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

Shu-Ling Chen
Assistant Professor
Department of Quantitative Finance
National Tsing Hua University
101, Sec. 2, Kuang-Fu Road, Hsinchu 30013, Taiwan
Email: slchen@mx.nthu.edu.tw

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國立清華大學
National Tsing Hua University

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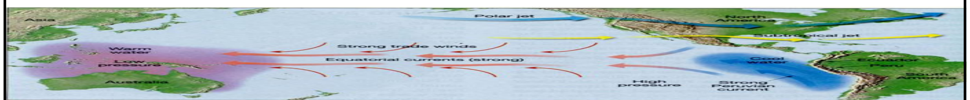
What is El Niño?



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

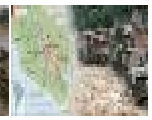
El Niño to Blame?


El Niño vs. wildfire


El Niño effect


a small El Niño effect


Flood - El Niño threats


Peru's flood hit


December 1997 El Niño


El Niño hits Peru

Impacts of El Niño on Peru

- 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

Research Questions

- 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 of decadal-scale climate variability

Objectives

- 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

- 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


Scatter plot of CORPAC Piura precipitation and El Niño 1+2 index, 1957:01-2004:04


Monthly El Niño 1+2 index with 5 breaks, 1856:01-2010:0

Step 2: Modelling El Niño index

- 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 1976:04, consistent with climatic literature if ***k***=5

Multiple structural break tests and estimated break dates

Test for multiple structural breaks

A test of no break versus some fixed number of breaks

$\sup F_T(1)$	$\sup F_T(2)$	$\sup F_T(3)$	$\sup F_T(4)$	$\sup F_T(5)$
2.22	1.40	1.72	1.34	1.09

A sequential test

$\sup F_T(2 \mid 1)$	$\sup F_T(3 \mid 2)$	$\sup F_T(4 \mid 3)$	$\sup F_T(5 \mid 4)$
0.23	2.14	0.01	0.01

Number of breaks chosen

Sequential procedure	0

The dates of the breaks for $k = 5$

1881:12	1906:01	1929:02	1952:03	1976:03

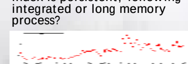
Summary statistics of El Niño 1+2 index

Time Period	Mean	Std. Dev.	Maximum	Minimum	Skewness	Kurtosis
1856:01 – 2010:01	0.07	0.97	4.49	-2.54	0.69	1.12
Subsample Time Period						
1856:01 – 1881:12	0.45	0.85	2.84	-1.16	0.53	-0.17
1882:01 – 1906:01	0.37	0.81	2.36	-1.12	0.25	-0.78
1906:02 – 1929:02	-0.09	0.92	2.38	-2.26	0.48	-0.42
1929:03 – 1952:03	0.06	0.73	2.42	-1.95	0.25	0.48
1952:04 – 1976:03	-0.41	0.96	2.45	-2.54	0.61	0.03
1976:04 – 2010:01	0.02	1.15	4.49	-2.16	1.47	2.94

Step 3: Modelling El Niño index

- 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?


Estimated conditional variance of AR(2)-GARCH(1,1) model

- 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

Forecast Horizon	AR(2)	AR(2)-GARCH(1, 1)	AR(2)-FIGARCH(1, *d*, 1)
1	0.094	0.120	0.121
3	0.126	0.132	0.132
6	0.220	0.223	0.222
9	0.402	0.394	0.392
12	0.415	0.395	0.392
15	0.406	0.375	0.371
13 - 15	0.369	0.297	0.290

Step 4: Rating El Niño Index Insurance

- 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

  Expected indemnity =

$$E\left[\min\left(1, \max\left(0, \frac{index - trigger}{loss - trigger}\right)\right)\right]$$

- Given QMLE 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)

Trigger	Stop Loss	AR(2)	AR(2)-GARCH(1,1)	AR(2)-FIGARCH(1,*d*,1)
2.0	2.5	0.089	0.563	0.455
2.0	3.0	0.059	0.479	0.334
2.0	3.5	0.042	0.402	0.246
2.0	4.0	0.032	0.336	0.188
2.5	3.0	0.029	0.395	0.212
2.5	3.5	0.018	0.321	0.141
2.5	4.0	0.013	0.260	0.099
3.0	3.5	0.007	0.248	0.071
3.0	4.0	0.005	0.193	0.043
3.5	4.0	0.002	0.138	0.015

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, ***d***, 1) model
  - As the forecast horizon increases, AR(2)-GARCH(1, 1) model and AR(2)-FIGARCH(1, ***d***, 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

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