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Actuarial Implication of Structural Changes in El Niño-Southern Oscillation Index Dynamics

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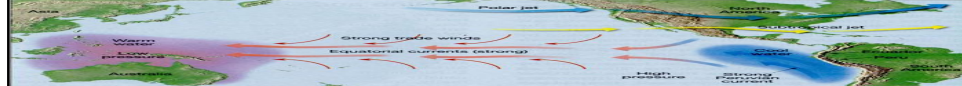


國立清華大學
National Tsing Hua University

Actuarial Implications of Structural Changes in El Niño-Southern Oscillation Index Dynamics

Shu-Ling Chen, Department of Quantitative Finance, National Tsing Hua University

What is El Niño?



Normal - the trade winds and strong equatorial currents flow toward the west. Meanwhile, an intense Peruvian current causes upwelling of cold water in east Pacific, keeping coastal Peru coast relatively cool and dry

El Niño - High pressure system develops over west Pacific, relaxes trade winds, reduces upwelling of cold water and raises water temperatures in east Pacific, causes above normal rainfall in coastal Peru

El Niño to Blame?



Impacts of El Niño on Peru	Research Questions	Objectives
<ul style="list-style-type: none"> Catastrophic rain and floods are most important catastrophic risks endured in Piura, Peru's richest agricultural region associated with major El Niños caused by high sea-surface temperature anomalies During severe Niño, rains increase in intensity, duration, and geographic scope - rainfall can reach levels more than 40 times normal Designed to manage catastrophic weather risks that impact agricultural credit in Peru's richest agricultural region, Piura Contract that indemnifies when sea-surface temperatures are high would allow agricultural banks in Peru to transfer El Niño risk to reinsurers 	<ul style="list-style-type: none"> Is El Niño changing? Premium rates on contracts depend on the dynamics of El Niño-Southern Oscillation Index El Niño is a consequence of human-induced global warming, implying that El Niño events may become "more intense" over the coming century El Niño is just an expression of natural or decadal-scale climate variability 	<ul style="list-style-type: none"> Test whether El Niños have become more frequent and severe since the 1970s Explore statistical time series models that can be readily used for actuarial rating of proposed catastrophic El Niño insurance contract for Peru

Design an El Niño-Southern Oscillation Index Insurance for Floods

Step 1: Choosing an Index	Step 2: Modelling El Niño index	Step 3: Modelling El Niño index	Step 4: Rating El Niño Index Insurance																																																																																																																											
<ul style="list-style-type: none"> Choose an index which is highly correlated with economic losses due to catastrophic floods evaluated via Quantile regression among four Niño index regions, El Niño 1+2 index, just off coast of Peru, is the most highly correlated with CORPAC Piura precipitation <p>Monthly El Niño 1+2 index with 5 breaks, 1856:01-2010:0</p>	<ul style="list-style-type: none"> Is El Niño Changing Testing for structural changes using Bai and Perron approach estimates number and date of shifts in the data generating process within a linear model allows for serial correlation and heteroskedasticity in the errors across time periods estimates suggest structural breaks at 1978:04, consistent with climatic literature if k=5 <table border="1"> <caption>Multiple structural break tests and estimated break dates</caption> <thead> <tr> <th>Break</th> <th>Year</th> <th>Month</th> <th>Day</th> <th>Statistic</th> <th>p-value</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>1978</td> <td>04</td> <td>01</td> <td>1.23</td> <td>0.000</td> </tr> <tr> <td>2</td> <td>1982</td> <td>01</td> <td>01</td> <td>1.40</td> <td>0.000</td> </tr> <tr> <td>3</td> <td>1982</td> <td>01</td> <td>01</td> <td>1.72</td> <td>0.000</td> </tr> <tr> <td>4</td> <td>1982</td> <td>01</td> <td>01</td> <td>1.94</td> <td>0.000</td> </tr> <tr> <td>5</td> <td>1982</td> <td>01</td> <td>01</td> <td>1.99</td> <td>0.000</td> </tr> </tbody> </table>	Break	Year	Month	Day	Statistic	p-value	1	1978	04	01	1.23	0.000	2	1982	01	01	1.40	0.000	3	1982	01	01	1.72	0.000	4	1982	01	01	1.94	0.000	5	1982	01	01	1.99	0.000	<ul style="list-style-type: none"> Statistical Models Conditional variance of El Niño 1+2 index has increased over time Conditional variance of El Niño 1+2 index is persistent, following integrated or long memory process? <ul style="list-style-type: none"> GARCH-family models, including AR-GARCH and AR-FIGARCH, and linear AR model are estimated via robust quasi maximum likelihood estimation method In-sample fit via AIC & SIC: 1856:01-2008:10 AR-GARCH and AR-FIGARCH models that allow variance to vary over time outperform linear AR model Out-of-sample forecast via Mean Absolute Error: 2008:11-2010:01 <table border="1"> <caption>Out-of-sample forecast via Mean Absolute Error: 2008:11-2010:01</caption> <thead> <tr> <th>Horizon</th> <th>AR(2)</th> <th>AR(2)-GARCH(1,1)</th> <th>AR(2)-FIGARCH(1,1)</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>0.126</td> <td>0.122</td> <td>0.122</td> </tr> <tr> <td>2</td> <td>0.230</td> <td>0.221</td> <td>0.222</td> </tr> <tr> <td>3</td> <td>0.402</td> <td>0.394</td> <td>0.392</td> </tr> <tr> <td>4</td> <td>0.442</td> <td>0.395</td> <td>0.392</td> </tr> <tr> <td>5</td> <td>0.466</td> <td>0.375</td> <td>0.373</td> </tr> <tr> <td>10</td> <td>0.589</td> <td>0.297</td> <td>0.290</td> </tr> <tr> <td>15-15</td> <td>0.589</td> <td>0.297</td> <td>0.290</td> </tr> </tbody> </table>	Horizon	AR(2)	AR(2)-GARCH(1,1)	AR(2)-FIGARCH(1,1)	1	0.126	0.122	0.122	2	0.230	0.221	0.222	3	0.402	0.394	0.392	4	0.442	0.395	0.392	5	0.466	0.375	0.373	10	0.589	0.297	0.290	15-15	0.589	0.297	0.290	<ul style="list-style-type: none"> The design of the contract is based on proportional indemnity schedules For a given value of El Niño 1+2 index, the expected indemnity that would be paid per unit of coverage is $\text{Expected Indemnity} = \begin{cases} 0 & \text{if } index < trigger \\ \frac{index - trigger}{loss - trigger} & \text{if } index > trigger \end{cases}$ <ul style="list-style-type: none"> Given OMLE parameters from the model, Monte Carlo simulation method is applied to generate the data and thus compute fair premium rates the computed premium rates are highest for the AR(2)-GARCH(1,1) model and least for the linear AR(2) <table border="1"> <caption>Expected Indemnity</caption> <thead> <tr> <th>Trigger</th> <th>Step</th> <th>AR(2)</th> <th>AR(2)-GARCH(1,1)</th> <th>AR(2)-FIGARCH(1,1)</th> </tr> </thead> <tbody> <tr> <td>2.0</td> <td>2.5</td> <td>0.069</td> <td>0.043</td> <td>0.043</td> </tr> <tr> <td>2.0</td> <td>3.0</td> <td>0.099</td> <td>0.079</td> <td>0.079</td> </tr> <tr> <td>2.0</td> <td>3.5</td> <td>0.042</td> <td>0.042</td> <td>0.046</td> </tr> <tr> <td>2.0</td> <td>4.0</td> <td>0.022</td> <td>0.036</td> <td>0.048</td> </tr> <tr> <td>2.5</td> <td>3.0</td> <td>0.029</td> <td>0.095</td> <td>0.212</td> </tr> <tr> <td>2.5</td> <td>3.5</td> <td>0.013</td> <td>0.221</td> <td>0.181</td> </tr> <tr> <td>2.5</td> <td>4.0</td> <td>0.013</td> <td>0.290</td> <td>0.099</td> </tr> <tr> <td>3.0</td> <td>3.0</td> <td>0.002</td> <td>0.248</td> <td>0.051</td> </tr> <tr> <td>3.0</td> <td>3.5</td> <td>0.000</td> <td>0.191</td> <td>0.081</td> </tr> <tr> <td>3.0</td> <td>4.0</td> <td>0.002</td> <td>0.118</td> <td>0.035</td> </tr> </tbody> </table>	Trigger	Step	AR(2)	AR(2)-GARCH(1,1)	AR(2)-FIGARCH(1,1)	2.0	2.5	0.069	0.043	0.043	2.0	3.0	0.099	0.079	0.079	2.0	3.5	0.042	0.042	0.046	2.0	4.0	0.022	0.036	0.048	2.5	3.0	0.029	0.095	0.212	2.5	3.5	0.013	0.221	0.181	2.5	4.0	0.013	0.290	0.099	3.0	3.0	0.002	0.248	0.051	3.0	3.5	0.000	0.191	0.081	3.0	4.0	0.002	0.118	0.035
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Summary and Conclusion

- Support the actuarial analysis of a proposed El Niño-Southern Oscillation Index insurance for Peru
- Is El Niño events becoming more volatile since the mid 1970s?
- The results of multiple structural changes test proposed by Bai and Perron (1998, 2003) implies standard deviation of El Niño 1+2 index are changing over time
- Three statistical time-series model of El Niño 1+2 index are examined and compared through in-sample fits and out-of-sample forecasts
- For in-sample fits, AR-GARCH and AR-FIGARCH models that allow disturbance variance to vary over time outperform linear AR model
- At short forecast horizons, out-of-sample forecasts from the linear AR(2) model are superior than AR(2)-GARCH(1,1) model and AR(2)-FIGARCH(1,1) model
- As the forecast horizon increases, AR(2)-GARCH(1,1) model and AR(2)-FIGARCH(1,1) model outperform the linear AR(2)
- The premium rate estimates based on such time-invariant econometric model could be too low and the insurer would therefore expose to undesired underwriting risk and ultimately the index insurance market would collapse