# STATSTICAL ANALYSIS OF THE SPREADS OF CATASTROPHE BONDS AT THE TIME OF ISSUE

By

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## ABSTRACT

In this paper the catastrophe bond prices, as determined by the market, are analysed. The limited published work in this area has been carried out mainly by cat bond investors and is based either on intuition, or on simple linear regression on one factor or on comparisons of the prices of cat bonds with similar features. In this paper a Generalised Additive Model is fitted to the market data. The statistical significance of different factors which may affect the cat bond prices is examined and the effect of these factors on the prices is measured. A statistical framework and analysis could provide insight into the cat bond pricing and could have applications among other things in the construction of a cat bond portfolio, cat bond price indices and in understanding changes of the price of risk over time.

## KEYWORDS

Catastrophe Bonds; Bond Pricing; Regression; Generalised Additive Models

## 1. INTRODUCTION

The recent increase in catastrophe (cat) bond issues has also created an interest in understanding how these instruments are priced. The purpose of this paper is to examine the factors that affect cat bond prices and measure the effect of these factors on the bond prices using statistical models.

This paper does not try to estimate what the price of a cat bond should be. This is a different subject and the answer to it depends, among other things, on the requirements, the restrictions and generally the risk appetite of the investors. Several theoretical aspects of cat bond pricing are covered in Cox, S. & Pedersen, H. (1997), in Schmock, U. (1999) and in Tilley, J.A. (1997). In this paper the bond prices are considered to be a given input determined by the market. Also this paper does not examine the fluctuations of the prices of the traded cat bonds. It analyses the prices at the time of the issue of the bond.

Some of the results in this article are known to practitioners. For example the fact that bonds which cover US natural perils have required a higher return than similar bonds which cover, for example, Mediterranean earthquake is common knowledge. However, a statistical analysis confirms this belief, estimates the difference in the reward that these two different perils require, and also enables us to separate the effect on the price of the covered perils from the effect of other features of the cat bond.

Usually there is not a single best statistical model. Different models can be used, giving different results. These models could provide a better insight in the way the market prices insurance risk. It could also provide a framework for analysing and monitoring the price movements of cat bonds as well as the changes in the perception of risk over time.

The model presented in the paper has been based on historical information. Therefore it should be used with care when estimating current or future prices of cat bonds. Despite the growth over the last two years the market is still small compared to that of bonds for other asset classes. The relatively limited amount of data introduces some uncertainty in our estimates.

The analysis showed that the principal factors driving the price of cat bonds are:

- *Expected loss* which also reflects to some extent the volatility of loss
- *Perils and territories covered* mainly reflecting the correlation with the investors' portfolio
- *Reinsurance cycle* reflecting loss experience, changes of perception of risk over time and availability of capital
- *Type of Trigger* mainly reflecting the amount of basis risk

## 2. MAIN FEATURES OF CAT BONDS

The workings of cat bonds have been described in detail in other papers, for example Doherty, N.A. (1997), Tilley J.A. (1997), Walker, S. et al (1999) and James, G. et al (2008). In this section only some of the main features of cat bonds are briefly mentioned. These are the features which were examined as explanatory variables in the statistical model.

A risk taker, often called the sponsor, issues a cat bond to one or more investors and the nominal amount of the bond is placed in a Special Purpose Vehicle. The investors receive regular payments, usually quarterly, called the coupon. If a certain insured event happens then the investor loses part or all of his capital and consequently part or all of his remaining coupons. The issuer of the bond receives part or all of the money in the SPV to mitigate his loss from the insured event.

Each cat bond has a term which is typically less than five years and on average a little less than three years. The term can usually be extended if there is uncertainty in the determination of the loss.

The size of the bonds has varied from a few million dollars to a few hundred million dollars. In recent years "shelf programs" have become common. Under this arrangement, only part of the full nominal amount is issued initially and later the issuer has the option to issue more capital if it is necessary. This has the advantage of savings in administration costs and ease of issuance of capital when it is needed.

Usually an independent natural hazards modelling agency carries out an analysis of the risk and provides details of the results including statistical summaries of the loss distribution. Very few cat bonds have had an annualised expected loss of more than 5%.

A cat bond may cover a variety of perils and territories such as US Hurricane, US Earthquake, European Wind, Japanese Earthquake, Mediterranean Earthquake, etc. Some cat bonds cover multiple territories and perils. In this case almost all of them have included US hurricane.

An event (an earthquake, hurricane or similar) can trigger the non payment of the coupon and or loss of capital of a cat bond. The type of trigger may be on an indemnity, modelled loss, industry index, or parametric basis or a combination of those.
*Indemnity*: The bond triggers a loss to investors if the losses to the sponsors' covered portfolio exceed a predetermined value. This works in a similar way to a reinsurance contract.
*Modelled Loss*: Under these bonds a notional portfolio of policies is used to determine the loss. The portfolio is selected in such a way to best reflect the expected portfolio of the sponsor.
*Parametric Index*: These bonds determine any losses to investors by creating an index based on the actual catastrophic natural hazard magnitude at different locations with each location carrying its own weight in the index. The weights are set at the start of the deal to best reflect the expected exposure of the portfolio of the sponsor
*Industry Loss*: An Industry Loss Index determines the loss in this case. Typically this form of trigger is used for US perils and is based on the Property Claims Services (PCS) index.

The state of the market, the perception of risk and the availability of capital varies over time. The market cycle of the cat bonds seem to closely follow the cycle of the (re)insurance markets.

## 3. DATA

Cat bonds issued between January 2003 and July 2008 were examined. The premiums for the early cat bonds issued before 2003 may have been influenced by some 'novelty effect'.

The following table shows the number of bonds by territory/peril and type of trigger in the data

| | indemnity | Industry Index Modelled Loss | parametric | Total |
|---|---|---|---|---|
| **US Hurricane only** | 5 | 28 | 7 | 40 |
| **Multi-peril including US Hurricane** | 26 | 23 | 19 | 68 |
| **US Earthquake** | | 16 | 18 | 34 |
| **Japanese Earthquake** | | | 10 | 10 |
| **European Storm, Japanese Typhoon, other** | 5 | 3 | 24 | 32 |
| **Non-Peak Territories** | | 1 | 7 | 8 |
| **Total** | 36 | 71 | 85 | 192 |

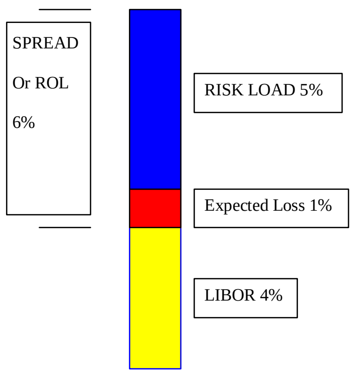
TABLE 1. Number of cat bonds in the data by trigger and peril/territory

Although almost all the bonds issued in the market are included in the data, there are cells in the above table which are empty. There are also correlations in the data which may make a statistical model unstable. For example most of the indemnity cat bonds cover US perils and most of the non peak territories bonds have a parametric trigger.

## 4. SOME INITIAL CONSIDERATIONS FOR THE STATISTICAL MODEL

The price of a cat bond especially for those exposed to weather perils is influenced by the annual variation (seasonality) in the risk and by other events such as the formation of a hurricane in the Atlantic. Prices at the date of issue of a cat bond were examined which are usually influenced to a lesser extent by this seasonality of risk. There are different ways of looking at the pricing of a cat bond. One of the most common ways is to look at the expected annual loss and the coupon payments to the investors. In most cases a cat bond pays a benchmark rate usually based on LIBOR or EURIBOR and on top of that an excess return for the risks taken by the investor. It is this excess return, which is comparable with the Rate on Line (ROL) paid for a similar reinsurance transaction, and the factors affecting it that we are interested in. This excess return is usually referred to as the spread.

The excess return is higher than the estimated expected loss and the difference (spread – expected loss) rewards the investors for the risk they take. We call the quantity (spread – expected loss) the risk load




Multiple = 6%/1%=6

FIGURE 1. Definitions and Numerical Example

### *4.1 Choice of Dependent Variable*

One of the first considerations was choosing an appropriate dependent variable. Practitioners often use the ratio of spread/expected loss which is usually called multiple. It shows how many times the premium covers the expected loss. However, ratios may behave erratically and multiples were not the preferred choice.

An alternative dependent variable is the spread. However, the analysis showed that one of the main factors affecting the price of a cat bond is the expected loss. The spread includes the expected loss and the use of a dependent variable which includes one of the independent variables is often avoided.

The final choice for the dependent variable was the risk load.

***4.2 Form of the Model***

There does not seem to be a clear intuitive answer as to whether the effect of the different factors affecting cat bonds will be additive or multiplicative. An additive model could potentially give negative values for the risk load which does not make sense. Actually the fitted additive model, although overall it provides a good fit to the data, it does give negative values of risk load for some types of cat bond with very low expected loss. Experiments with both types of model gave reasonably good fits to the data, but the preferred model was in the end a multiplicative one.

One thing that quickly became obvious was that the risk load depends on the annualised expected loss. Generally, the higher the annualised expected loss is, the higher the risk load. The following graph shows the risk load against the expected loss for the cat bonds we examined:

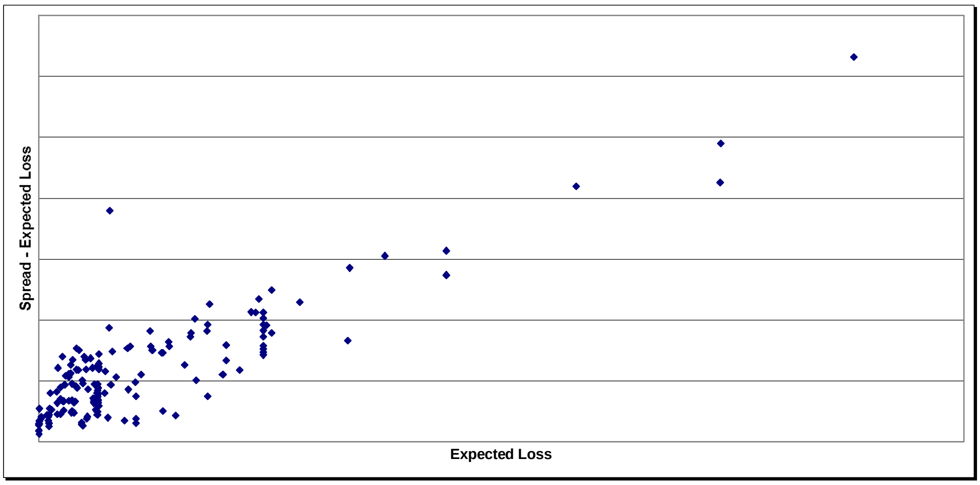



FIGURE 2. Risk Load against Expected Loss

At first sight the relation looks linear. However, trials with linear models showed that the fit was not very good for the lower values of expected loss, where a relatively large number of cat bonds lies.

In addition, based on observations in prices in the reinsurance market, a linear relation between the risk load and the expected loss is unlikely to hold for high values of expected loss.

Trials with linear and piece wise linear model did not give a satisfactory fit to the whole range of expected losses and in the end smoothing functions were employed to describe the relation between the risk load and the expected loss.

Smoothing functions were also considered an appropriate way to describe the relation between the risk load and the market cycle. The market cycle could be alternatively described by a factor variable probably with three levels: "soft market", "hard market" and "other". However such a classification would be somewhat arbitrary. Furthermore, during these chosen periods of "hard" or "soft" markets the prices would not remain stable. A three level variable could only describe the average risk load in the selected periods.

The selected model has the form:

$$Log(RL_i) = f_1(\log(EL_i)) + f_2(time_i) + Peril/Territory_i + Trigger_i + \varepsilon_i\,, \qquad (4.1)$$

where $RL_i$ is the risk load, $EL_i$ the expected loss, the $f$ s are smoothing functions, the Peril/Territory and Trigger are factor variables and the $\varepsilon_i$ s are i.i.d. $N(0,\sigma^2)$ random variables.

***4.3 One Model or Several Sub-models***

It did not seem possible to find a simple single model which would fit all the cat bonds. The main reason for this was that the market cycle seemed to be different for different territories. The volatility of the risk loads for US bonds seemed to be a little higher than that of the other territories. Therefore two models were used: one for cat bonds including US perils and another for the remaining bonds. The multi-peril, multi-territory bonds invariably covered US perils and were included in the first group.

## 5. MAIN FACTORS DRIVING THE SPREADS AND SUMMARY RESULTS

In this section the factors which were included in the model as well as some which were not included are discussed. Also some summary results are shown.

***5.1 Expected Loss***

The main driver of the risk load is the expected loss. The expected loss we examine is an "annualised" expected loss. Consider a cat bond exposed to European storm with a term of 3.5 years issued in October. Although the bond has a term of 3.5 years it is exposed to 4 winters. In this case, a direct comparison of the annual expected loss, which refers to four winters, and the coupon, payable for 3.5 years, is not valid. Modelling agencies adjust the expected loss to an annual basis so that such comparisons are meaningful.

The higher the expected loss is, the higher the risk load. However, the relationship is not linear, with a doubling of the expected loss not carrying a proportionately higher risk load. Investors require a minimum risk load as compensation for factors including the provision of capital, uncertainties inherent in the product, expenses and the relatively low liquidity of cat bonds.

Recently there have been some cat bonds for what are considered to be very remote events with very small annualised expected loss of less than 0.01%. The risk loads for these bonds have been around 1 to 2%. The high ratio of spread to the annualised expected loss may be due to a premium required for the lower liquidity of the cat bond market, for the uncertainty in the results of natural hazards models, the cost of capital, expenses, or some other reasons.

Other alternatives to the expected loss could be suggested as the main driver of the risk load. For example the probability of a first loss and the conditional (given that the event occurred) expected loss could be used. Although this is theoretically and intuitively appealing, the use of the conditional expected loss in addition to the probability of first loss had little additional predictive power and therefore it was not used in the model.

Another alternative suggestion could be the rate assigned to a cat bond by a rating agency. The rating agencies base their rating on the probability of first loss or expected loss, but also on other factors which include legal risk, credit risk and other. The expected loss seemed to have more predictive power than the rating.

The expected loss is usually estimated by a specialist company. Different companies may come up with different estimates. However, here it has been assumed that the investors rely on the analysis of the specialist company as far as the estimation of the expected loss is concerned.

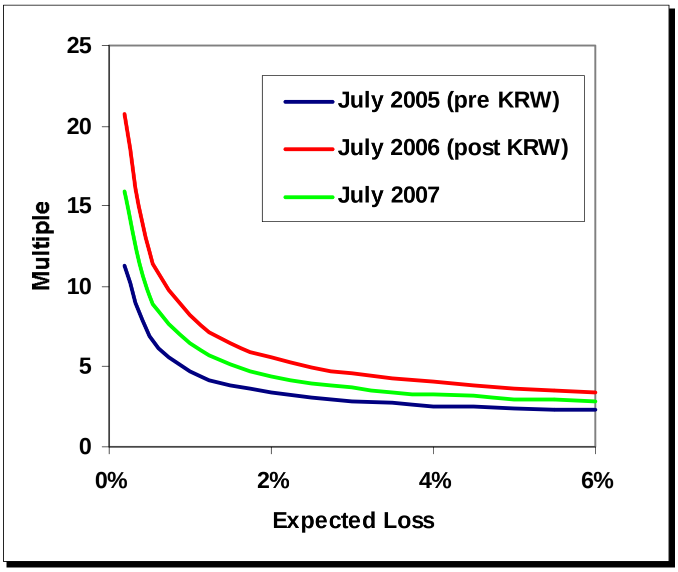



FIGURE 3. Modelled multi-peril including US hurricane multiples (the number of times spread covers expected loss) at three different dates.

### *5.2 Date of Issue –Market Cycle*

Cat bonds issued at different points in time are subject to different market conditions. Following the 2005 hurricanes Katrina, Rita and Wilma (KRW), the risk loads for US perils increased by around 30% since their 2003 levels. This shows the link between cat bond and reinsurance risk loads. Generally, as it can be seen in Figure 4, the market cycle has been more pronounced for US perils than for non US perils in the last five years. It would be interesting to see how the market would react if large losses occur in non US territories.

Another factor which is likely to have affected the risk load is the timing of the changes in the natural hazard models. For example most of the US hurricane models were revised by the middle of 2006 showing significantly higher probabilities for the same US hurricane events. The belief that the revised models have been more conservative may have been another factor that the market started levelling off after the middle of 2006 for US perils.

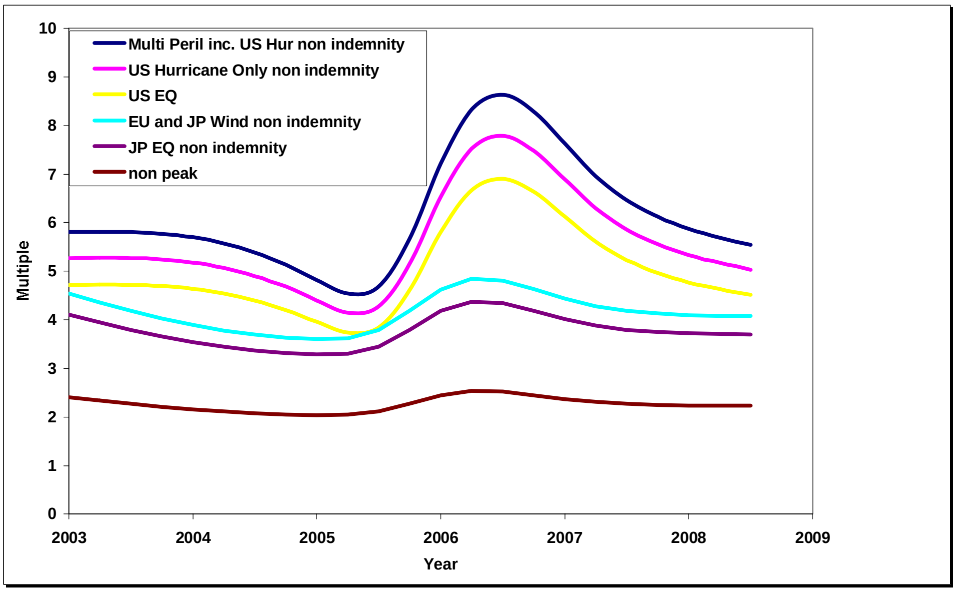



FIGURE 4. Modelled Multiples for annualised expected loss 1% over time for different Perils/Territories

### *5.3 Peril and Territory*

After experiments with different combinations, the following groups of peril/territory were chosen:

a. Multi-peril, multi-territory including US hurricane
b. US hurricane only
c. US earthquake
d. European storm and Japanese typhoon
e. Japanese earthquake
f. "non- peak" territories

Levels a to c formed one sub-model and levels d to f formed another sub-model. The "non peak" level includes cat bonds covering risk su ch as Mexican earthquake or Mediterranean earthquake and other similar types of risk.

The differences in the risk loads for different perils/territories vary over time. Figure 5 shows estimated relative risk loads at the end of 2007 for cat bonds for different perils (with a US hurricane-only peril used as the benchmark). For example, if the risk load for a US hurricane-only cat bond was 10%, for an identical bond covering European and Japanese wind, the load is estimated to be around 7.25%. Risk loads for non-peak zones have been significantly lower than those for other perils, reflecting the diversifying nature of non-peak territories in a cat bond portfolio.

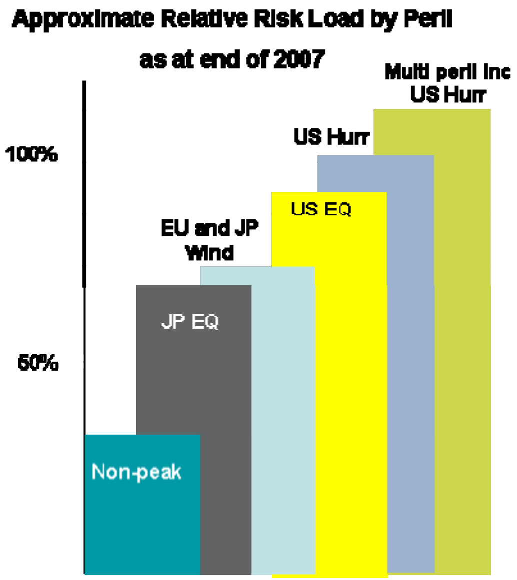


FIGURE 5. Relative risk loads by peril/territory

***5.4 Trigger***

After experiments with different combinations, the following levels for the factor variable Trigger were chosen:

a. Indemnity
b. Industry Loss and Modelled Portfolio
c. Parametric and Parametric Index

For indemnity bonds the investor assumes moral hazard risk. This will influence the price demanded, though for cat bonds the additional risk load required has not been significant - it seems the reputation of the sponsor is more important in placing an indemnity cat bond. With non-indemnity products such as parametric cat bonds basis risk is retained by the cedant.

As mentioned earlier in the paper, there has been correlation between the type of trigger and peril. For example the vast majority of indemnity bonds include US hurricane. On the other hand non-peak peril bonds have usually been issued on parametric triggers. This type of correlation and the relatively small amount of data makes the model unstable and the results need to be interpreted with care.

***5.4.1 Bonds covering risks including US hurricane***

For bonds covering risks including US hurricane, the risk load for indemnity bonds compared to the other types of trigger is no more than 5-10% higher. Someone needs to bear in mind that the majority of indemnity bonds have been issued by established insurers or reinsurers who have been in the cat bond market for several years and have developed a relation with the investors. Parametric triggers seem to carry a slightly lower but not statistically significantly different risk load. This may be at least partly explained by the perception of the market that the data quality and validity of natural hazard models for US hurricane is higher than for other territories. Another relevant point is that there are several bonds covering perils including US hurricane where both the sponsor and placement agent belong to the Swiss Re group. For these bonds there seems to be a slightly higher differentiation between triggers.

***5.4.2 Bonds covering risks not including US hurricane***
For bonds not covering risks which include US hurricane the scarce data do not allow an estimation of the indemnity premium. The parametric triggers seem to have a risk load which is lower by 10-15%, although this is not statistically significant at the 5% level.

***5.4 Other Features of Bonds not Included in the Model***
It is interesting to comment on some other features of the cat bonds that do not appear to be statistically significant factors of the cat bonds prices.

***5.4.1 Term to Maturity***
For other bonds, like government bonds, the yield usually depends on the duration of the bond, as usually expressed by the yield curve. There are different reasons for this dependence of the yield on the term which include future expectations about interest rates, variations in demand of certain terms for matching purposes and other.

Unlike a government bond which usually pays a fixed coupon, a cat bond usually pays the current rate of LIBOR or EURIBOR until the next coupon date. The attachment point may also be reset annually so that the probability or expected loss remains the same. Both of these features of cat bonds make the dependence of the yield on the term weaker, because the interest payment and risk of a cat bond generally adjust with the market conditions, possibly with some delay.

The natural hazards model that is used to assess these probabilities is often set at the time of the issue and it does not change. Therefore, there is some sort of "model" risk, the risk that the model used may not reflect changes in the perception of the risk and updates in the parameters of the risk. Someone would expect that a longer term for a cat bond will require an additional risk load. However, the data do not support a higher spread/load, or maybe the differences in spread/load are small and not easy to detect.

The relation between risk load and term may be further complicated by the market cycle. For example, an investor who buys a bond of say 4 years term locks into favourable (or unfavourable) rate for a relatively long term. This investor may be prepared to accept the higher model risk in return for locking into what he believes to be a favourable rate. The amount of available data does not allow a detail investigation of these effects.

Figure 6 shows the residuals of the fitted model against the term of the bonds:

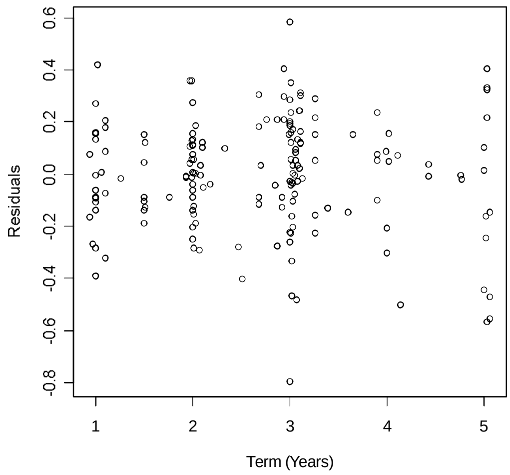



FIGURE 6. Residuals against term of the bond

There is not any obvious trend in the residuals in Figure 6. Adding the term as an additional variable into our model does not improve the results with any statistical significance.

***5.4.2 Size of the Transaction***

It is believed that the size of the transaction has an effect on the premium. This is something that has been observed in markets for other assets. The rationale is that a larger size of deal may require a bigger number of investors and therefore a higher reward as more investors need to be satisfied by the price. However, there is not any obvious statistically significant relation between the size of the deal and the risk load in the historical data.

***5.4.3 Time of Issue within a Calendar Year***

Some practitioners have expressed the view that the time of the issue within a calendar year may have some effect on the risk load. For example a bond covering US hurricanes issued just before the US hurricane season may have a higher risk load. This is not supported by the data and this factor is not statistically significant. This effect may be more significant in the reinsurance market.

***5.4.4 Second Event Cover***

Some preliminary work by the author in the retrocession market has shown that for the same expected loss and covered perils, a second event cover tends to demand a higher risk load than a first event cover in the retrocession market. This may reflect retrocession underwriters' views about the increased probability of a second event in the wake of an earlier major catastrophe (i.e. "clustering") and the aggregation of risk in their portfolios, but it is also probably a reflection of their lack of confidence in models to accurately assess second-event probabilities. This factor does not seem to have a significant impact on the cat bond risk loads.

## 6. FITTED MODEL

***6.1 Bonds Covering Risks Including US Hurricanes***

The selected model which describes bonds covering risks including US hurricanes is as follows:

$$Log(RL_i) = S(\log(EL_i)) + NS(time_i) + Peril/Territory_i + Trigger_i + \varepsilon_i \,, \qquad (6.1)$$

Where $RL_i$ is the risk load

$EL_i$ the expected loss

$time_i$ the date of issue of the bond

$Peril/Territory_i$ is a discrete variable with three levels:

1. multi-peril, multi-territory including US hurricane
2. US hurricane only
3. US earthquake

$Trigger_i$ is also a discrete variable with two levels:

1. indemnity
2. other

and the $\varepsilon_i$ s are i.i.d. normally distributed errors with zero mean.

The function $S$ is a smoothing spline and $NS$ is a natural spline.

A summary of the model is given by Table 2.

| added term | Residual df | Residual Deviance | Difference in df | Difference in Deviance | P(>\|Chi\|) |
|---|---|---|---|---|---|
| Intercept | 141 | 53.845 | | | |
| s(log(EL)) | 137 | 11.137 | 4 | 42.708 | 0.0000% |
| ns(year) | 132 | 5.931 | 5 | 5.206 | 0.0000% |
| Peril/Territory | 130 | 4.251 | 2 | 1.680 | 0.0000% |
| Trigger | 129 | 4.155 | 1 | 0.097 | 8.3000% |

TABLE 2. Summary of Model

Figure 7 shows the Student residuals of the model and the normal qq plots of the student residuals together with 95% confidence intervals respectively.

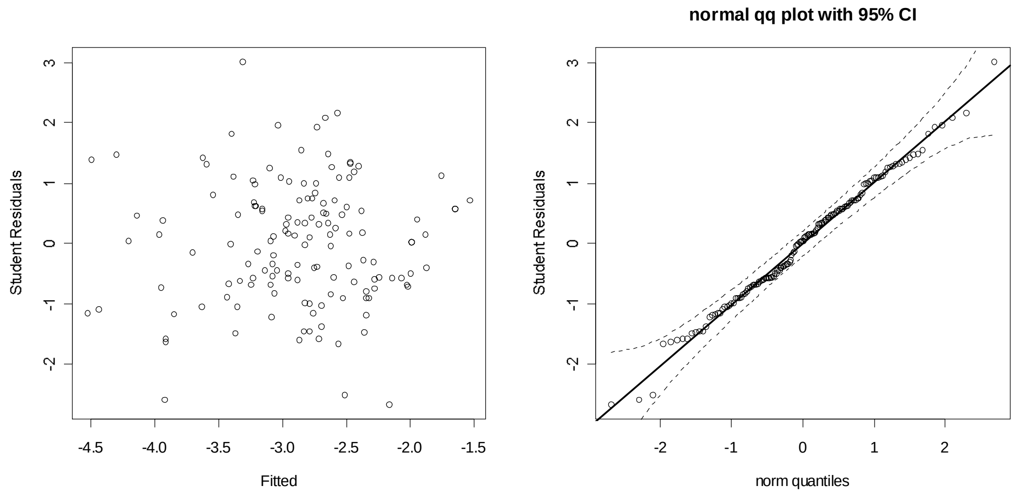
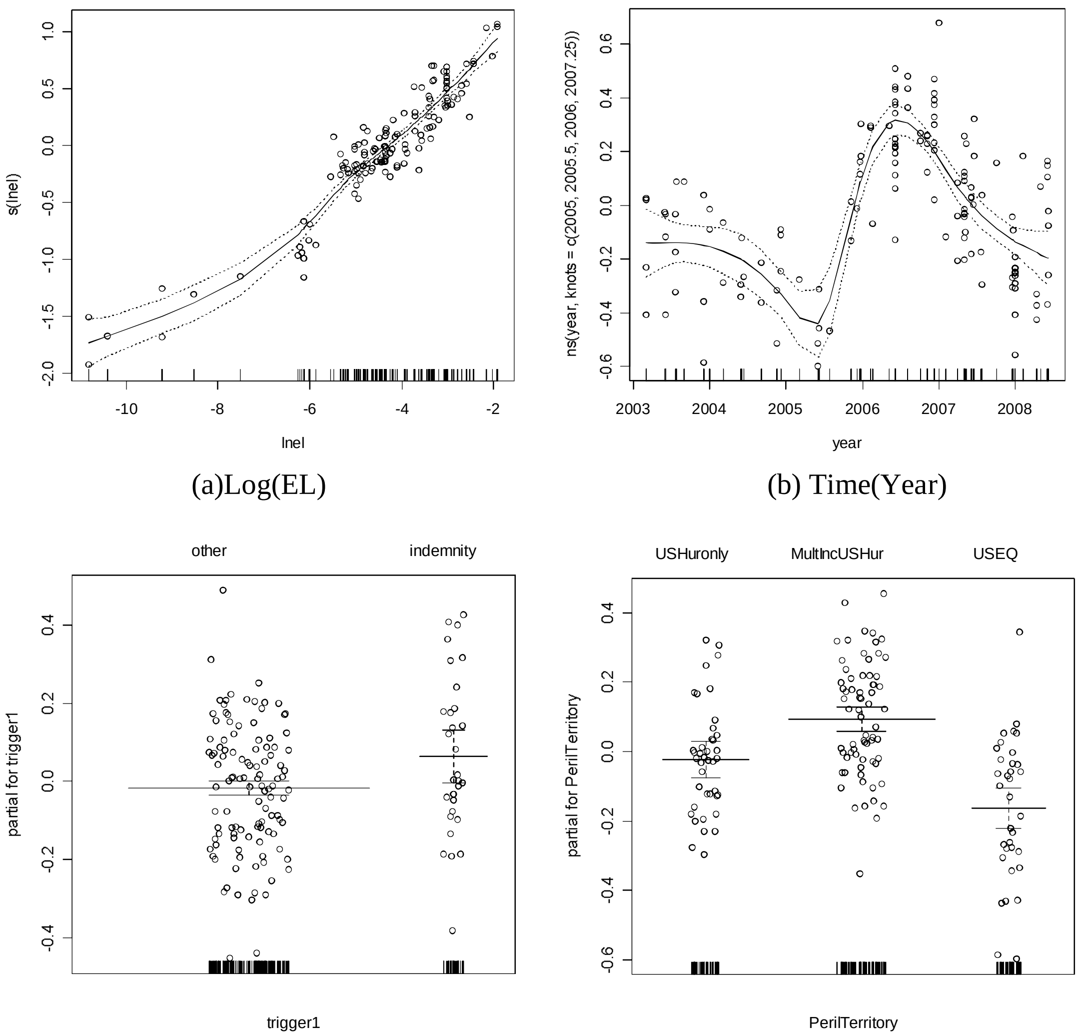



FIGURE 7. Residuals and Normal qq plot

The partial residuals are shown in Figure 8.




(a)Log(EL)

(b) Time(Year)

(c) Trigger

(d) Peril/Territory

FIGURE 8. Partial Residuals

In figure 8b, where the partial residuals of the variable time (year) are shown, the spline function has knots at time 2005 and 2005.5, 2006 and 2007.25. The knot at 2005.5 is not statistically significant. However, if we omit the knot at this point the "bottom" of the market occurs early in 2005 as a result of the data smoothing and the small number of points around 2005.5. It is known that the market "hardened" after the middle of 2005 following the three big North Atlantic hurricanes.

Figure 9 shows the logarithm of the estimated and actual risk loads. Each blue dot represents the estimated risk load for each of the cat bonds. The pink dots show the actual risk loads. The light blue lines are the 95% confidence intervals for the estimates. The yellow lines are the 2.5% and 97.5% points of the distribution of the risk loads. The estimated risk loads have been sorted in ascending order so that the graph can be visualised more easily.

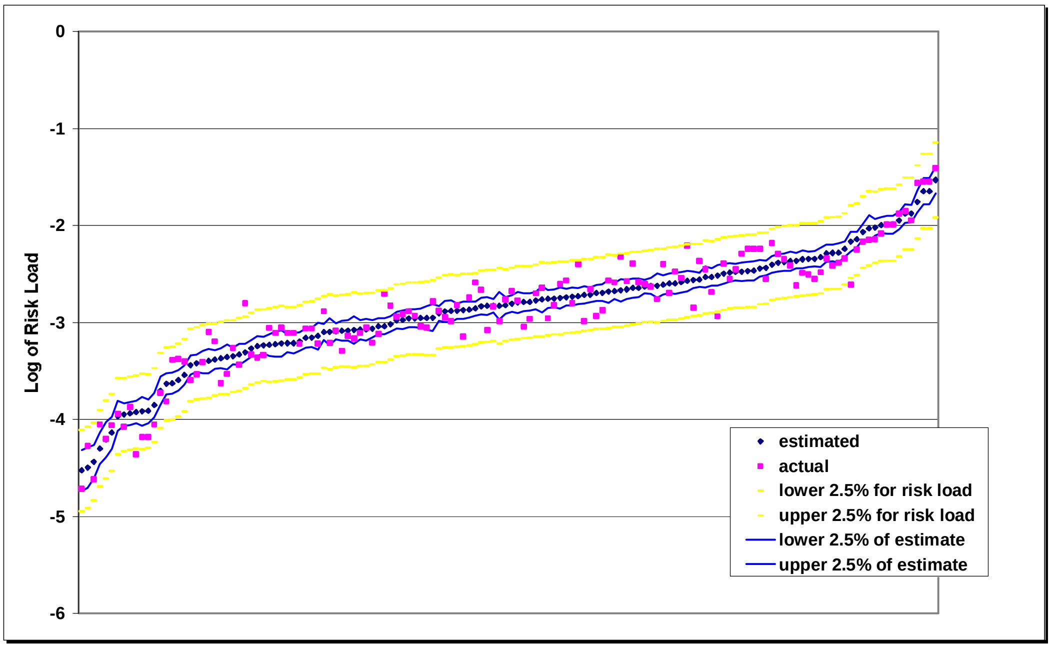



FIGURE 9. Actual and fitted risk loads on a logarithmic scale

Figure 10 shows the estimated and actual risk loads. The estimates for the risk loads are the medians of the distribution.

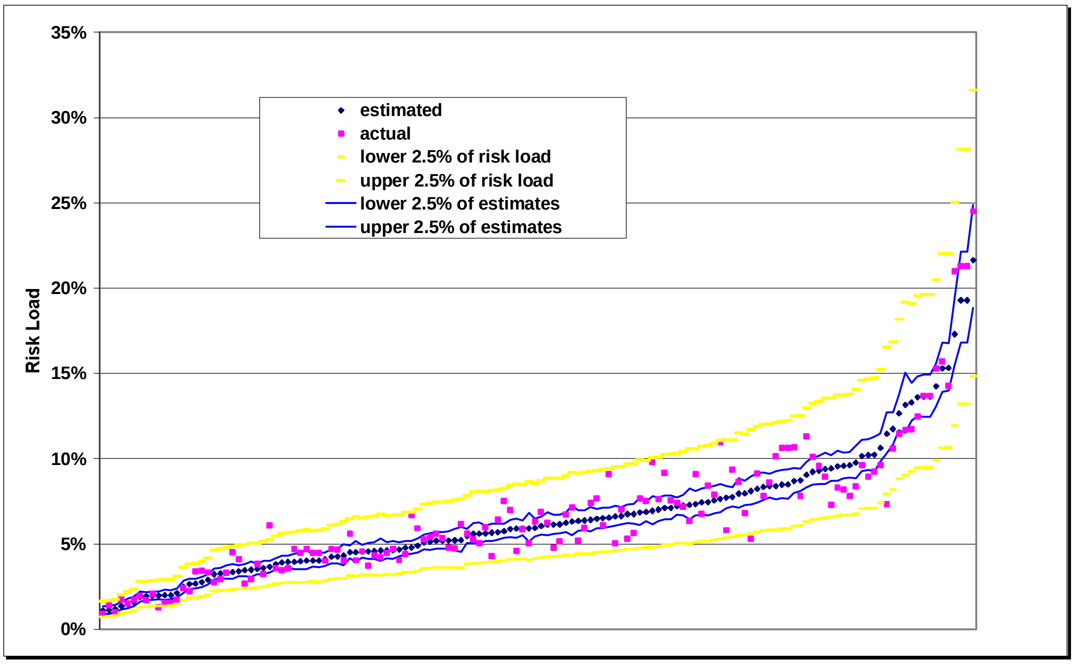



FIGURE 10. Actual and Fitted Risk Loads

It can be seen from the previous graphs that there is significant residual volatility.

### *6.2 Non US Risks*

The selected model for non US risks is as follows:

$$Log(RL_i) = S(\log(EL_i)) + lo(time_i) + Peril/Territory_i + Trigger_i + \varepsilon_i, \qquad (6.2)$$

where $RL_i$ is the risk load, $EL_i$ the expected loss, $time_i$ the date of issue of the bond, $Peril/Territory_i$ is a discrete variable with three levels:

1. European Storm and Japanese Typhoon
2. Japanese Earthquake
3. "non- peak" Territories ,

$Trigger_i$ is also a discrete variable with two levels:

1. Industry Loss and Modelled Portfolio
2. Parametric and Parametric Index,

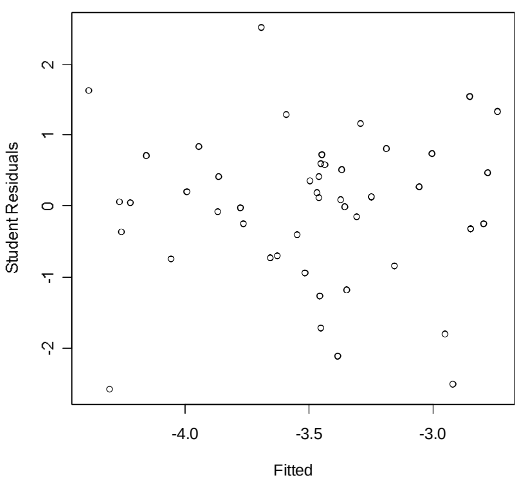
and $\varepsilon_i$ are i.i.d. normally distributed errors with zero mean.
The function $S$ is a smoothing spline and $lo$ is a locally fitted polynomial.
A summary of the model is given by Table 3.

| added term | Residual df | Residual Deviance | Difference in df | Difference in Deviance | P(>\|Chi\|) |
|---|---|---|---|---|---|
| **Intercept** | **49** | **11.1143** | | | |
| **s(log(EL))** | **45** | **6.2776** | **4** | **4.837** | **0.0000%** |
| **lo(year)** | **42** | **5.3399** | **3** | **0.938** | **0.0001%** |
| **Trigger** | **41** | **5.2233** | **1** | **0.117** | **4.5600%** |
| **Peril/Territory** | **39** | **1.1264** | **2** | **4.097** | **0.0000%** |

TABLE 3. Summary of the model

The term "Trigger" is not statistically significant at 5% if we change the order of adding the terms. A locally fitted polynomial in "time" does not necessarily give a better fit than some type of spline function, but it gives a fit which is more consistent with our knowledge of the market cycle.

Figure 11 shows the Student residuals of the model and the normal qq plots of the student residuals together with 99% confidence intervals respectively.



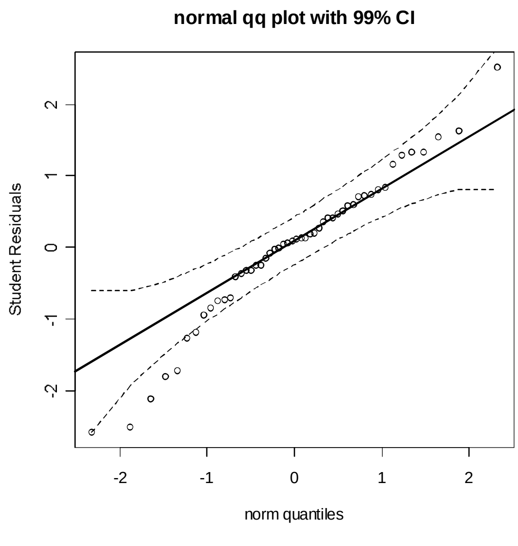
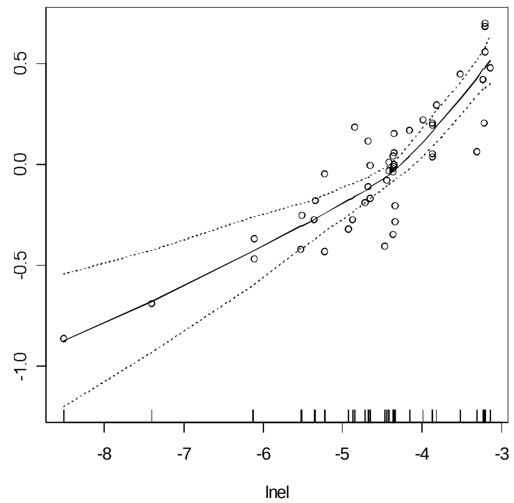



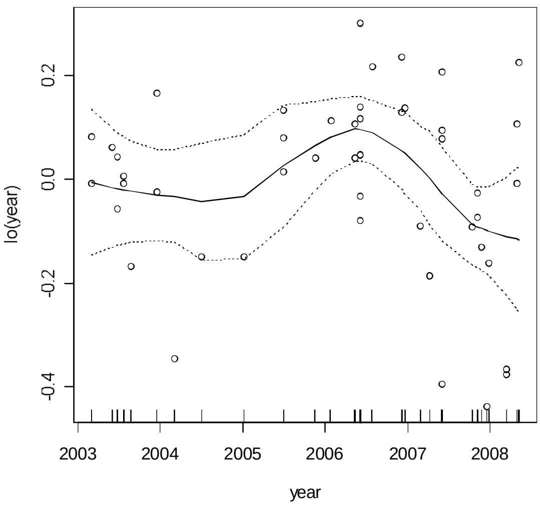

FIGURE 11. Residuals and Normality Test

The normality assumption is weak at the left tail.

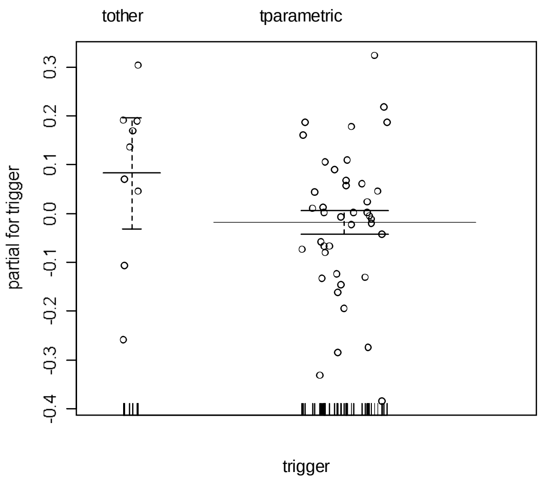
The partial residuals are shown in the Figure 12



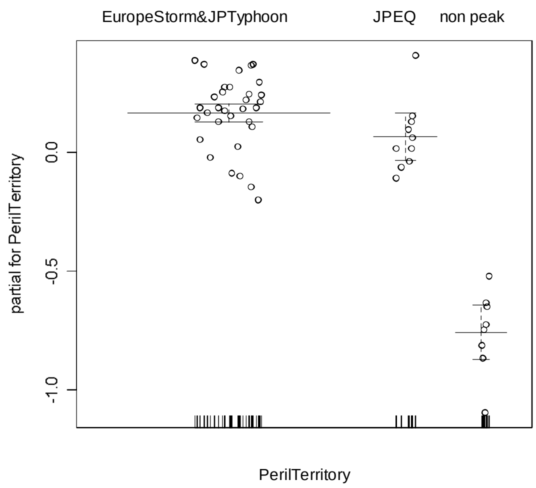

(a) Log(EL)




(b) Time(Year)




(c)Trigger




(d) Peril/Territory

FIGURE 12. Partial Residuals

Figure 13 shows the logarithm of the estimated and actual risk loads. Each blue dot represents the estimated risk load for each of the cat bonds. The pink dots show the actual risk loads. The light blue lines are the 95% confidence intervals for the estimates. The yellow lines are the 2.5% and 97.5% points of the distribution of the risk loads. The estimated risk loads have been sorted in ascending order so that the graph can be visualised more easily.

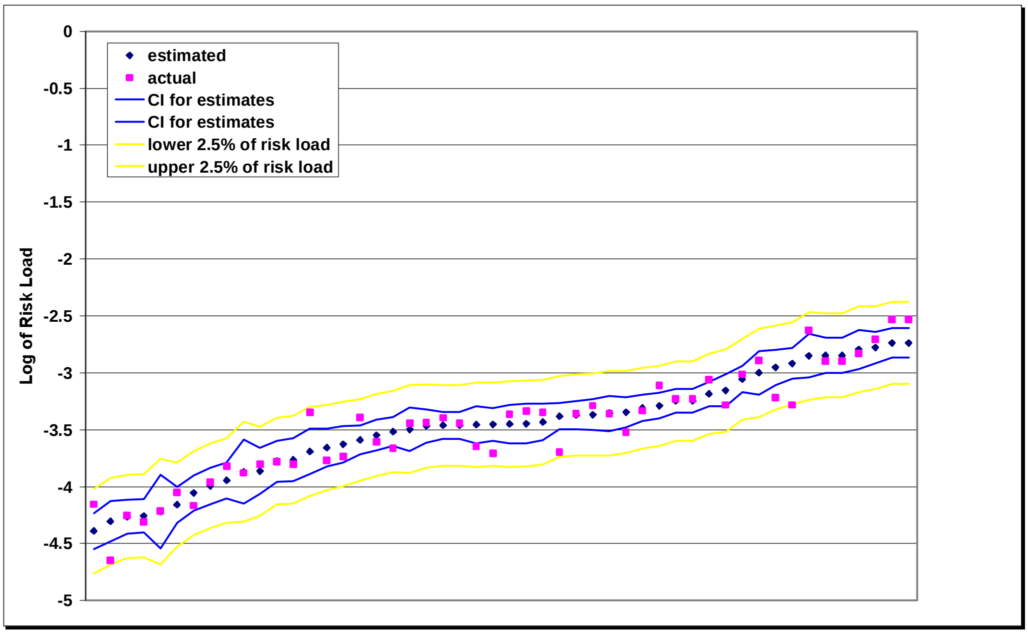



FIGURE 13. Actual and Fitted Risk Loads on a logarithmic scale

Figure 14 shows the estimated and actual risk loads. The estimates for the risk loads are the medians of the distribution.

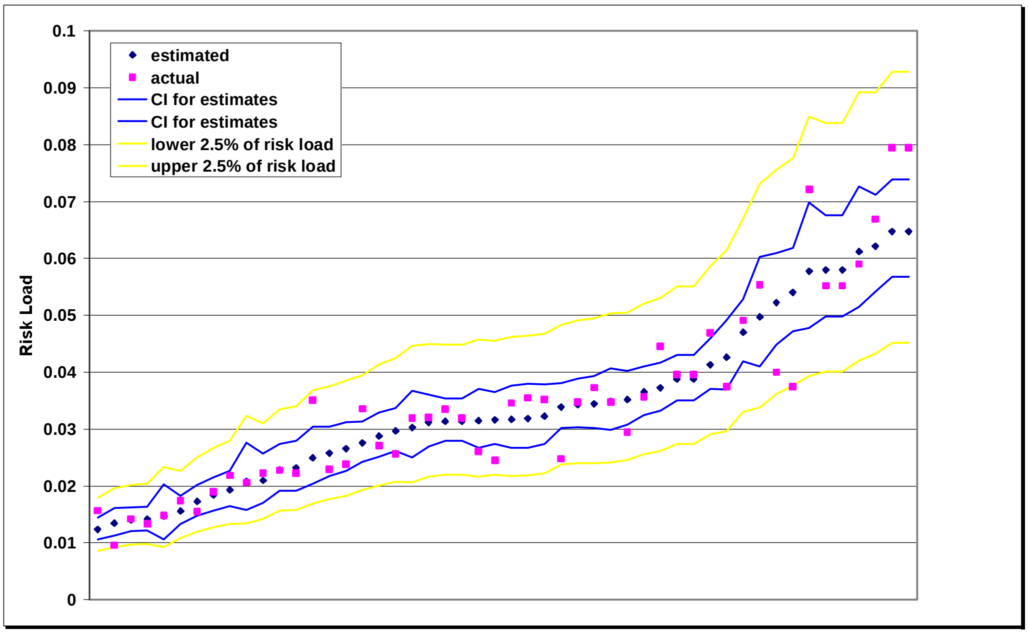



FIGURE 14. Actual and fitted risk loads

## 7. CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

The market of the insurance linked bonds and the volume of trading in these securities have been relative small. As the volumes increase it will be helpful to have a framework to analyse the market. In this paper an attempt was made to provide one possible framework for analysing the factors that affected the cat bond prices at issue in the last few years and show a way of quantifying the effect of these factors. The main driver of the risk load of a cat bond has been the expected loss. Peril/Territory, market cycle and to a lesser extent the type of trigger have been important factors affecting the cat bonds price.

A statistical framework is a good way to go about analysing the cat bond market. The statistical analysis will lead to a better understanding of the market and a more informed environment for the trading of cat bonds. However, the relative small amount of available data places some limitations on what the statistical analysis can currently achieve. As the amount of data accumulates more accurate estimates and firmer conclusions could be drawn. In addition, work in the following areas could be carried out:

### *7.1 Comparisons Between the Prices of Cat Bonds and Reinsurance and Retrocession*

This is an area that everybody involved in the risk transferring market is interested in. Although there are similarities between risk transfer mechanisms, there are also differences in the risk transfer products and the markets they operate. A statistical analysis of the prices and for measuring the value of some specific features of the risk transfer products will be useful for practitioners. Some initial analysis was presented in Dallison, Papachristou and Potter (2008), but the results were approximate. The difficult areas were the accuracy of expected loss estimates and the treatment of expenses. Despite the progress and effort in estimating the distribution of losses to reinsurance/retrocession programmes in recent years, the quality of data, especially for retrocession, is not always ideal and parts of the portfolio can only be modelled approximately. This is in contrast to the portfolios covered by a cat bond where even for indemnity triggers the data quality is generally of good standard and the portfolios often very specific. Some of the expenses of issuing a cat bond such as legal fees, modelling agency fees, etc., are explicit and are not included in the spread. On the other hand reinsurance/retrocession premiums make implicit allowance for the company expenses.

### *7.2 Factors Affecting the Prices of Cat Bonds in the Secondary Market*

In this paper only prices at the time of issue were considered. Cat bonds are traded and an interesting area of research would be the analysis of the prices in the secondary market. The prices of a bond are affected by the seasonality of some natural perils. Adjustments need to be made for these temporal variations in the risk before the prices are analysed. The relatively infrequent trading of cat bonds may place some limitations to such a statistical analysis.

### *7.3 Comparison of Market Prices to Actuarial Pricing Methods*

The relatively detailed information provided in a cat bond circular on the statistical analysis of the risk enable us to examine the true market prices and compare them with standard actuarial premium methods, such as the standard deviation, Esscher, and other premium principles. The parameters of these methods could be estimated and they may be different for different perils/territories and they will certainly vary over time. Some initial research by the author showed that the standard actuarial premium methods do not seem to agree with the market prices over the whole range of expected losses. However, these methods appear to come more in line with the market prices when approximate allowance is made for parameter uncertainty. Maybe underwriters and investors, although not necessarily familiar with the mathematics of parameter uncertainty, they do intuitively take it into account.

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