Multiple</td>
<td>2006 - 2007</td>
<td>Hard Market</td>
<td>ConstantAll %</td>
<td>2.07%</td>
<td>0.41%</td>
<td>1.23%</td>
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<tr>
<td>Multiple</td>
<td>Multiple</td>
<td>2006 - 2007</td>
<td>Hard Market</td>
<td>Additional ConstantPeak %</td>
<td>2.30%</td>
<td>0.38%</td>
<td>1.51%</td>
</tr>
<tr>
<td>Multiple</td>
<td>Multiple</td>
<td>2006 - 2007</td>
<td>Hard Market</td>
<td>Loss MultiplierEQ</td>
<td>1.94</td>
<td>0.14</td>
<td>1.65</td>
</tr>
<tr>
<td>Multiple</td>
<td>Multiple</td>
<td>2006 - 2007</td>
<td>Hard Market</td>
<td>Loss MultiplierWind</td>
<td>2.34</td>
<td>0.09</td>
<td>2.15</td>
</tr>
</tbody>
</table>

All parameters are significant
Extending to Other Perils

- What about other perils such as Australia EQ, Mexico EQ, Japan Wind, Mediterranean EQ, etc.?

- Extend the “multiperil” combined model to an “all peril combined model”

- Assign perils to 3 buckets
  - Peak: USA Wind, California EQ
  - Non-peak (but major): Europe Wind, Japan EQ
  - Diversifying: Australia EQ, Mexico EQ, etc.
All Perils Model

Spread % =

constant_{All} %

+ constant_{Peak} % * peak peril indicator variable

+ constant_{Diversifying} % * diversifying peril indicator variable

+ loss multiplier_{EQ} * expected loss_{EQ} %

+ loss multiplier_{Wind} * expected loss_{Wind} %
All Perils Model Results

Using Data from All Years

<table>
<thead>
<tr>
<th>Peril Zone</th>
<th>Years</th>
<th>Market Condition</th>
<th># of Observations</th>
<th>Adjusted R Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>All</td>
<td>All years</td>
<td>Full cycle</td>
<td>115</td>
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</table>

Healthy R Square

<table>
<thead>
<tr>
<th>Peril Zone</th>
<th>Years</th>
<th>Market Condition</th>
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<th>Confidence Interval (95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>All</td>
<td>All Years</td>
<td>ConstantAll %</td>
<td>2.35%</td>
<td>0.25%</td>
<td>1.85% 2.85%</td>
</tr>
<tr>
<td>All</td>
<td>All</td>
<td>All Years</td>
<td>Additional ConstantPeak %</td>
<td>1.28%</td>
<td>0.27%</td>
<td>0.76% 1.81%</td>
</tr>
<tr>
<td>All</td>
<td>All</td>
<td>All Years</td>
<td>Additional ConstantDiversifying %</td>
<td>-1.09%</td>
<td>0.35%</td>
<td>-1.79% -0.39%</td>
</tr>
<tr>
<td>All</td>
<td>All</td>
<td>All Years</td>
<td>Loss MultiplierEQ</td>
<td>1.60</td>
<td>0.10</td>
<td>1.40 1.81</td>
</tr>
<tr>
<td>All</td>
<td>All</td>
<td>All Years</td>
<td>Loss MultiplierWind</td>
<td>2.29</td>
<td>0.10</td>
<td>2.10 2.48</td>
</tr>
</tbody>
</table>

All parameters are significant

Diversifying Perils’ intercept equals “constantAll %” plus the additional amount of “constantDiversifying %”, which is negative.

Thus Diversifying Perils have a lower intercept than other perils.
## All Perils Model Results

Using Data from Hard Market 2006 - 2007

<table>
<thead>
<tr>
<th>Peril Zone</th>
<th>Years</th>
<th>Market Condition</th>
<th># of Observations</th>
<th>R Square</th>
<th>Adjusted R Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>All</td>
<td>2006 - 2007 Hard Market</td>
<td>43</td>
<td>95.5%</td>
<td>95.1%</td>
</tr>
</tbody>
</table>

### Parameter Results

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</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>All</td>
<td>2006 - 2007 Hard Market</td>
<td>Constant&lt;sub&gt;all&lt;/sub&gt; %</td>
<td>2.20%</td>
<td>0.40%</td>
<td>1.38%</td>
<td>3.02%</td>
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<tr>
<td>All</td>
<td>All</td>
<td>2006 - 2007 Hard Market</td>
<td>Additional Constant&lt;sub&gt;peak&lt;/sub&gt; %</td>
<td>2.31%</td>
<td>0.38%</td>
<td>1.54%</td>
<td>3.08%</td>
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<tr>
<td>All</td>
<td>All</td>
<td>2006 - 2007 Hard Market</td>
<td>Additional Constant&lt;sub&gt;diversifying&lt;/sub&gt; %</td>
<td>-1.66%</td>
<td>0.45%</td>
<td>-2.56%</td>
<td>-0.76%</td>
</tr>
<tr>
<td>All</td>
<td>All</td>
<td>2006 - 2007 Hard Market</td>
<td>Loss Multiplier&lt;sub&gt;EQ&lt;/sub&gt;</td>
<td>1.87</td>
<td>0.13</td>
<td>1.60</td>
<td>2.14</td>
</tr>
<tr>
<td>All</td>
<td>All</td>
<td>2006 - 2007 Hard Market</td>
<td>Loss Multiplier&lt;sub&gt;Wind&lt;/sub&gt;</td>
<td>2.31</td>
<td>0.09</td>
<td>2.12</td>
<td>2.50</td>
</tr>
</tbody>
</table>

All parameters are significant

Healthy R Square
**All Years vs Hard Market**

<table>
<thead>
<tr>
<th>Peril</th>
<th>Zone</th>
<th>Years</th>
<th>Market Condition</th>
<th>Parameter Name</th>
<th>Parameter Value</th>
<th>Standard Error</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
<th>Confidence Interval (95%)</th>
<th>Confidence Interval (95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>All</td>
<td>All Years</td>
<td>Full Cycle</td>
<td>Constant_{All} %</td>
<td>2.35%</td>
<td>0.25%</td>
<td>1.85%</td>
<td>2.85%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>All</td>
<td>All Years</td>
<td>Full Cycle</td>
<td>Additional Constant_{Peak} %</td>
<td>1.28%</td>
<td>0.27%</td>
<td>0.76%</td>
<td>1.81%</td>
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<td></td>
</tr>
<tr>
<td>All</td>
<td>All</td>
<td>All Years</td>
<td>Full Cycle</td>
<td>Additional Constant_{Diversifying} %</td>
<td>-1.09%</td>
<td>0.35%</td>
<td>-1.79%</td>
<td>-0.39%</td>
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<td></td>
</tr>
<tr>
<td>All</td>
<td>All</td>
<td>All Years</td>
<td>Full Cycle</td>
<td>Loss Multiplier_{E/Q}</td>
<td>1.60</td>
<td>0.10</td>
<td>1.40</td>
<td>1.81</td>
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<td></td>
</tr>
<tr>
<td>All</td>
<td>All</td>
<td>All Years</td>
<td>Full Cycle</td>
<td>Loss Multiplier_{Wind}</td>
<td>2.29</td>
<td>0.10</td>
<td>2.10</td>
<td>2.48</td>
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</tbody>
</table>

These parameters increased in absolute magnitude during the hard market (additional constant for diversifying perils became even more negative)

These parameters did **not** change much during the hard market
Summary

- A linear model with peril-specific parameters:
  - compactly describes an array of data points
  - fits the historical data well
  - is straightforward to explain
  - aligns with portfolio theory
  - reflects tail downside risk
  - satisfies Venter’s “no arbitrage” criterion
  - will produce the same overall price for a reinsurance tower no matter how you split into “layers” or “tranches”
  - illuminates the “credit spread puzzle”
  - measures how risk aversion waxes and wanes across the cycle
Caveats

- Limited data points / small sample size
- Did not perform “out of sample” testing
- Only used spread data for bonds “when issued”
- Only used data for single peril bonds
- Slotting bonds into “buckets” of perils is somewhat arbitrary
- Only used standard regression and error structure
Areas for Future Research

- Expand choices of linear model and error structure (generalize the linear model)

- Include multiperil bonds in the analysis
  - do multiperil bonds suffer price penalty?
  - which choice is preferable: sponsoring one bond covering multiple perils versus sponsoring multiple bonds, each covering one peril?

- Time series model of the parameters of the linear model
  - Additional constant_{peak} % (time t+1) = function {Additional constant_{peak} % (time t), actual cat loss (time t), etc.}?

- Would similar linear model work for describing the market price of traditional reinsurance contracts?
  - need to handle reinstatement of limit and reinstatement of premium
  - how would parameters for traditional reinsurance compare / contrast to parameters for cat bonds?
  - would the different parameters highlight that certain exposures are more efficiently handled via reinsurance versus cat bonds and vice versa?
    - implications for optimizing capital structure
References

Questions?

Send email to:

neil.bodoff@willis.com and yunbo.gan@willis.com