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CATASTROPHE BONDS: the effect of structural change on pricing during the financial crisis

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ABSTRACT

- TITLE:** CATASTROPHE BONDS: THE EFFECT OF STRUCTURAL CHANGE ON PRICING DURING THE FINANCIAL CRISIS
- AUTHORS:** Lukas Jovaisa and Sonya Petkova
- ADVISOR:** Prof. Lars Oxelheim
- COURSE:** BUSM36 Degree project in Corporate and Financial Management
- SEMINAR DATE:** 7th June 2010
- KEYWORDS:** Catastrophe bonds, ILS market, reinsurance, pricing models, total return swap counterparty, collateral, structural change, financial crisis
- PURPOSE:** The main purpose of this work is to investigate whether the price of catastrophe bonds would be significantly affected if a dummy variable reflecting the change in the catastrophe bond structure is incorporated into the reviewed pricing models
- THEORETICAL FRAMEWORK:** The theoretical framework includes modern theories related to catastrophe bonds, the catastrophe bonds market development and several existing catastrophe bond pricing models
- EMPIRICAL FRAMEWORK:** Data sample consisting of 211 catastrophe bonds issued during the period 2004 - 2010
- METHODOLOGY:** Quantitative approach using multiple regression analysis with cross-sectional data
- CONCLUSIONS:** Our findings show that catastrophe bonds' spreads are significantly affected by the safer TRS structure introduced after September 2008. Also, structures which do not involve TRS counterparty do not influence bonds' spreads significantly. The changes in the structure show a positive effect on bonds' spread, which was proven by all pricing models, except for the Lane and Mahul (2008) all-bonds model with a "Single Peril Indicator".

TABLE OF CONTENTS

ABSTRACT	1
TABLE OF CONTENTS.....	2
1. INTRODUCTORY CHAPTER.....	4
1.1. BACKGROUND	4
1.2. PROBLEM DISCUSSION	8
1.3. PURPOSE.....	9
1.4. DELIMITATIONS	9
1.5. TARGET GROUP	10
1.6. THESIS OUTLINE	10
2. THEORETICAL BACKGROUND CHAPTER.....	11
2.1. RECENT CATASTROPHE BOND THEORETICAL RESEARCH	11
2.2. CATASTROPHE BONDS STRUCTURE	13
2.3. THE CHANGE IN CATASTROPHE BOND STRUCTURE	17
2.4. TRIGGER MECHANISMS	19
2.5. CATASTROPHE BONDS PRICING MODELS	21
2.5.1. <i>Catastrophe bonds pricing principles</i>	21
2.5.2. <i>Bodoff pricing model</i>	22
2.5.3. <i>Lane pricing model</i>	24
2.5.4. <i>Papachristou pricing model</i>	26
2.6. HYPOTHESIS	28
3. METHODOLOGY CHAPTER.....	29
3.1. REVIEW OF THE PROBLEMS	29
3.2. METHODOLOGICAL APPROACH	29
3.3. DATA COLLECTION	31
3.3.1. <i>Sample data</i>	31
3.3.2. <i>Excluded observations</i>	32
3.4. VARIABLES	32
3.5. EXPECTED RESULTS	33
3.6. VALIDITY.....	33
3.7. RELIABILITY	34
3.8. PROBLEMS AND LIMITATIONS.....	34
4. EMPIRICAL ANALYSIS CHAPTER	36
4.1. DESCRIPTIVE STATISTICS.....	36
4.2. BODOFF MODEL	40

4.2.1.	<i>Model adjustment</i>	40
4.2.2.	<i>Tests</i>	41
4.2.3.	<i>Empirical results</i>	42
4.3.	LANE AND MAHUL MODEL	44
4.3.1.	<i>Model adjustment</i>	44
4.3.2.	<i>Tests</i>	45
4.3.3.	<i>Empirical results</i>	47
4.4.	PAPACHRISTOU MODEL	50
4.4.1.	<i>Model adjustment</i>	50
4.4.2.	<i>Tests</i>	51
4.4.3.	<i>Empirical results</i>	52
5.	QUALITATIVE ANALYSIS AND DISCUSSION CHAPTER	54
6.	CONCLUSIONS AND FURTHER RESEARCH CHAPTER	60
6.1.	FUTURE RESEARCH.....	61
6.2.	ACKNOWLEDGEMENTS	62
	REFERENCES	I
	APPENDIX	VII
I.	THE ILS MARKET AND CATASTROPHE BONDS	VII
II.	MECHANICS OF THE CATASTROPHE BOND STRUCTURE	X
III.	INSURANCE MARKET CYCLES	XI
IV.	MARKET CYCLICALITY INDEX (ROL).....	XII
V.	ORIGINAL MODELS REGRESSION RESULTS	XIII

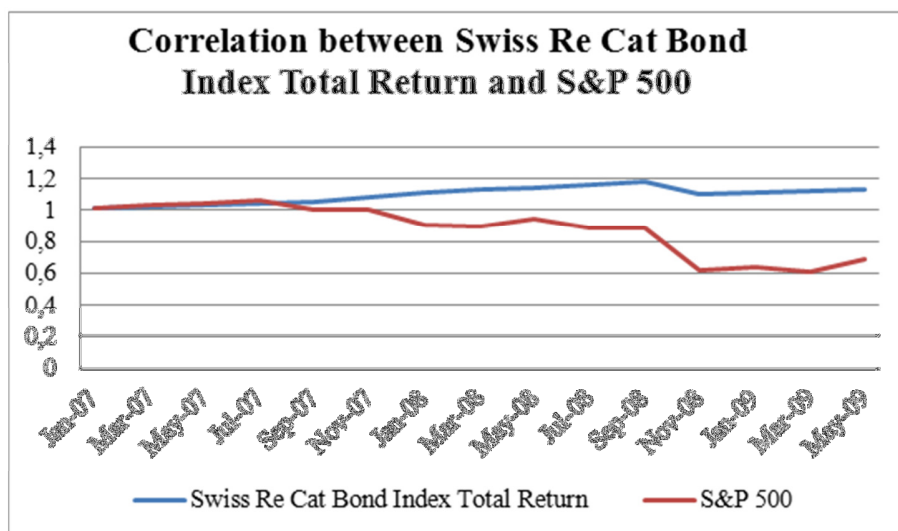
1. INTRODUCTORY CHAPTER

In the introductory chapter a general view of the development of the catastrophe bond market will be presented. Further, an overview of the problems that are of importance to the analysis and the purpose of the present work will be outlined.

1.1. Background

Catastrophe bonds¹ were first issued in the early 1990s, following hurricane Andrew (1992). Initially, catastrophe derivatives were introduced and these later developed into different forms and became part of the insurance-linked securities (ILS) market. Over the next decade, these bonds became its most important and successful component (Cummins, 2008). The primary reason for this trend is that catastrophe bonds are backed-up by highly-rated assets, while at the same time they show little or no correlation with major financial market indices (Figure 1.1) (Lane Financial LLC, 2009).

Figure 1.1: Correlation between Swiss Re Cat Bond Index Total Return and S&P 500



Source: Swiss Re Capital Markets (2009)

¹ A catastrophe bond is a synthetic reinsurance instrument whereby the issuer sells reinsurance to the originator. The amount is fully collateralized with one or several classes of securities. (Culp, 2006)

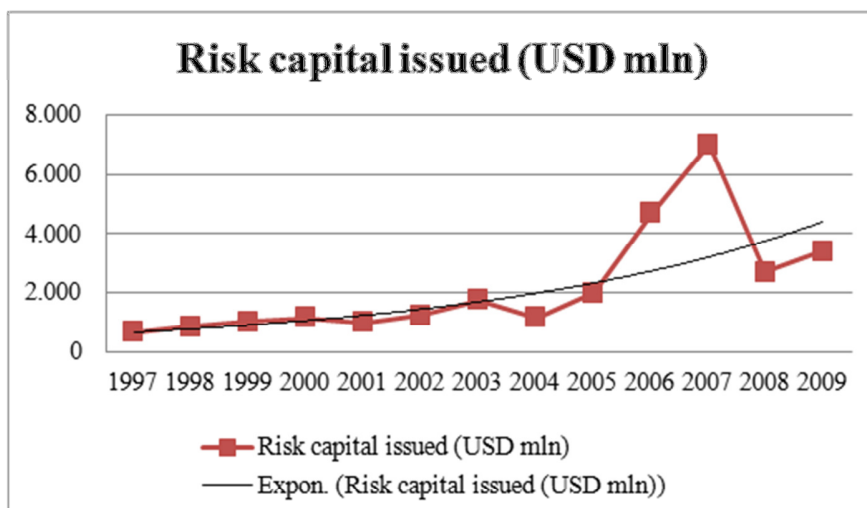
The minimal market correlation is due to the fact that catastrophe bonds' triggers are connected to natural disaster parameters, which also determine the distribution of the catastrophes' expected losses. With such a negligible level of correlation, catastrophe bonds are an instrument that provides good opportunities for diversifying investors' portfolios while almost completely avoiding credit risk (Cummins, 2008).

From 1997 up until 2004 the catastrophe bond market was not highly developed and grew slowly over the years. The structure of cat bonds became more robust and started to contain common features. Still, it remains one of the bonds' characteristics which are most often a subject to change. (Marsh&McLennan Securities, 2002)

During this period, risk capital issued was increasing in size, reaching \$ 1.22 bln in 2002. In 2004 the market experienced a slowdown and fell to \$ 1.14 bln of risk capital issued (MMC Securities, 2004).

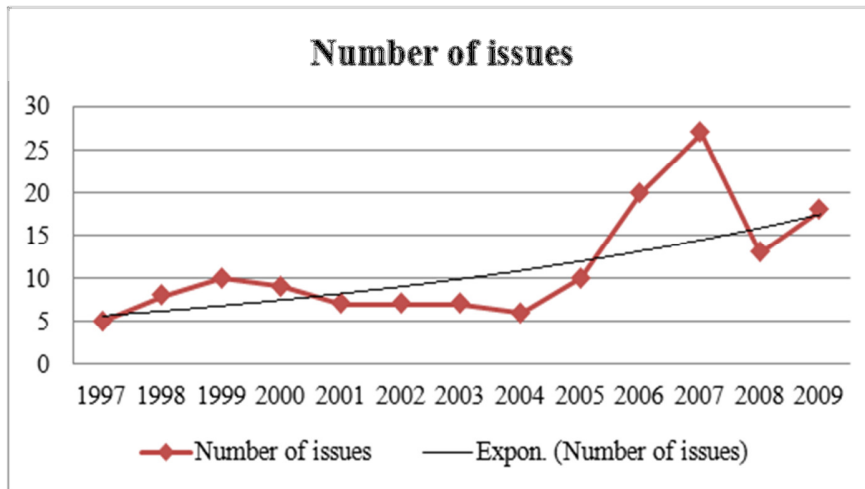
However, the market started to rapidly expand after 2005, following the catastrophic events of the hurricanes Katrina, Rita and Wilma (Guy Carpenter & Company LLC, 2007). The number of catastrophe bonds issued rose dramatically and the market reached record levels of \$ 4.9 bln in 2006. (Figure 1.2 and Figure 1.3)

Figure 1.2: Risk capital issued (1997-2009)



Source: Guy Carpenter & Company, LLC

Figure 1.3: Number of catastrophe bond issues (1997-2009)



Source: Guy Carpenter & Company, LLC

The upward trend continued until the recent financial crisis hit in 2007. It affected, among other industries, the insurance and reinsurance sector as well. During this period of weak ILS performance (2007-2009), correlations were experienced in almost all markets (including to an extent the insurance and reinsurance) and there was an increasing demand for liquidity in all of them. (Lane Financial LLC, 2009)

The beginning of the slowdown for catastrophe bonds was marked by the collapse of Lehman Brothers in September 2008, who were acting as total return swap counterparty for several catastrophe bonds. This event also coincided with the occurrence of hurricanes Gustav and Ike (Lane Financial LLC, 2009). Lehman Brothers failed mainly for the reason of holding extensive portfolios of lower-rated mortgage-backed securities (MBS). The excess leverage the company was facing combined with its depressed liquidity levels precipitated the company's collapse and this was compounded by the US real estate crash (D'Arcy, 2009). After Lehman's collapse investors in catastrophe bonds were left without the rates they were supposed to receive from the swap counterparty and this led to a drop in the value of the bonds. Consequently, had a trigger event occurred at that time, the collateral that bond sponsors should use would not have been sufficient to cover the incurred losses (Fritsch and Laplante, 2008)

Shortly after the effects of the crisis began to be felt less acutely by the markets, catastrophe bonds started to recover quickly with increasing amounts of risk capital and bond issuances. The main trends in the cat bond market for 2009 included (Munich Re, 2010):

- Increased initial spreads since many investors sold catastrophe bonds on secondary markets, due to the collapse of Lehman Brothers;
- Increase in demand from investors, showing expanding liquidity levels and market recovery;
- Securitization was mostly done through money market funds and government securities in order for counterparty and credit risk to be minimized.

The collapse of Lehman Brothers was important to the performance of catastrophe bonds since investors feared that the increased credit risk would penetrate the structure of these bonds. This was the turning point for the development of cat bonds. Factors of importance to the analysis are the nature of the collateral investments in asset backed securities and collateralized debt obligations (CDOs), which were highly affected by the crisis, as well as TRS counterparties' credit rating decrease (Towers Perrin, 2009). These events brought uncertainty in the cat bond market and there was a sharp decrease in new issues during the six months following the Lehman's collapse.

This downward trend lasted for less than a year after which the market started to recover. This process was marked by the change in the bonds' collateral investment. More transparency and greater restrictions were imposed to TRS counterparties, while at the same time new features such as collateral top-up provisions were added (Towers Perrin, 2009). This has facilitated the execution of a due diligence process which has helped investors when they are deciding about their future investment plans. Also, restrictions that allowed only the use of government-backed securities as collateral investments were introduced for some deals (Fritsch and Laplante, 2008). There now exists the possibility for the swap counterparty to be changed for another if necessary (Towers Perrin, 2009). Other deals were established as event structures which did not involve TRS counterparty at all (Towers Perrin, 2009). Thus, as more information becomes available to the market participants and collateral is invested into more stable and less risky securities, the premiums paid to investors should decrease.

In general, catastrophe bonds have performed well in these times of uncertainty and remained resilient, which makes them an important part of the financial sector. Transactions costs were reduced, as well as the time needed for a transaction to be completed (Guy Carpenter & Company LLC, 2010). After a short period of fluctuation, the market has picked up again and grew stronger in 2009 and the beginning of 2010. Along with the overall market upturn, catastrophe bonds' increased performance was facilitated by the low hurricane activity in 2009 (Guy Carpenter & Company LLC, 2010). The quick recovery of the market and its increasing liquidity levels are among the main reasons why analysts claim that it keeps maturing and that catastrophe bonds can endure the shocks of the negative global financial trends.

1.2. Problem discussion

During the past decade a number of articles and research papers have been published about catastrophe bonds and their undisputable advantages. Speculations about their minimal correlation with major financial indices and the stabilizing effect they have on investors' portfolios have continued since their inception. Catastrophe bonds have shown that they often perform at a higher level than expected and deliver excess yields. Not only that, but their easy to understand way of working is attractive to investors (the risk, the geographical zone and the trigger are known in advance and do not change), something that is not always true when investing in other types of securities (Guy Carpenter & Company LLC, 2008).

However, since their inception in the early 1990s up until 2008, no major financial catastrophes have occurred in order to test their endurance and whether their features would remain resilient under the pressures of a crisis (Gusman, 2009). The credit crisis provided proof that any market segment can be affected by it, including the insurance/reinsurance market through the collapse of Lehman Brothers. In response to the crisis, the structure of catastrophe bonds has changed and it is becoming safer and more transparent. In several transactions after 2008 no TRS counterparties were used at all (Towers Perrin, 2009).

A selection of pricing models for catastrophe bonds will be reviewed later in the thesis and the variables determining their price will be explored. During the course of this research it has been noticed that the existing pricing models do not include a variable, reflecting the change in

catastrophe bond structure that occurred after 2008. It is expected that the spreads of catastrophe bonds will tighten with some lag after the financial crisis mainly because of their safer and more transparent structure and the lower risk for investors. Therefore, it is considered that the topic should be further explored and a variable reflecting the changed bond structure should be included in the pricing models. Thus, the main research question can be defined as:

Will the change in the catastrophe bond structure significantly affect catastrophe bond prices and if so, will these changes have a positive or negative effect on prices?

It is believed that this would be a strong topic for future research and it would be advisable to investigate whether the potentially significant impact on prices will remain stable in the years to come when the effects of the financial crisis will have vanished completely.

We hope that this study would contribute to the knowledge of catastrophe bonds and their pricing models and will be value-adding to researchers in the area. We expect that our work would be of interest to catastrophe bonds consulting companies, catastrophe bonds' issuers interested in the accurate timing of bonds and rating agencies. Moreover, the conclusions drawn in this paper might be beneficial to the future development of the regulatory framework of the insurance-linked securities market.

1.3. Purpose

The main purpose of this work is to investigate whether the price of catastrophe bonds would be significantly affected if a dummy variable reflecting the change in the catastrophe bond structure is incorporated into the reviewed pricing models.

1.4. Delimitations

The study is a subject to several delimitations. Catastrophe bonds issued before 2004 are excluded from the analysis since the number of these is small and the market during this period was not significantly developed. Also, only the primary catastrophe bond market is analyzed in the research; therefore, the secondary ILS market remains beyond the scope of this work. The main aim of the thesis is not to explain what the price of catastrophe bonds should be, but to

prove the presence of any significant effect on prices precipitated by the structural change of bonds.

1.5. Target Group

The study may be of interest to researchers in the field of insurance and reinsurance, to lecturers and students in business schools, to the general academic audience, as well as any other groups that hold a keen interest in the researched topic. Furthermore, it might be beneficial to issuing and consulting companies in the insurance/reinsurance market, regulators in this field, as well as any other businesses which are affected by the development of this sector.

1.6. Thesis outline

This thesis will be developed as follows: in Chapter 1 we introduced the subject and gave a brief overview of the latest trends in the catastrophe bond market. We presented the problem and outlined the purpose of our research. In Chapter 2 we provide theoretical background of the issue including relevant research that has been carried out so far and outlining the way catastrophe bonds work and their specific characteristics. Also, we review several catastrophe bond pricing models, which will serve as a theoretical basis for our further research. In Chapter 3 the methodology that the current work follows is presented and arguments about the choice of methodological approach are given. Chapter 4 presents our empirical analysis and findings and the results of the performed tests. Chapter 5 is an analytical chapter in which we discuss our findings and present our arguments for what we have observed. Chapter 6 is a concluding chapter which summarizes the overall outcome of our work and gives recommendations for future research in the area.

2. THEORETICAL BACKGROUND CHAPTER

In this section an overall view of the development of modern theories related to catastrophe bonds will be presented. We will also recap the characteristics of catastrophe bonds and how they work. Further attention will be paid to several catastrophe bond pricing models as these will be outlined and an explanation of their relevance to our research will be provided.

2.1. Recent catastrophe bond theoretical research

Insurance-linked securities (ILS) refer to the securities with insurance aspect which cede insurance-related risks to the capital markets. Analysts usually categorize ILS by risk type (property/casualty (P&C) and life risks), as well as by the amount of risk (catastrophe and non-catastrophe risks) (Brookvine Pty Limited, 2010). By issuing catastrophe bonds, insurance and reinsurance companies aim to cover their P&C catastrophe risk (deriving from earthquakes, hurricanes, windstorms, etc.) and to transfer it to the capital markets (Swiss Re Capital Markets, 2006). These companies sell the securities to the market and raise capital which is used provided a pre-defined loss event (usually a natural disaster) occurs and the bond is triggered. At the same time, investors receive an attractive return (Cummins, 2008). Analyses show that catastrophe bonds' triggers are mainly connected to the characteristics of a natural disaster, but recently there has been a tendency for man-made risks like terrorism, nuclear accidents or war to be insured (Koller, 2008). If the catastrophic event occurs, the principal paid by investors and possibly part of their coupon are used to cover the losses. If no event occurs, investors receive their coupon payments, and also get back the initial amount of principal paid (Bodoff, 2009).

A significant amount of research has been carried out about the essence of catastrophe bonds, the development of the market and their pricing methodologies. The interest in this field has grown during the past five years, after hurricanes Katrina, Wilma and Rita hit in 2005 and especially after the financial crisis has started to develop in 2007. Valuable surveys of the ILS market's development were presented by Cummins (2008), Culp and O'Donnell (2009), Gatumel and Guegan (2008) and Ozizmir (2009). Some of the major characteristics of the ILS market are outlined in Appendix (I).

Cummins (2008) presents an evolutionary view of the overall development of the market for catastrophe risk up until 2007 and the place that catastrophe bonds hold in it. Catastrophe bonds are presented as fully collateralized event-linked bonds which have enjoyed great success during the relatively short history of their development and possess numerous advantages over traditional reinsurance. More focused on catastrophe bond pricing and the components of catastrophe bond spreads is the work of Gatamel and Guegan (2008). They explore the Lane Financial LLC Model, the Fermat Capital Management model and the Wang model and use them in order to explain the components of catastrophe bond spreads. Culp and O'Donnell (2009) research the development of the catastrophe bond market during the recently experienced financial crisis and the effect it had on catastrophe bond spreads and the overall market capacity. Furthermore, the advantages and disadvantages of these sources of risk capital are presented while the financial crisis' effects are taken into consideration. Another valuable survey is presented by Ozizmir (2009). It outlines the effects of the Lehman Brothers' collapse on the ILS market and presents valuable views about its future development. All these studies provided us with a sound theoretical base for developing our research.

Moreover, pricing methodologies which were found to be of significant relevance to this work were developed by Bodoff (2009), Papachristou (2009), and Lane and Mahul (2008). These models are reviewed in more detail later in the work.

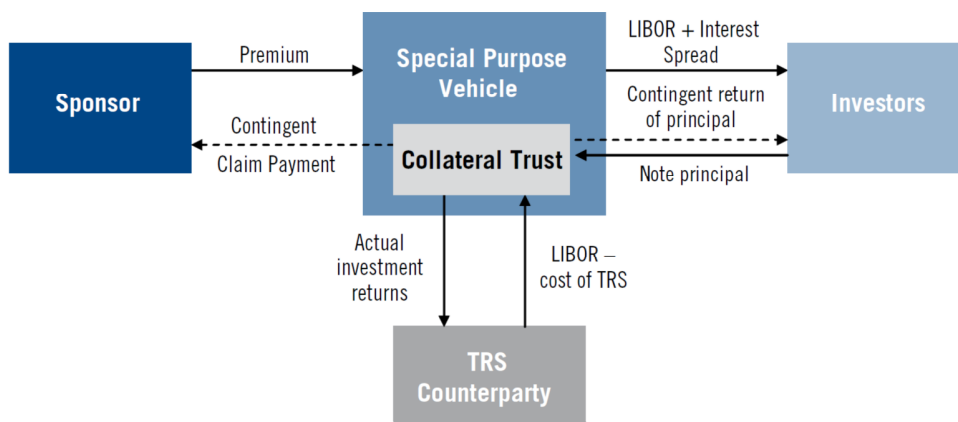
Of extreme importance to the empirical analysis are the reports by major rating agencies (Standard & Poor's, A.M. Best, etc.) and financial services companies such as MMC Securities, Towers Perrin, AON Benfield, Lane Financial LLC, etc.

This chapter continues with outlining the structure of catastrophe bonds and will touch upon the major principles under which they work. Later, an overview of catastrophe bond triggers and their ratings will be presented. Finally the theoretical pricing models which are of relevance to our research will be described.

2.2. Catastrophe bonds structure

The aim of this section of the research is to analyse the special place that a TRS counterparty holds in the structure of the bonds. Therefore, a brief review of the mechanics of catastrophe bonds and the separate parts of their structure will be made. The typical structure of a catastrophe bond connects its parts through a Special purpose entity/vehicle (SPE/SPV) (Figure 2.1).

Figure 2.1: Catastrophe bond structure



Source: Towers Perrin, 2009

As part of the ILS market, sponsors in these structures are insurance and reinsurance companies which make the initial efforts to set up the catastrophe bond via a remote special purpose vehicle. Insurance/reinsurance companies enter these contracts mainly to transfer the risk of their portfolios to third parties and to remain able to serve their debt if a major natural disaster occurs (MMC Securities, 2006). Third parties are represented by investors like hedge funds, specialized catastrophe funds and asset management companies. Other external participants include legal firms, modeling companies, rating agencies, etc. (MMC Securities, 2006).

The major advantages to sponsors issuing catastrophe bonds are:

- In case of a loss, it can be fully covered because of the total collateralization of the structure (MMC Securities, 2006)

- There are cases whereby it is cheaper to insure risk through catastrophe bonds than by traditional reinsurance (Lakdawalla and Zanjani, 2006)
- Catastrophe bonds are a source of diversified risk capital to the sponsor (MMC Securities, 2006)
- The use of catastrophe bonds is a reasonable measure which would reduce any risks coming from the traditional reinsurance market (MMC Securities, 2006)

On the other hand, a couple of disadvantages are connected to catastrophe bonds from the sponsors' point of view, namely that the yield paid to investors is relatively high (spreads for some catastrophe bonds have reached 2500 and even 3000 bps, e.g. Successor II E-III, Successor I B-1 and B-2), while at the same time sponsors need to pay administrative costs for setting up the SPV. Also, disadvantages might derive from the chosen trigger mechanism, since some of them involve higher basis risk (e.g. index-linked triggers) (Koller, 2008).

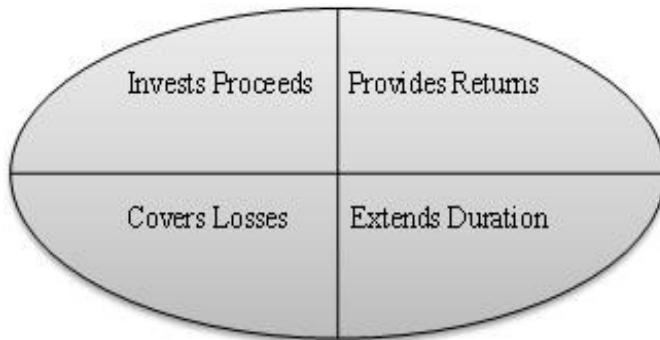
Investors in catastrophe bonds are attracted to the high premium over the risk they take. They benefit from investing in catastrophe bonds since the returns they would receive from these investments are largely uncorrelated with those of other financial instruments (e.g. corporate bonds). This makes them extremely appealing to investors looking for diversification of their portfolios. A negative feature of catastrophe bonds from the investors' point of view is that these instruments are relatively illiquid assets (Dixon, 2004).

As in other securitization transactions, the special purpose vehicle is an independent and bankruptcy remote entity which issues catastrophe bonds and acts as a main entity to all contracts and transactions. In cases whereby the cat bond is triggered, the SPV would use the proceeds from the investment in order to reimburse the losses that the sponsor has suffered (Culp and O'Donnell, 2009).

Being one of the most important structure units, the total return swap (TRS) counterparty has several main roles (Figure 2.2). Firstly, on the closing day of the transaction, TRS counterparties invest the proceeds of the collateral in stable and high-quality assets. Secondly, the counterparty provides investors with LIBOR rate investment returns (after subtraction of the cost of the swap). The real amount earned from the trust assets does not matter and investors receive their return

irrespectively. Thirdly, in the event that the bond is triggered, the TRS counterparty frees the collateral assets in order to cover the losses that the sponsor would suffer and pays back the principal to the investors according to the contract. Finally, if required, the swap dealer can extend the duration of the total return swap contract accordingly (Towers Perrin, 2009).

Figure 2.2: TRS counterparty functions.



Source: Towers Perrin, 2009

As shown above, the TRS counterparty has a particularly important place in the cat bond structure mainly because it is responsible for covering the losses in the case of a natural disaster. The mechanics of the catastrophe bond structure are presented in Appendix (II).

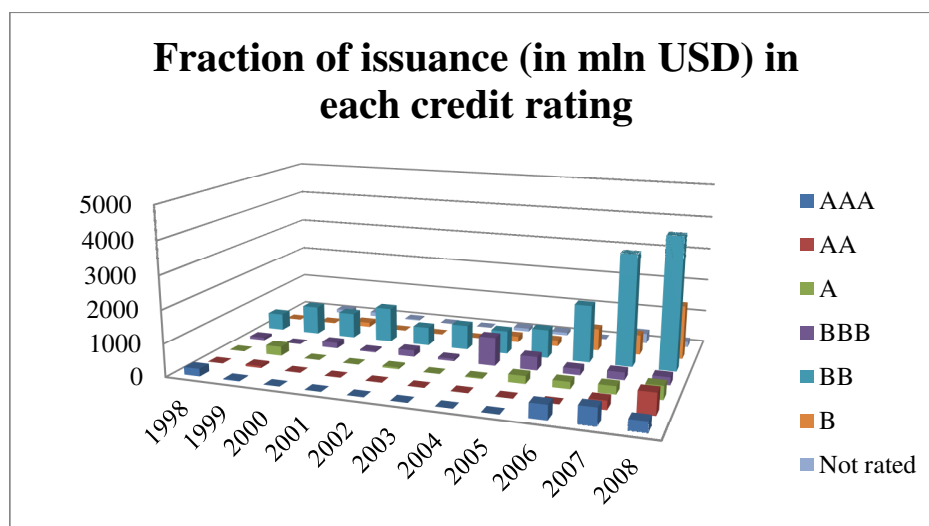
The structure of catastrophe bonds, which use a TRS counterparty, was significantly affected during the recent financial crisis after the collapse of Lehman Brothers. Further analysis on the changes that followed these events will be done later in this work and an explanation of their significance will be made.

Catastrophe bond transactions also benefit from the services provided by a modeling company, i.e. a company that consults sponsors about setting up the structure, provides models that derive the expected amounts of insurance risk and gives advice on the type of trigger mechanisms. This company also provides data to rating agencies and investors about the risks involved and the expected loss calculations (Koller, 2008).

Rating agencies can significantly influence bonds' pricing and their demand since the investment grade of the bond is one of the main factors that would attract investors to buy it. Rating agencies rely mostly on data provided by modeling companies and their risk calculations (Koller, 2008).

Catastrophe bonds are rated by major rating agencies such as Standard & Poor's, A.M. Best, Moody's and Fitch. The majority of the ratings given to catastrophe bonds are below investment grade (usually BB or B), but there are also cases when A or AA ratings are given (Koller, 2008) (Figure 2.3).

Figure 2.3: Catastrophe bond credit ratings



Source: Lane Financial LLC, 2008

Rating agencies have different methodologies which they use to rate catastrophe bonds, but the probability of default is one of the main factors that is common to all of them. Another important factor which takes part in the valuation process of catastrophe bonds is the type of trigger chosen for the transaction. (A.M. Best, 2008)

After hurricane Katrina occurred in 2005, rating agencies started reviewing their methodologies when rating catastrophe bonds and assumed a greater probability that cat bonds would be triggered. In order to maintain the same ratings, these agencies required additional capital to be set aside by insurers (Patel, 2006). This adds a certain level of safety to catastrophe bonds, but still does not mitigate the credit risk involved in these structures. Furthermore, it increases the costs for supporting these securities.

Catastrophe bonds normally have a tenor longer than one year, usually between two and five years. To compare, in most cases reinsurance contracts have maturities of one year (Fritsch and Laplante, 2008). Longer maturities have their advantages, e.g. they help to avoid short-term

volatilities in reinsurance prices. At the same time, they allow issuers to amortize costs over extended periods, which would reduce their expenses (Sullivan and Prestia, 1998). However, bonds that have duration of more than five years carry disadvantages since they do not allow for new market information to be incorporated in their price. (Fritsch and Laplante, 2008) For the current analysis, this would mean that events such as the financial crisis could have a detrimental effect on catastrophe bonds whose structure does not take into consideration the increase in credit risk in crisis periods. Therefore, if catastrophe bonds' maturities are to remain the same, the TRS counterparty, as the main conductor of credit risk, should change in order to mitigate to some extent the threats that long maturities impose. This is what was observed after 2008 when the TRS component became safer or was generally removed from the catastrophe bond structure.

2.3. The change in catastrophe bond structure

Of particular importance to the analysis contained within this research is the change in catastrophe bond structure which took place after the collapse of Lehman Brothers in 2008. Since the aim of this work is to investigate whether the change in the structure has had an effect on the pricing of catastrophe bonds, it is necessary to perform an analysis on how and why this structure changed.

The TRS counterparty holds a significant place in the catastrophe bond structure since it provides investors with returns (LIBOR and spread), while at the same time, in cases where a catastrophe bond is triggered, the TRS counterparty would free the collateral assets in order to cover the suffered losses (Towers Perrin, 2009). It also means that the counterparty bears the risk of reduction in the value of the collateral assets but irrespective of that it is obliged to pay for the suffered losses.

If an event that triggered a cat bond occurred along with either a default of the TRS counterparty or a decrease in the value of the collateral assets, the sponsor might bear extreme losses. Such was the case of Lehman Brothers which filed for bankruptcy protection on September 15th, 2008. Two weeks later, on September 30th, 2008, Standard & Poor's revised the ratings of four catastrophe bonds (namely Willow Re 2007-1, Ajax Re Class A, Carillon Ltd. Re Series 1, and Newton Re Class A 2008-1) whose TRS counterparty was Lehman Brothers, and downgraded

them (Culp and O'Donnell, 2009). The reason for this was the fact that the collateral held by Lehman Brothers was comprised of low-quality assets such as mortgage-backed securities. As soon as the credit crisis hit the USA, these assets lost their value causing the downgrade of the catastrophe bonds. In normal circumstances, the TRS counterparty would cover the decrease in value of these assets, but Lehman Brother's collapse made that impossible and meant that the losses could not be recovered (Culp and O'Donnell, 2009).

Tower Perrins (2009) presents several major reasons why a default of the TRS counterparty was possible in this case. First, the structure of the collateral assets, including asset-backed and mortgage-backed securities suffered great impairment as a result of the credit crisis. Second, the maturity of those assets reached numbers as high as 40 years, while the catastrophe bonds' usual maturity period was between two and five years. This caused a great mismatch in duration which brought concerns among the investors, since the decrease in asset values had occurred simultaneously with the decrease in the TRS counterparty's creditworthiness. Third, no rules on how often and to what extent the collateral assets should be monitored were strictly established². After Lehman Brothers collapsed, an unregulated situation whereby sponsors desperately tried to change their swap dealers occurred. Moreover, the operational efficiency worsened after investors started requesting information on the collateral assets they were investing in.

These factors made it clear that there was a great need for change in the TRS mechanism and the catastrophe bond market quickly reacted to this. Investors started looking for exposures to only natural perils and for ways to minimize credit and counterparty risks as much as possible. Consequently, the catastrophe bond structures built after the Lehman Brothers' collapse were much more transparent (Fritsch and Laplante, 2008). A well-established turn from the previously used structures appeared in 2009. From all 15 transactions in that year, only four were structured with the use of a swap dealer, and they closed in the first quarter of 2009. Moreover, those four transactions had established strict rules on the type of collateral that could be used – in case of mark-to-market losses, the swap dealer would have to post additional collateral (Standard & Poor's, 2010).

² Regulations are of particular importance to the future development of the ILS market. These issues are becoming more and more important nowadays. This is proved by the views of some analysts who see regulatory problems as one of the major reasons behind the recently experienced financial crisis (Blundell-Wignall, A., 12th Annual SNEE European Integration Conference, Mölle, 2010)

Overall, the change in the catastrophe bond structure took two directions – either a modified and improved form of the existing TRS counterparty or no counterparty at all. The improvement in the TRS took the form of collateral investments in government-guaranteed assets, treasury bills and money market funds, which were observed in the most recent cat bond transactions (Fritsch and Laplante, 2008). The new structure provides investors with more security, while at the same time still pays LIBOR and a spread to investors for the risk taken (Boucher, 2009).

To conclude, the actions taken after the default of Lehman Brothers provide investors with a new transparent and secure structure which is based on sound and strict rules and monitored regularly. Such actions include (Tower Perrins, 2009):

- The collateral assets now include cash, government-backed bonds and other government-backed securities;
- Illiquid or “hard-to-price” assets are excluded from the collateral;
- There was an improvement of the duration matching of the collateral and the catastrophe bond; extension periods are also allowed;
- Rules which require the underlying collateral to be marked-to-market on a daily basis are established.

The analysis carried out in the following chapters aims to investigate how this change has affected the price of catastrophe bonds.

2.4. Trigger Mechanisms

Trigger mechanisms are a significant feature of catastrophe bonds since they determine under what conditions the bond is triggered, i.e. when the losses incurred by the natural disaster should be covered by the catastrophe bond. Triggers are one of the determinants of Cat bond prices and are used as a variable in one of the pricing models reviewed later in our work (Papachristou, 2009). Therefore, they are of particular relevance to our analysis and a brief review of the main trigger types will be made in this section.

Based on the information about the trigger, agencies and reinsurance companies give advice about the transparency of the bond and the amount of basis risk involved. There are six trigger

mechanisms which are most widely used and their main characteristics are presented below (Cabrera, 2006).

When using an indemnity trigger, of importance are the sponsor's actual losses caused by the insured event (Cabrera, 2006). The real level of loss determines the amount of reimbursement that the sponsor should receive; therefore there is a limited amount of basis risk incorporated (Cabrera, 2006). However, there is a need for the sponsor to disclose more information, which means that there is a possibility of a moral hazard occurring (MMC Securities, 2006).

The amount of reimbursement with the industry index trigger depends on the losses suffered by the industry as a whole (Cabrera, 2006). The loss is measured by various indices (e.g. Property Claims Services in the USA). There is no need for the sponsor to disclose any specific information, but this trigger type involves higher basis risk, while at the same time possible payouts in the event of loss tend to require a longer time period to clear (MMC Securities, 2006).

In the case of a pure parametric trigger, the recovery is based on the actual physical and objective characteristics of the catastrophic event like magnitude (for earthquakes), speed of wind (for hurricanes), geographic location, etc. (Cabrera, 2006). The actual losses suffered by the sponsor are not taken into account with this mechanism, which implies higher basis risk (MMC Securities, 2006). However, some authors state that this trigger has definite advantages since it is information-insensitive and reinsurers receive objective information about portfolios' risk, therefore the investment process is not affected by adverse selection (Brandts and Laux, 2007).

With the parametric index trigger, the sponsor's exposure to losses from different perils and in different zones is weighted and an overall parametric index trigger is arrived at (Cabrera, 2006). This type of trigger involves lower basis risk than the pure parametric trigger (A.M. Best, 2006).

When using the modeled loss trigger, the losses to the sponsor are determined by a modeling firm, which uses the actual physical and objective parameters of the natural disaster to create and run a model that determines the amount of expected losses. If the estimates of the model are above a certain predefined level, the bond is triggered. (Cabrera, 2006)

Finally, the mechanism of hybrid (multi) triggers uses two or more of the above mentioned trigger types in order to be combined and used in one separate transaction. This makes the process more flexible, while at the same time basis risk is lowered. Also, there is no moral hazard issue, but the structure that is built could sometimes be more complex and investors might find it difficult to understand (MMC Securities, 2006).

2.5. Catastrophe bonds pricing models

The main purpose of catastrophe bonds is to transfer the risk of property/casualty catastrophe loss to the credit market (investors) (Swiss Re Capital Markets, 2006). During this process investors provide capital which later can be used to recover potential losses from a catastrophic event. This is beneficial to both sides of the catastrophe bond contract, as insurers and reinsurers hedge the catastrophe risk while investors gain returns on their capital in the form of coupon payments on the bonds (Bodoff, 2009). Early studies on catastrophe bond pricing were conducted by Cox and Pedersen (1997), Schmock (1999) and Tilley (1997). Most authors do not try to estimate what the price of a catastrophe bonds should be but instead explain the main factors which influence the prices and measure their effect using various statistical models (Papachristou, 2009). This research is based on some of the most recent studies made by Bodoff (2009), Lane and Mahul (2008) and Papachristou (2009) which will be described later in this part.

2.5.1. Catastrophe bonds pricing principles

The price of catastrophe bonds³ is normally comprised of two main parts. (Bodoff, 2009). On one hand, since the maturity of catastrophe bonds varies usually between two and five years, investors are reimbursed for the time value of their money. They receive interest payments normally based on the LIBOR rate (Bodoff, 2009). On the other hand, since investors bear the risk of a possible catastrophe loss, they receive a premium which compensates them for this risk as well; usually this premium is also called “risk spread”, “spread over LIBOR”, “premium spread” and “spread” (Bodoff, 2009). Therefore, the total coupon rate can be defined as:

$$\text{Total coupon rate \% to investors} = \text{LIBOR \%} + \text{premium spread \%} \quad (1.1)$$

³ The price of catastrophe bonds is defined as the coupon rate received by investors (Bodoff, 2009)

As LIBOR is designed to compensate for the time value of money, the price can be defined as:

$$Price = premium\ spread\ \% \quad (1.2)$$

As the price represents the risk transfer and a probability of bond default, investors take into account the expected loss, which is usually calculated by a modeling firm (Bodoff, 2009). Generally, the premium spread is larger than the modeled expected loss, since the spread should be able to cover the average loss and also provide additional positive rate of return (margin) (Bodoff, 2009). Therefore, the following standard pricing model was devised:

$$Premium\ spread\ \% = expected\ loss\ \% + margin\ \% \quad (1.3)$$

Experts in the catastrophe bond market often calculate the premium spreads as a “multiple of expected loss” (Bodoff, 2009). Therefore:

$$Premium\ spread\ \% = expected\ loss\ \% * multiple \quad (1.4)$$

The multiple is dependent on the amount of expected loss. If the expected loss is high, according to Bodoff (2009), the multiple is low; if the expected loss is relatively low, the multiple would be higher. However, quotation (1.4) is not widely used by researchers because it does not provide an explanation of the main factors which influence the price.

The pricing models, on whose basis we have constructed our study, are built on these basic pricing principles. A detailed description of the original pricing models is presented in the following sections.

2.5.2. Bodoff pricing model

Bodoff (2009) has developed a model with a focus on the peril adjustment of the price. He suggests that the premium spread over LIBOR should be able to cover the expected loss while providing an “additional positive rate of return on capital” (previously described as “margin”). It is also suggested that the overall risk exposure of the portfolio would depend on the specific perils which are covered (Bodoff, 2009). Thus, a simple linear model can be defined:

$$Spread\ \% = expected\ loss\ \% + peril\ specific\ margin\ \% \quad (2.1)$$

From this point of view, this model is similar to other existing models because the premium for the risk taken is seen as an additional rate of return (Bodoff, 2009).

Moving onward, Bodoff (2009) describes the margin as an increasing function of expected loss and presents another linear model:

$$\begin{aligned} \textit{Peril specific margin \%} &= \textit{peril specific flat margin \%} \\ &+ \textit{peril specific factor} * \textit{expected loss \%} \end{aligned} \quad (2.2)$$

and after combining functions (2.1) and (2.2) comes up with an absolute linear function:

$$\begin{aligned} \textit{Spread \%} &= \textit{peril specific flat margin \%} \\ &+ \textit{expected loss \%} * (1 + \textit{peril specific factor}) \end{aligned} \quad (2.3)$$

Further, the final function for each peril is:

$$\textit{Spread \%} = \textit{constant \%} + \textit{loss multiplier} * \textit{expected loss \%} \quad (2.4)$$

The “loss multiplier” reflects the uncertainty when calculating the expected loss (Bodoff, 2009). The real value of the expected loss is unknown; in reality, modeling firms provide only estimates of the expected loss which can vary significantly from each other (Bodoff, 2009). Thus, having the uncertainty in the estimated expected loss, the model is adjusted by a “loss multiplier”.

Bodoff (2009) uses the type of peril as one of the main determinants of catastrophe bond prices. After applying the model to different peril types, also categorized by geographic zones, Bodoff (2009) differentiates the peril/zone parameter into “peak” (USA Wind and California Earthquake (EQ)), “non-peak” (non-peak European Wind and Japanese EQ) and “Diversifying” (Japanese Wind, Australian EQ, Mexico EQ, Mediterranean EQ, Central USA EQ, and Pacific Northwest USA EQ). The empirical results suggest that the “constant” in the model (2.5) varies by zone (peak versus non-peak) and the “loss multiplier” varies by peril (Wind versus EQ). Bodoff (2009) combines all perils into a single uniform model:

$$\begin{aligned}
\text{Spread \%} &= \text{Constant}_{\text{All}} \% \\
&+ \text{Additional Constant}_{\text{Peak}} \% * \text{Peak Peril Indicator} \\
&+ \text{Additional Constant}_{\text{Diversifying}} \% * \text{Diversifying Peril Indicator} \\
&+ \text{Loss Multiplier}_{\text{EQ}} * \text{Expected Loss}_{\text{EQ}} \% \\
&+ \text{Loss Multiplier}_{\text{Wind}} * \text{Expected Loss}_{\text{Wind}} \%
\end{aligned} \tag{2.5}$$

Peril indicators are used as dummy variables which reflect the bond's belonging to a specific zone/peril group. As expected by the author, the “Constant_{Diversifying} %” variable has a negative sign because a diversifying peril is characterized by a lower required rate of return on capital and also a lower intercept than other perils (Bodoff, 2009).

The presented model is used in the research as one of the basis test tools.

2.5.3. Lane pricing model

The model developed by Lane and Mahul (2008) aims at explaining the ILS pricing principles and describing the relationship between capital and bond prices. Lane and Mahul (2008) use data about the premium spread over LIBOR and the catastrophe bond expected loss and present a simple linear model:

$$\text{Spread} = a + b * (\text{Expected Loss}) \tag{3.1}$$

If $a = 0$, Lane and Mahul (2008) suggest that the spread is proportional to the expected loss. If $b > 1$, the spread includes a “load” above the expected loss (Lane and Mahul, 2008). The model incorporates some insurance pricing principles stating that:

$$\text{Spread} = \text{Function} (\text{Expected Loss}, \text{Load}, \text{Other Expenses}) \tag{3.2}$$

Later, Lane and Mahul (2008) test empirically the model and conclude that the price depends significantly on the expected loss, but the model itself may predict the price in an inaccurate way. However, it proves that the price carries a certain load which, in its simplest linear version, is the amount above the expected loss (Lane and Mahul, 2008).

Lane and Mahul (2008) use a five and a ten year time period for testing the model. The ten year period proves to be more reliable since it involves two full market cycles but in the same time it includes the unstable period of low issuance from the end of the 1990s. The five year period includes recent issues which have taken place in a more predictable ILS market (Lane and Mahul, 2008).

Developing the model further, it is adjusted for the market cyclicity, since market conditions experience changes and move from “hard” to “soft” ones. This gives the model a certain level of stability and provides it with the opportunity to come up with a cycle-adjusted price (Lane and Mahul, 2008). In order to measure the market cycle, the authors use the Paragon index reported by Guy Carpenter & Company LLC which reflects price movements for the period 1984-2000. After that, Lane Financial LLC built an innovative index based on observations from the ILS and ILW market, as well as expected loss series from Swiss Re Capital Markets original issues (Lane and Mahul, 2008). This was the index used to measure the market cycle from 2000 onwards. This index can have values of above or less than 1 depending on whether the market is hard or soft respectively. Thus, the adjusted model is:

$$(\text{Spread})_t = a + b * (\text{Expected Loss}) + c * (\text{Cycle Level})_t \quad (3.3)$$

If $a = 0$, the cycle level can be viewed as a load factor, which is not connected to the expected loss and experiences volatility through time. It can also be defined as an estimate of the capital load which is related to the market cycle; thus, during a hard market when supply cannot cover the demand the cost of capital rises. On the other hand, during a soft market, i.e. when excess capacity exists, the cost of capital is lower (Lane and Mahul, 2008).

Later, the model is applied to a data sample categorized by perils, whereby different levels of expected loss are associated with different types of peril (Lane and Mahul, 2008).

This model will also be used in the present work for hypothesis testing and in comparison with other presented models.

2.5.4. Papachristou pricing model

The last model which serves as a basis in our research is the Papachristou (2009) pricing model which combines not only the market cyclicity and peril/zone factors but also the trigger type factor.

Papachristou (2009) examines the factors that affect catastrophe bond prices and measures their effect on bonds' prices. In order to test the model, Papachristou (2009) uses data comprised of catastrophe bonds issued between January 2003 and July 2008.

After testing previously developed models, Papachristou (2009) suggests that the preferred model is a multiplicative one (4.1). After empirically examining the relationship between spread and expected loss, the author concludes that the initial model resembles a linear one but the fit is not completely correct with lower values of expected loss. Thus, Papachristou (2009) suggests the following model to start with:

$$\text{Log}(RL_i) = f(\text{log}(EL_i)) + f_2(\text{time}_i) + \text{Peril/Territory}_i + \text{Trigger}_i + \varepsilon_i \quad (4.1)$$

where RL_i is the risk load, EL_i is the expected loss, f is a smoothing function, Peril/Territory and Trigger are factor variables and the ε_i is an i.i.d. $N(0, \sigma_2)$ random variable.

According to Papachristou (2009), it is difficult to find a single model which fits the characteristics of all catastrophe bonds. This could be explained with the fact that the market cycle varies according to different territories. The volatility of the spreads for US bonds is slightly higher than that of other zones. Consequently, Papachristou (2009) divides the data into two groups and develops two different models – for catastrophe bonds including US perils and another one for bonds including other types of perils.

Thus, two pricing models are suggested. The model covering US perils is defined as:

$$\text{Log}(RL_i) = S(\text{log}(EL_i)) + NS(\text{time}_i) + \text{Peril/Territory}_i + \text{Trigger}_i + \varepsilon_i \quad (4.2)$$

Where RL_i is the risk load, EL_i is the expected loss, time_i is the date of issue of the bond, Peril/Territory_i is a discrete variable with three levels (Papachristou, 2009):

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

$Trigger_i$ is also a discrete variable with two levels (Papachristou, 2009):

1. Indemnity;
2. Other;

and ε_i is an i.i.d. normally distributed error with zero mean. The function S is a smoothing spline and NS is a natural spline.

The second model covering non-US risks is:

$$\text{Log}(RL_i) = S(\text{log}(EL_i)) + \text{lo}(\text{time}_i) + \text{Peril/Territory}_i + \text{Trigger}_i + \varepsilon_i \quad (4.3)$$

Where RL_i is the risk load, EL is the expected loss, $time$ is the date of the issuance of the bond, $Peril/Territory_i$ is again a discrete variable with three levels (Papachristou, 2009):

1. European Storm and Japanese Typhoon;
2. Japanese Earthquake;
3. “Non- peak” Territories;

$Trigger_i$ is also a discrete variable with two levels (Papachristou, 2009):

1. Industry Loss and Modeled Portfolio trigger;
2. Parametric and Parametric Index trigger;

and ε_i is an i.i.d. normally distributed error with zero mean. The function S is a smoothing spline and lo is a locally fitted polynomial.

The model developed by Papachristou (2009) is tested in the thesis in order to define the structural change effect on catastrophe bond prices.

2.6. Hypothesis

After analyzing the development of the catastrophe bond market and its effects, one can conclude that after the financial crisis hit and particularly after the collapse of Lehman Brothers, catastrophe bonds' structure has undergone significant changes. As mentioned in the previous parts of the thesis, it has become safer and more transparent for two main reasons. First, the collateral investments are now less risky since they include US treasury money market funds, government-backed assets and tri-party repurchase agreements. For other transactions no TRS counterparty was used at all which completely eliminates credit risk.

Our hypothesis is:

H₀: The structural change of catastrophe bonds, whereby the collateral investment becomes safer or the structure does not involve a TRS counterparty at all, exerts a downward pressure on bonds' spreads.

This would mean that there would be a reduction in catastrophe bonds investment returns since the risk exposure for investors would be lowered. By conducting our further analysis we aim at proving or discarding the above-mentioned hypothesis.

We are aware that the current market situation is such that it might influence the results of our analysis. Spreads might be affected by the current market cycle and the severe effects of the global financial crisis. Therefore, a purification of the pricing models by adjusting them for the effects of the financial crisis is needed. However, our aim is not to estimate what the price of the bonds should be, but to see whether the structural change will have any significant effect on their prices.

3. METHODOLOGY CHAPTER

In this chapter we will review the problem of the thesis and will describe the methodology we use in order to prove our hypothesis. Moreover, we will describe our data collection approach, whether we exclude any part of the data available and how we adjust the reviewed pricing models in order to test our hypothesis.

3.1. Review of the problems

As described previously, the catastrophe bond structure has changed significantly after the Lehman Brothers' collapse in 2008. We expect this change to affect the price of catastrophe bonds since their structure becomes safer and more transparent. In order to develop our analysis we review several catastrophe bond pricing models and incorporate a dummy variable reflecting the change in bonds' structure into them. This would provide us with results showing the extent to which the structural change affects the price of catastrophe bonds. Our general expectations are that the catastrophe bonds' spread would tighten and that the regression models will demonstrate a negative sign for the incorporated factor.

3.2. Methodological approach

The overall methodological approach used in the thesis is the quantitative inductive approach. The inductive approach means that general conclusions are made on the basis of empirical findings (Smith, 2007). We use this approach since we reached the problem of the thesis after performing a trend analysis and making observations regarding the change in structure of catastrophe bonds, i.e. we start from facts and based on these facts we create a hypothesis and move towards theory. Based on the observations regarding catastrophe bonds issued after 2004 we aim at exploring the effect that the structural change would have on the pricing of the bonds. In this sense, we expect to add to the existing catastrophe bond theory by further developing the reviewed pricing models.

By contrast, the deductive approach is a method whereby one uses a set of existing theories that lead to the formation of a hypothesis. This hypothesis is later tested with empirical data and accepted or rejected (Bryman, 2001). This approach would not be applicable to the present study since it involves the application of existing theories to empirical factors and therefore might omit the effects of new trends or laws formulated after the initial hypothesis. This method would therefore fail to provide us with the necessary level of flexibility required to generate reliable results.

The research topic itself often defines whether the overall methodological approach will be quantitative or qualitative. In the present work, the quantitative approach is more widely utilized as this study is based on and aims to obtain numerical, measurable values. The quantitative approach was considered to be the method that would yield the highest degree of objectivity and was therefore chosen as the most appropriate technique with which to form our hypothesis and analyze our data.

We use the Lane and Mahul (2008), Bodoff (2009) and Papachristou (2009) catastrophe bond pricing models as base models in order to test our hypothesis. We develop a comparative analysis of the results that each of these models would bring. Also, we construct dummy variables for the change in structure in catastrophe bonds, incorporate them in these models and test them in order to prove a statistically significant change in the bond price. For this purpose, an OLS regression analysis is run. This is done by the use of the statistical software EViews and the Statistical Package R.

Our data consists of a fixed number of observations and has the characteristics of cross-sectional data. Thus, we observe the features of catastrophe bonds at a certain point of time, i.e. the moment of issuance in the primary market. Therefore, we do not follow the development of bonds' prices over time. We also test the data sample for multicollinearity, normality, heteroscedasticity and linearity which are the main assumptions by OLS regression model.

Chapter 4 of the thesis applies mainly the quantitative approach. Where applicable, qualitative reasoning will be sought and given. When exploring the change in catastrophe bond structure, there is a need to determine what does “safer” and more “transparent“ structure mean. The

criteria set for determining these categories are based on qualitative analysis of the collateral of all catastrophe bonds issued after September 2008. These criteria include TRS collateral investments in (Hills, 2010):

- U.S. Treasury money market funds;
- Government-backed assets;
- Tri-party repurchase agreements.

We assume these are safe investments because they are either backed by governments or involve a high level of liquidity, features which were not characteristic of the mortgage-backed securities. Also, catastrophe bond structures which do not involve a TRS counterparty are also considered to be safe and transparent for the purposes of the present work. This is assumed since such bonds do not carry any amount of credit risk.

3.3. Data collection

3.3.1. Sample data

The sample data needed to carry out the present research consists of all catastrophe bonds issued in the period 2004 - 2010. Due to the fact that catastrophe bond transactions are private and information about their details cannot be collected directly from the issuers, we have collected our data from the Standard & Poor's preliminary reports and full analyses about catastrophe bond deals (Ratings Direct database). They contain details about catastrophe bonds at the moment of their issuance and not information from secondary markets. The specific information that was needed for the conduction of the research was then manually extracted from these documents and fed into an MS Excel database. Where data was lacking, other sources of information were used. The most significant of them were the Lane Financial LLC annual reports and research papers. The data used contains details about the price of the bond, expected loss, the sponsor, issuer, maturity of the bond, swap dealer (if any), etc. The data about the presence of a TRS counterparty and the type of collateral investment is of particular empirical importance since this is the proof that the catastrophe bond structure has changed in the past two years.

Data about the market cycle is obtained through the Lane Financial LLC quarterly and annual reports. Of great significance to the pricing of catastrophe bonds is the information about “hard” and “soft” markets (Appendix, III). The market cycle is seen as one of the most important determinants of price. In order to achieve objectivity of results, we need to outstrip the effect of the cycle. For this purpose, indices reflecting the soft, hard and middle markets are introduced (Lane Financial LLC, 2009). We use the quarterly adjusted values of the ROL (Rate-on-Line) reinsurance index presented by Lane Financial LLC (2010) because this is the index which most closely reflects the development of the ILS market. We believe that even though the ROL index is based on quarterly adjusted values, in this case it is more reliable than the Volatility S&P 500 (VIX) index since the ILS market shows low levels of correlation to other financial markets.

Data about the amount of the bond and the trigger mechanism is also obtained from the S&P database and where necessary from the Lane Financial LLC and AON Benfield’s reports.

3.3.2. Excluded observations

Some observations (i.e. catastrophe bonds) were excluded from the analysis. These were bonds for the issuance of which there was not enough data or no reports have been published. Also, we excluded two bonds whose expected loss and/or spread was equal to zero. Thus, we were left with a total sample of 211 catastrophe bonds issued in the period 2004-2010⁴, of which 105 are single peril .

3.4. Constructed Dummy Variables

Different variables are used for the different models developed by Lane and Mahul (2008), Bodoff (2009) and Papachristou (2009). The main explanatory variables for each model were discussed previously in the thesis. A common feature of the pricing models is that the expected loss is used as a main control variable and has the highest correlation with the dependent variable. When testing the three models we use the spread as our dependent variable in order to analyze the effect on catastrophe bond pricing (as defined in equation (1.2)).

⁴ The sample data is available upon request.

We adjust the already developed cross-sectional regression models by adding independent dummy variables for the change in the structure of catastrophe bonds and test them in order to prove a statistically significant effect on the bond price. Dummy variables can be used in cross-sectional regression analysis in the same way as other explanatory variables and the coefficients can be interpreted as average differences of the dependent variable for each category (Brooks, 2008). Our built-in variables reflect the structural change which occurred after Lehman’s collapse and are defined as “Safer TRS Indicator”, which indicates all TRS structures recognized as safer (explained above), and “No TRS Indicator”, which reflects the lack of a TRS counterparty in the catastrophe bond structure. These are binary variables coded as one if the structure has either incorporated a safer TRS or is structured without any TRS counterparty and zero otherwise. The dummy variables are added to the three existing pricing models, therefore three different regressions will be performed and results will be compared. We expect that the models would show relatively similar results.

3.5. Expected results

After adjusting the outlined pricing models and adding two dummy variables reflecting the change in the structure of catastrophe bonds, we expect to obtain results showing negative coefficients for the incorporated variables. We believe that this would be the outcome of our

Variable	Expected sign
No TRS	Negative
Safer TRS	Negative

research because the safer bonds’ structure would be a factor which reduces the risk load for investors and therefore leads to a decrease in bonds’ spreads. By completing our tests we aim at

proving or discarding our expectations.

3.6. Validity

In order to be “valid”, the research needs objective data and robust methods of its interpretation. The conclusions drawn should be a direct consequence of the research, or as Bryman (2001) states: “the indicator that is devised to gauge the concept really measures that concept”. Moreover, there must be a sound logical relation between the explored problems and the

outcomes we expect to achieve, i.e. the hypothesis should lie upon robust, straightforward and objective relations.

Furthermore, in our analysis we aim at achieving full objectivity of research and aim at minimizing mistakes that would be an obstacle to the overall validity, e.g. calculation mistakes, technical misprints, mistakes when using statistical software, etc.

3.7. Reliability

In order to ensure the quality of this research, a certain level of reliability must be achieved. If a study can be replicated by other researchers and provide the same results, it can be assumed that this study is reliable (Bryman, 2001). This means that the results of the research will be independent of bias and will therefore be less subjective.

The main issues concerning the reliability of the thesis are connected to the data sample and the method of research. The data used in this study has been collected from the Standard & Poor's database as this is considered to be one of the most reliable sources of data available to catastrophe bond analysts. In order to further the reliability of the study, three existing pricing models were used to develop and test our hypothesis. Our method of research is widely used among analysts in this area and is considered to be straightforward. Therefore, a high level of reliability should be expected.

3.8. Problems and Limitations

The research has encountered several problems. One of them is connected to the operational definitions, i.e. how to define a “change” in the structure. In order to solve this problem we used the information provided by Thomson Reuters (Hills, 2010) about the types of safe collateral investments. If the collateral investments of the catastrophe bonds match the three types presented by Thomson Reuters (as described earlier in the work), we assume the structure has changed to a safer one. Also, if there is no TRS involved in the structure, we treat the bond as changed and safer as well.

A limitation of this study is that the number of catastrophe bonds issued after 2008 (i.e. those with a changed structure) is not large enough in order to completely ensure the reliability of the research. However, we believe the trend of change is strong and will not change in the future.

In future analyses of this matter, an extended time period (after 2008) will be needed in order to prove whether the change in structure will lead to a constant and uninterrupted change in catastrophe bond prices or whether the effect that we expect to observe is only temporary and connected mainly to current market fluctuations.

4. EMPIRICAL ANALYSIS CHAPTER

In this chapter we provide a descriptive statistics analysis of our data sample. We outline the way we adjust the pricing models as well as the various tests performed in order to ensure the models' reliability. Also, we present the empirical findings obtained after testing each of them.

We use the Lane and Mahul (2008), Bodoff (2009) and Papachristou (2009) catastrophe bond pricing models as base models in order to test our hypothesis. We explain which variables are used, how each model is built and how the models are tested, after which we develop a comparative analysis of the results that each of these models provides.

4.1. Descriptive Statistics

The basic characteristics of the sample data used in our research will be provided in this part of the thesis. Our data sample consists of 211 catastrophe bonds of which 105 are single peril. Depending on the requirements of the pricing model, we use a different set of catastrophe bonds' data. In order to highlight the differences between the models, we carry out a descriptive statistics analysis for each of them. A significance level of 95% is used in the research.

To test the Bodoff (2009) model, a sample of single peril catastrophe bonds issued between 2004 and 2010 is used. After excluding several outliers, we were left with a total of 101 observations, of which 6 involve a safer TRS structure and 7 do not have a TRS counterparty (Table 4.1).

Table 4.1: Descriptive statistics for the adjusted Bodoff (2009) model

	SPREAD	SAFER TR S_IND	PEAK PE RIL_IND	NO TRS _IND	EXPECTED LOSS_WIND	EXPECTED _LOSS_EQ	DIVERSIF PERIL_IND
Mean	0.078	0.059	0.455	0.069	0.012	0.006	0.327
Median	0.063	0	0	0	0.008	0	0
Maximum	0.245	1	1	1	0.063	0.079	1
Minimum	0.019	0	0	0	0	0	0
Std. Dev.	0.049	0.238	0.500	0.255	0.015	0.012	0.471
Skewness	1.399	3.728	0.179	3.392	1.616	3.273	0.739
Kurtosis	4.869	14.896	1.032	12.503	5.296	16.296	1.546
Sum	7.928	6	46	7	1.186	0.625	33
Observations	101	101	101	101	101	101	101

The table presents information about the variables included in the Bodoff (2009) model. In order to explore its central tendency, we analyze the mean and the median values. As can be seen from Table 4.1, the mean of all model parameters is higher than the median, which implies a certain level of positive skewness, i.e. most of the values are situated on the left of the mean. An interesting result is that the mean and the standard deviation of the expected loss for earthquake perils are lower than those for wind perils. However, the maximum expected loss is higher for earthquakes, which shows that this type of peril can cause larger catastrophic losses. Also, if we do not take into consideration the dummy variables, the parameter showing the highest dispersion in this model is the spread (price) of bonds.

After initially analyzing the Lane and Mahul (2008) pricing model, we decided to divide it into three sub-models in order to achieve better comparative results. The first sub-model is tested only with single-peril bonds' data for the purpose of comparing it with the Bodoff (2009) model. We would refer to this sub-model as Lane and Mahul (2008) SP model. The second sub-model is tested with all bonds (single and multi-peril) and will be referred to as Lane and Mahul (2008) AB model. The third sub-model's data sample also includes all bonds but a "Single Peril Indicator" variable will be added to it. It will be referred to as Lane and Mahul (2008) AB_{adj} model. Details of these models' adjustments will be provided later in the analysis.

Lane and Mahul's (2008) SP pricing model includes a sample of 99 catastrophe bonds (after excluding outliers). Of these, 6 incorporate a safer TRS structure and 7 do not involve a TRS counterparty at all. Results of the tests are given below in Table 4.2:

Table 4.2: Descriptive statistics for the Lane and Mahul (2008) SP model

	SPREAD	EL	ROL	NO_TRS	SAFER_TRS
Mean	0.080	0.018	1.3	0.071	0.061
Median	0.064	0.013	1.26	0	0
Maximum	0.245	0.067	1.82	1	1
Minimum	0.019	0.002	0.75	0	0
Std. Dev.	0.049	0.015	0.246	0.258	0.240
Skewness	1.370	1.564	-0.076	3.349	3.683
Kurtosis	4.742	4.901	2.941	12.219	14.566
Sum	7.877	1.799	128.7	7	6
Observations	99	99	99	99	99

The sample is very similar to the one used in the Bodoff (2009) model. Thus, the results remain largely unchanged, with means of the parameters higher than the medians. This model does not take into account the perils factor but instead incorporates the Rate-on-Line (ROL) reinsurance market cycle index. This variable has the highest standard deviation in the model (without taking into account the dummy variables for the structural change) which shows the importance of its utilization when estimating the effect on the spread.

Further, we analyzed Lane and Mahul's AB pricing model, which includes a total of 211 single and multi-peril catastrophe bonds issued in the period 2004-2010. There are 15 bonds with safer structures and 22 which do not involve a TRS counterparty. The results are shown in Table 4.3.

Table 4.3: Descriptive statistics for the Lane and Mahul (2008) AB model

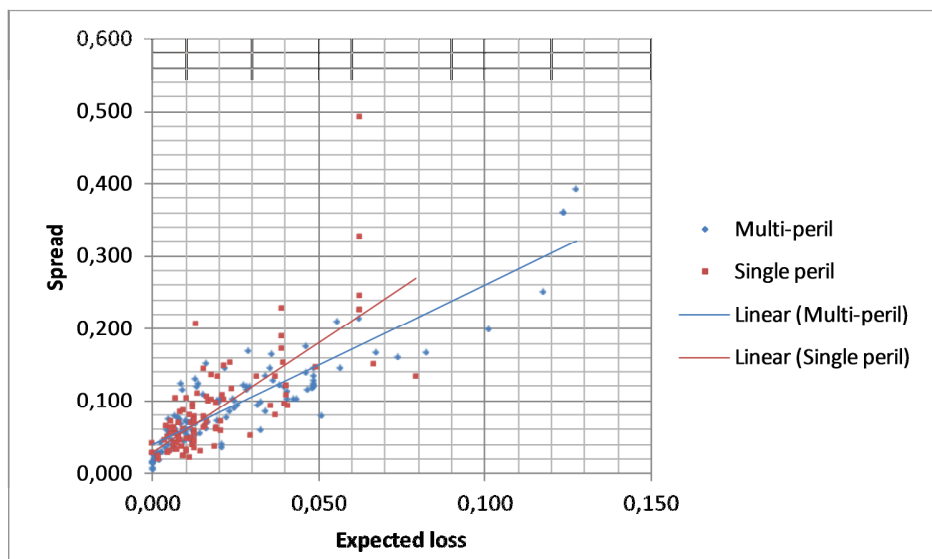
	SPRFAD	EL	ROL	SAFER_TRS	NO_TRS	SINGLE_PERIL_IND
Mean	0.090	0.023	1.276	0.074	0.109	0.490
Median	0.075	0.014	1.26	0	0	0
Maximum	0.393	0.128	1.82	1	1	1
Minimum	0.007	0.000	0.75	0	0	0
Std. Dev.	0.059	0.023	0.265	0.263	0.312	0.501
Skewness	1.961	2.168	-0.354	3.248	2.511	0.040
Kurtosis	9.214	8.841	2.578	11.547	7.304	1.002
Sum	18.109	4.680	257.850	15	22	99
Observations	202	202	202	202	202	202

It is valuable to make a comparison between the two Lane and Mahul (2008) sub-models (single peril (SP) and all-peril model (AB)) since this would show the significance of multi-peril catastrophe bonds when analyzing pricing methodologies. As presented in Table 4.3, the dispersion of the spread values in the all-bonds model is higher compared to the single peril one, i.e. multi-peril bonds exert pressure on both the minimum and maximum values of the spread. Therefore, it cannot be claimed with absolute certainty that multi-peril bonds always lead to higher catastrophe bond spreads. A larger sample would be necessary in order to prove or discard this statement.

The expected loss in the all-bonds (AB) model shows increasing values of the mean and median when compared to the single peril (SP) model. A possible interpretation is that the multi-peril bonds carry higher level of expected losses, therefore a higher risk load for investors.

To make a visual comparison, we present the relationship between spread and expected loss for both single peril and multi-peril bonds (Graph 4.1). As can be seen from the graph, the linear function shows that if the level of expected loss is the same for both types of bonds, single peril bonds would usually have a higher spread. This means that single peril bonds' spread is theoretically more sensitive to expected loss than the spread of multi-peril bonds. However, for very small levels of expected loss, the spread is higher for multi-peril bonds. A possible explanation could be that multi-peril bonds involve a higher level of peril diversification; thus, for larger expected losses they would have a smaller spread.

Graph 4.1: Relationship between spread and expected loss by peril type



Further, we analyzed Papachristou's (2009) model and its data sample. During this process, we found that for the "Non-US bonds" sub-model the number of observations is extremely limited which did not allow us to analyze it further. Therefore, we decided to test only the first Papachristou (2009) model. It includes catastrophe bonds covering single perils like US hurricanes and US earthquakes, as well as all multi-peril bonds which have the US hurricanes as their component. A total of 117 observations were included in the sample. Of these, 8 are

observations with safer TRS structure and 13 do not involve TRS at all. The data cannot be directly compared to the sample from previously described models because it is more diverse. The results from the analysis are presented in Table 4.4.

Table 4.4: Descriptive statistics for the adjusted Papachristou (2009) model

	SPREAD	EL	TRIGGER INDEMN	SAFER_ TRS	NO_TRS
Mean	0.097	0.024	0.239	0.068	0.111
Median	0.080	0.013	0	0	0
Maximum	0.393	0.128	1	1	1
Minimum	0.018	0.000	0	0	0
Std. Dev.	0.065	0.026	0.429	0.253	0.316
Skewness	2.076	2.225	1.222	3.420	2.475
Kurtosis	9.326	8.439	2.493	12.698	7.125
Sum	11.389	2.752	28	8	13
Observations	117	117	117	117	117

Again, the mean of the spread and the expected loss is higher than the median. It is interesting to note that this model’s data sample shows the highest mean and median from all pricing models presented in the thesis. Even though the sample is much smaller than that of the Lane and Mahul’s (2008) AB model, Papachristou’s (2009) model shows maximum and minimum spread and expected loss values similar to those of Lane and Mahul (2008). This means that from all multi-peril bonds, the US hurricane peril is of greatest significance to the price and losses, while other perils like European storm, Japanese typhoons, etc. are of marginal importance.

4.2. Bodoff model

4.2.1. Model adjustment

As discussed above, the Bodoff (2009) regression model (2.5) will be used as one of the base models in our research. We adjust it by adding two extra dummy variables. The Bodoff (2009) model covers the effect of different perils and geographic zones on bonds’ spreads. It is adjusted by adding the “Safer TRS Indicator” and “No TRS Indicator” variables, as well as their coefficients:

$$\begin{aligned}
\text{Spread \%} &= \text{Constant}_{All} \% \\
&+ \text{Additional Constant}_{Peak} \% * \text{Peak Peril Indicator} \\
&+ \text{Additional Constant}_{Diversifying} \% * \text{Diversifying Peril Indicator} \\
&+ \text{Loss Multiplier}_{EQ} * \text{Expected Loss}_{EQ} \% \\
&+ \text{Loss Multiplier}_{Wind} * \text{Expected Loss}_{Wind} \% \\
&+ \text{Additional Constant}_{No TRS} * \text{No TRS Indicator} \\
&+ \text{Additional Constant}_{Safer TRS} * \text{Safer TRS Indicator}
\end{aligned} \tag{5.1}$$

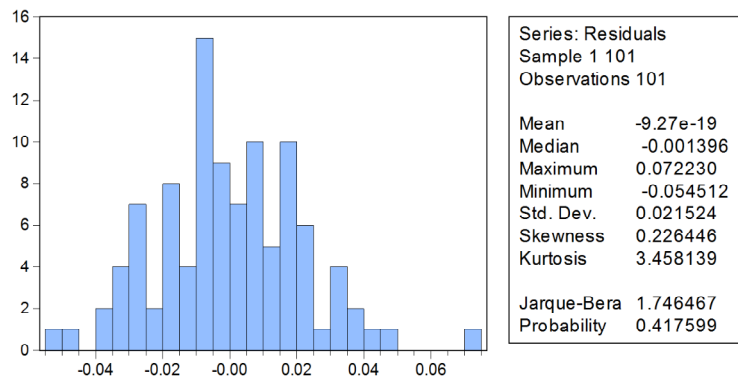
This model is used to determine the structural change effect on the prices of catastrophe bonds.

4.2.2. Tests

By using the statistical software package Eviews, multiple regression tests were performed in order to obtain reliable results. Theory suggests (Brooks, 2008) that the average of all residuals should be equal to zero. As can be seen from equation (5.1), we use an intercept, which guarantees that this requirement is not violated. To ensure that the homoscedasticity requirement is met (i.e. the variance of errors should be finite and constant) we use the White test. It showed that the assumption of homoscedasticity is not rejected. Few outliers were detected by the Jarque-Bera test for testing normal distribution. According to Brooks (2008), there are two alternative ways of dealing with outliers - construct them as dummy variables or remove them from the observations. We have found four outlying observations and we consider this number as relatively high to construct dummy variables with, having in mind that our total sample includes 105 observations. Therefore, we chose to remove them. We are aware that excluding some of the observations might be a risky

step. In order to check its significance for our analysis, we ran the tests with and without the excluded variables. The tests gave results which were not significantly different from each other (both models' coefficients

Graph 4.2: Adjusted Bodoff (2009) model Normal distribution



and probabilities showed similar values). We believe that by excluding these variables we did not harm the overall validity of the model, i.e. its tails do not include information whose removal can mislead our regression results. After adjusting the model, the Jargue-Bera test showed normal distribution (Graph 4.2). Also, outliers' removal improved the model's linearity, which was proven by performing the Ramsey RESET test (Table 4.5).

Table 4.5: Adjusted Bodoff (2009) model test results

Heteroscedasticity Test: White

F-statistic	1.684561	Prob. F(6,94)	0.1333
Obs*R-squared	9.805684	Prob. Chi-Square(6)	0.1331
Scaled explained SS	10.43920	Prob. Chi-Square(6)	0.1073

Ramsey RESET Test:

F-statistic	0.021683	Prob. F(1,93)	0.8833
Log likelihood ratio	0.023545	Prob. Chi-Square(1)	0.8780

Furthermore, a multicollinearity test was performed to check whether the explanatory variables are mutually correlated. Results show values of less than 0.6, which means that no significant correlation is detected. Finally, in order to check for autocorrelation we used the Wald-Wolfowitz runs test, which is appropriate for cross-sectional data. It showed random distribution of the signs of the residuals, therefore no autocorrelation is detected by using this tool.

After adjusting and testing the Bodoff (2009) model, we can conclude that the results from this regression should be statistically reliable and the model's validity remains intact.

4.2.3. Empirical results

The empirical results obtained after running the regression model are presented in Table 4.6. The model was slightly modified in order to meet the linear regression requirement. A total of 105 observations were used, of which four were removed as outliers. As can be seen from Table 4.6, the R-squared and Adjusted R-squared values show acceptable levels and therefore prove the model's reliability. Only one of the variables ("No TRS Indicator") has no explanatory power as

its significance level is below 95%. After analyzing the coefficients, we can see that the expected loss has the highest impact on the prices of catastrophe bonds.

Table 4.6: Bodoff (2009) adjusted regression results

Dependent Variable: SPREAD

Method: Least Squares

Sample (adjusted): 1 101

Included observations: 101 after adjustments (excluding 4 outliers)

	Coefficient	Std. Error	t-Statistic	Prob.
C	0.011283	0.005603	2.013719	0.0469
DIVERSIF_PERIL_IND	0.023815	0.006184	3.850786	0.0002
EXPECTED_LOSS_EQ	1.560624	0.207572	7.518479	0.0000
EXPECTED_LOSS_WIND	3.089248	0.164182	18.81598	0.0000
NO_TRS_IND	0.004981	0.009223	0.540097	0.5904
PEAK_PERIL_IND	0.024824	0.006026	4.119644	0.0001
SAFIER_TRS_IND	0.031013	0.009670	3.207187	0.0018
R-squared	0.805071	F-statistic		64.70446
Adjusted R-squared	0.792629	Prob (F-statistic)		0.000000

After comparing our findings with those of the original Bodoff model (2009) (see Appendix V/I) we can conclude that both models' coefficients are similar. The only difference is the positive sign of the "Diversified Peril Indicator" provided by our adjusted model. There could be two reasons for this. Firstly, the whole model and its coefficients can be affected by adding the two dummy variables. Thus, the effect on the price, caught by the original model, is now spread to the additional two variables. Another explanation could be that Bodoff (2009) used a sample data which does not include issuances after mid-2008. After this year the diversification benefits which these parameters bring might be outstripped by the negative effects of financial crisis, since it is globally spread. Prices can be increasing even though bonds' features are still diversified.

After analyzing our constructed dummy variables we can see that only one of them ("Safer TRS indicator") is significant (within 95% significance level). A main finding is that the regression model provides us with results which are opposite to those expected. As can be seen from Table 4.6., the "Safer TRS indicator" has a positive effect on catastrophe bond prices. This means that

bonds which incorporate a safer TRS structure⁵ are priced with some premium. This could be due to the effect of the current credit crisis. A more detailed analysis is carried out in the following chapter.

4.3. Lane and Mahul model

4.3.1. Model adjustment

In contrast to Bodoff (2009), Lane and Mahul (2008) develop a model, which includes a variable representing the market conditions instead of perils and geographic zones. The model construction was explained in Chapter 2 (equation (3.3)). As mentioned above, we add two dummy variables for the structural change in bonds, the same ones added to the Bodoff (2009) model. Moreover, we use the same Rate-on-Line reinsurance index to define the market cycle level. Lane and Mahul (2008) use three index levels and determine the hard, soft and neutral markets on a yearly basis. We decided to take the quarterly index value which would provide us with more flexibility and accuracy since quarterly values reflect market fluctuations more quickly. This is of extreme importance during the years of the current crisis. Lane and Mahul (2008) use a catastrophe bonds sample which includes single and multi-peril bonds. In contrast, Bodoff (2009) uses only single peril bonds data. In order to compare the results from the Lane and Mahul (2008) and Bodoff (2009) models, firstly we use only single peril (SP) bonds data in Lane and Mahul's SP model:

$$\begin{aligned}
 \text{Spread} &= \text{Constant}_{All} \\
 &+ \text{Loss Multiplier} * \text{Expected Loss} \\
 &+ \text{Additional Constant}_{Cycle Level} * \text{Cycle Level Index (ROL)} \\
 &+ \text{Additional Constant}_{No TRS} * \text{No TRS Indicator} \\
 &+ \text{Additional Constant}_{Safer TRS} * \text{Safer TRS Indicator}
 \end{aligned} \tag{5.2}$$

After that, we include all multi-peril cat bonds data into the same model and test it again. Also, we find it useful to add a "Single Peril Indicator" dummy variable (its value equals 1 if the bond is single peril and zero if it is multi-peril) in the Lane and Mahul (2008) all-bonds (AB) model.

⁵ The definition of a "safer" structure is provided in Chapter 3

This would give us the opportunity to see whether the type of bond has an effect on the pricing and whether this variable could improve the model. Therefore, two regressions for the AB model were performed – with and without the “Single Peril Indicator”. The models will be compared later in this work. The Lane and Mahul (2008) AB_{adj} model which includes a “Single peril indicator” can be defined as:

$$\begin{aligned}
 Spread &= Constant_{All} \\
 &+ Loss Multiplier * Expected Loss \\
 &+ Additional Constant_{Cycle Level} * Cycle Level Index (ROL) \\
 &+ Additional Constant_{No TRS} * No TRS Indicator \\
 &+ Additional Constant_{Safer TRS} * Safer TRS Indicator \\
 &+ Additional Constant_{Single Peril} * Single Peril Indicator
 \end{aligned} \tag{5.3}$$

These three adjusted models will be used when comparing the results of the tests with those of other pricing models.

4.3.2. Tests

After adjustments, the Lane and Mahul (2008) SP model is tested in order to fulfill major linear model requirements (Brooks, 2008). Similarly to the adjusted Bodoff (2009) model, we use an intercept to maintain the assumptions that the average of all residuals should be equal to zero.

Graph 4.3: Adjusted Lane and Mahul (2008) (SP) model Normal distribution

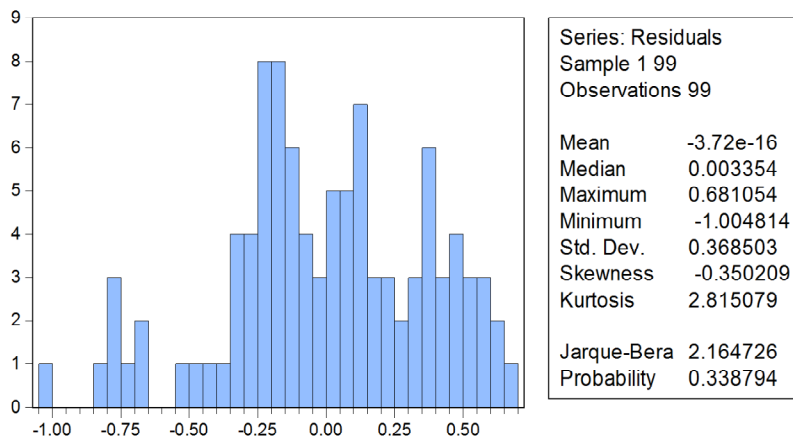


Table 4.7: Lane and Mahul (2008) SP model test results

Heteroscedasticity Test: White

F-statistic	0.961770	Prob. F(4,94)	0.4323
Obs*R-squared	3.892410	Prob. Chi-Square(4)	0.4208
Scaled explained SS	3.184706	Prob. Chi-Square(4)	0.5274

Ramsey RESET Test:

F-statistic	2.681823	Prob. F(1,93)	0.1049
Log likelihood ratio	2.814456	Prob. Chi-Square(1)	0.0934

For the adjusted single peril model (5.2) the normal distribution test detected four outliers. Having encountered the same outliers' issues in the Bodoff (2009) model, we compared the regression results before and after their removal. No significant changes were found and we assumed that the results of the model will not be harmed if outliers were removed. The Jarque-Bera test shows normal distribution after the removal of outliers (Graph 4.3). In order to improve the model's homoscedasticity, natural logarithm was used. Heteroscedasticity was rejected by the White test, while linearity was proven by the Ramsey Reset test (Table 4.7). Autocorrelation was also rejected after performing the Wald-Wolfowitz runs test. The correlation between independent variables does not exceed 34%. Expected loss and Spread (the dependent variable) are correlated by 73% which, according the Brooks (2008) is considered healthy for a regression model.

Graph 4.4: Lane and Mahul (2008) AB model Normal distribution

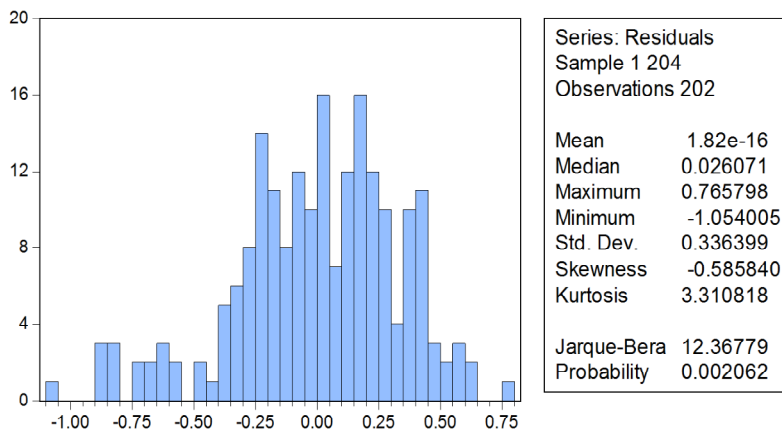


Table 4.8: Lane and Mahul (2008) AB model variables correlation

	SPREAD	EL	ROL	NO_TRS	SAFER_TRS	SINGLE_PERIL_IND
SPREAD	1					
EL	0.863463	1				
ROL	0.125048	0.020244	1			
NO_TRS	0.06649	0.097552	0.301165	1		
SAFER_TRS	0.077812	-0.09562	0.299604	-0.10042	1	
SINGLE_PERIL_IND	-0.1683	-0.18432	0.081444	-0.12906	-0.048079	1

After testing the Lane and Mahul (2008) AB model, we corrected the main equation by adding natural logarithms in

order to improve homoscedasticity. Also, the linearity of the model was corrected by introducing a square of the main independent variable (expected loss) and adding it as an extra variable to the equation. As in the previously described models, four outliers were excluded in order to correct the normal distribution (Graph 4.4). Autocorrelation was rejected, as well as cross-variable correlation (Table 4.8). The Lane and Mahul (2008) AB model does not show significantly different results when tested with and without the additional dummy variable (“Single Peril Indicator”).

4.3.3. Empirical results

As previously described, the results of the model are split into three main sub-groups according to included variables and data sample.

Table 4.9: Adjusted Lane-Mahul (2008) model regression results; single peril data

Dependent Variable: SPREAD_LOG

Method: Least Squares

Sample (adjusted): 1 101

Included observations: 99 after adjustments (excluded 4 outliers)

	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.536925	0.317812	-1.689440	0.0944
EL_LOG	0.584863	0.051777	11.29575	0.0000
ROL	0.234338	0.172729	1.356681	0.1781
NO_TRS	0.132435	0.156830	0.844449	0.4006
SAFER_TRS	0.432989	0.171453	2.525415	0.0132
R-squared	0.603220 F-statistic			35.72684
Adjusted R-squared	0.586336 Prob(F-statistic)			0.000000

The regression results from the Lane and Mahul (2008) SP model are provided in Table 4.9. The sample includes 101 observations, of which two were removed. The reason for this is that some of these observations' variables were equal to zero, which led to errors when estimating the natural logarithms. The results obtained through the Lane and Mahul (2008) SP model are used in comparison with the adjusted Bodoff (2009) model results. As can be seen from the table, the model is reliable and its R-squared value is relatively high. Two variables show insignificant results, namely the ROL index and the "No TRS indicator". Even though the "No TRS indicator" is insignificant, it has a positive coefficient. When analyzing the expected loss variable, one should take into account that this is the natural logarithm of expected loss. Our main aim is to explore the additional dummy variables and particularly the signs of their coefficients. Similarly to the adjusted Bodoff (2009) model, the safer TRS structure of cat bonds shows a positive effect on the bond price. A detailed analysis of this will be done later in the work.

Table 4.10: Lane and Mahul (2008) AB model regression results

Dependent Variable: SPREAD_LOG

Method: Least Squares

Sample (adjusted): 1 207

Included observations: 202 after adjustments (excluded 4 outliers)

	Coefficient	Std. Error	t-Statistic	Prob.
C	0.017640	0.266960	0.066079	0.9474
EL_LOG	0.893653	0.093112	9.597590	0.0000
EL_LOG^2	0.043983	0.008986	4.894793	0.0000
ROL	0.230970	0.101927	2.266020	0.0245
NO_TRS	0.028962	0.083185	0.348170	0.7281
SAFER_TRS	0.319747	0.099141	3.225165	0.0015
R-squared	0.728238	Prob(F-statistic)		0.000000
Adjusted R-squared	0.721305	Akaike info criterion		0.713403

The same Lane and Mahul (2008) sub-model was tested again after adding the multi-peril bonds sample to it (Table 4.10). Slightly different results were obtained. When analyzing Table 4.10 it can be seen that the model's reliability improved as the R-squared value increased to 73%. As in the previously described models, the "No TRS indicator" has an insignificant effect on bonds' pricing and has a positive coefficient. The presence of more observations (207) improved the

cyclicality index significance, which shows a positive effect on the spread. The dummy variable indicating a “Safer TRS” structure is within the significance range and also shows a positive effect on the spread. This was observed in the previous models as well. When analyzing the results from the Lane and Mahul (2008) AB model, we can conclude that the variable which affects the spread the most is the expected loss.

The Lane and Mahul (2008) all-bond (AB) model was further modified by adding a “Single peril indicator” (Table 4.11) and was named Lane and Mahul (2008) AB_{adj} model. This was done in order to investigate the effect of this variable and to potentially purify the model. The effect of this step on the overall results was positive. The R-squared value improved to 73.6 % (from 72.8%). The AIC (Akaike information criterion) was improved from 71.3% to 69.3%⁶. The “No TRS indicator” again shows no significance. However, in this model it has a negative sign. The “Safer TRS” structure shows significance and has a positive sign in front of its coefficient. The “Single Peril Indicator” has a significant negative coefficient which means that single perils are parameters which exert downward pressure on bonds’ prices.

Table 4.11: Adjusted Lane-Mahul (2008) model regression results; single and multi-peril data; with “Single Peril Indicator”

Dependent Variable: SPREAD_LOG

Method: Least Squares

Sample (adjusted): 1 207

Included observations: 202 after adjustments (excluded 4 outliers)

	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.149891	0.272722	-0.549613	0.5832
EL_LOG	0.819444	0.096993	8.448500	0.0000
EL_LOG^2	0.036616	0.009387	3.900564	0.0001
ROL	0.280322	0.102753	2.728125	0.0070
NO_TRS	-0.008966	0.083670	-0.107156	0.9148
SAFER_TRS	0.278516	0.099423	2.801321	0.0056
SINGLE_PERIL_IND	-0.123755	0.051290	-2.412872	0.0168
R-squared	0.736117	Prob (F-statistic)		0.000000
Adjusted R-squared	0.727997	Akaike info criterion		0.693885

To conclude, after analyzing the three modifications of the Lane and Mahul (2008) model we can see that in all of them the “Safer TRS” structure is significant and has a positive effect on the

⁶ According to theory, the lower the value of AIC, the more stable the model (Bozdogan, 2000)

bond pricing, which was opposite to our expectations. The “No TRS indicator” shows no significance, but its coefficient has a negative sign in the model that incorporates all bonds and has the “Single peril indicator”. Qualitative analysis of these results is provided in the next chapter.

4.4. Papachristou model

4.4.1. Model adjustment

The Papachristou (2009) pricing model incorporates variables reflecting the cyclicity effect, perils, geographic zones as well as catastrophe bond trigger types. As previously mentioned (Chapter 2, equations (4.2) and (4.3)), the model is divided into two sub-models (for US and non-US cat bonds). Papachristou (2009) used the software program “Statistical Package R” for the analysis. Due to the necessity of some specific statistical functions we used “Statistical Package R” as well instead of Eviews in order to test our hypothesis.

Papachristou (2009) divides his model on the basis of the Peril/Territory variable. The first sub-model includes multi-peril bonds, which have the US Hurricane peril as their component, as well as single peril US hurricane and single peril US earthquake bonds. The second sub-model includes European storm and Japanese Typhoon bonds, as well as Japanese earthquake and non-peak territory bonds.

As previously mentioned, we encountered problems using the second sub-model, since it includes only 40 observations. Of those, only one is a bond issued after September 2008 and had a safe TRS structure. Due to this reason and the potentially insignificant results we decided to test only the first sub-model (which includes 123 observations). We believe that the second one will be tested in future researches when the data about catastrophe bonds issued after 2008 becomes larger.

Furthermore, we modified the Papachristou (2009) original model (4.2) by incorporating two additional dummy variables reflecting the structural change (“No TRS” indicator and “Safer TRS” indicator). Thus, the model can be defined as:

$$\text{Log}(RL_i) = S(\log(EL_i)) + NS(\text{time}_i) + \text{Peril/Territory}_i + \text{Trigger}_i + \varepsilon_i + \text{No TRS} + \text{Safer TRS} \quad (5.3)$$

4.4.2. Tests

At first, we tested the model in its original form without adding the dummy variables reflecting the change in structure. The obtained results showed stability of the model. We base this statement on the goodness of fit measure, which was performed by applying the AIC test. It showed values of 52%. The “Statistical Package R” provided the probability of only one variable (the expected loss) which was equal to 0.1353.

After that, we added two dummy variables reflecting the change in catastrophe bond structure. The result showed stability of the model again.

Table 4.12: Descriptive statistics of the adjusted Papachristou (2009) model variables

	Min	1Q	Median	3Q	Max
Original Model	-1.011458	-0.19512	-0.009325	0.210979	0.909472
Adjusted Model	-0.96561	-0.17932	-0.00475	0.18641	0.94568

Moreover, after adding the two additional parameters, the goodness of fit test (AIC) was improved and was equal to 45%. This means that by adding the variables reflecting the change in structure the original model was improved and became more stable. We expect that this model will be developed further in future researches. The summary table for the adjusted model is provided below.

Table 4.13: Adjusted Papachristou model regression results

Dependant variable **logSpread**
 Sample 123
 Adjusted sample 117
 $\text{logSpread} = \text{nsIssued} + \text{s(logEL)} + \text{Peril_Territory} + \text{Trigger} + \text{SafierTRSind} + \text{No TRSind}$

Variable	Coefficient	Df	Npar Df	Npar F	Pr(F)
c	-0.5019	1			
ns(Issued)	0.0452	7			
s(logEL)	0.4634	1	3	2.561	0.059
Peril Territory US EQ	-0.2833	1			
Peril TerritoryUS Hurr	-0.0033	1			
Trigger Other	-0.0191	1			
Safier TRS ind	0.4039	1			
No TRS ind	0.0772	1			

AIC: 45.0604

The significance level of the expected loss has also improved after adding the dummy variables. However, any data on the other variables’ significance levels was not provided by the software package which is seen as a flaw in the model.

The coefficients of the dummy variables reflecting the changes in structure are positive, which is a result similar to the ones obtained through the Bodoff (2009) and Lane and Mahul (2008) pricing models.

We are aware of the fact that the model is not complete and not fully stable even after adding the dummy variables. Our knowledge of the “Statistical package R” is also a limiting factor to improving the model and at this stage we aim to only interpret the signs of the coefficients of the dummy variables. However, we are going to improve our results in a future research. We also believe that the reliability of this model can be improved by using larger data samples.

4.4.3. Empirical results

The “Statistical package R” was used when testing the adjusted Papachristou (2009) model. Thus, the regression results are expected to slightly differ from those of other models. As discussed above, further investigation of the model is required, as well as a better understanding of this specific statistical program. Table 4.13 shows that 123 observations were used. Of those, five

were removed after applying natural logarithms and splines for some variables. The total model's reliability is measured by the AIC value and it shows that the model is reliable when compared to the adjusted Lane and Mahul (2008) AB model. The F-probability was provided only for the expected loss variable. However, we cannot conclude that other variables' probabilities are below the significance level of 95%. The number of degrees of freedom is 7 for the variable "Issued". This parameter represents the market cyclicity. Such a number was necessary because 7 knots were used to determine the critical turning market points (e.g. hurricane Katrina, the collapse of Lehman Brothers, etc.). Papachristou (2009) used 5 knots since the catastrophe bonds that were originally analyzed were issued between January 2003 and July 2008 and therefore do not cover the events of Lehman's collapse and the recovery of the market in 2009. Our data sample covers the period until the first quarter of 2010.

After comparing the obtained results with those of Papachristou (2009) paper updates (the original results of the updates are provided in Appendix V/4) it can be seen that only the sign of the coefficient for the US Earthquake peril is the same, while signs differ for other variables. Papachristou (2009) does not provide an explanation of the specific features of the statistical program; therefore we were unable to replicate the model completely. The difference in the obtained results could also be caused by adding the most recent data to the sample (Q3 2008 until Q1 2010) and the two dummy variables. However, the main variables in both models have positive coefficients. Also, the "Safer TRS indicator" shows a larger value than the "No TRS indicator" variable. As already mentioned, the program does not provide probabilities for each variable which is an obstacle to evaluating their significance.

5. QUALITATIVE ANALYSIS AND DISCUSSION CHAPTER

In this chapter we will discuss the characteristics of catastrophe bonds in general. We will also provide a qualitative analysis of the results obtained after testing the adjusted pricing models. An overall view of the reasons behind the observed results will be given and our expectations about the future development of catastrophe bonds will be presented.

In Chapter 4 we presented the results obtained after testing the adjusted pricing models as well as various empirical findings that were made during the analytical process. In this part of the thesis we will perform qualitative analysis and will discuss the results we have obtained.

The catastrophe bonds data sample can be characterized in various ways and it differs according to the pricing model. In this part we present an overall comparative analysis of catastrophe bonds issued during the period 2004-2010, including those with a changed structure. Tables 5.1 and 5.2 show some interesting features of the spread and expected loss for single peril and multi-peril bonds. Also, some of the features of bonds issued before and after September 2008 (“unsafe” and “safe” bonds respectively) are presented. As can be seen from Table 5.1, the number of single and multi-peril bonds is evenly distributed (106 and 105). The average spread and expected loss of multi-peril bonds is higher than those of single peril bonds. This means that multi-peril bonds provide a higher return to investors but also involve higher level of risk load. Further, of all bonds with safer TRS structure (issued after September 2008), 60% are classified as multi-peril and 40% as single peril bonds. Of all bonds with no TRS counterparty in the structure, almost 70% are multi-peril bonds and around 30% are single peril bonds. This means that multi-peril bonds after 2008 generally have safer structure than single peril ones and are constructed more often without a TRS counterparty (see Table 5.1). This could be due to the fact that a higher level of safety is sought for bonds which involve higher expected loss.

Table 5.1: Single and multi-peril bonds distribution across the sample

Type of bond	No of bonds	Average of		No of bonds		% of safer struct. bonds	
		Spread	Exp.loss	Safer TRS	No TRS	Safer TRS	No TRS
Multi-peril	106	0.0978	0.0268	9	16	60.0%	69.6%
Single peril	105	0.0867	0.0192	6	7	40.0%	30.4%
Total	211	0.0922	0.0230	15	23	100.0%	100.0%

Table 5.2 shows that of all catastrophe bonds issued in the period 2004-2010, 15 (7.1%) have a safer TRS structure and 23 (10.9%) do not involve a TRS counterparty at all. Also, while the average spread of bonds with a safer TRS structure is higher than that of bonds without a TRS counterparty, the expected loss of these bonds is significantly lower. It is worth noting that bonds without a TRS counterparty have higher spread and higher expected loss than the average spread and expected loss of all bonds issued before 2008. It can be concluded that the lack of a TRS counterparty is a feature of bonds which involve higher than average expected loss (usually multi-peril bonds).

Table 5.2: Single and multi-peril bonds distribution across the sample

Type of structure	No of bonds	% out of all	Average of	
			Spread	Exp.loss
Safer TRS	15	7.1%	0.1053	0.0151
No TRS	23	10.9%	0.1000	0.0292
Other	173	82.0%	0.0901	0.0229
Total	211	100.0%	0.0922	0.0230

The next step in our qualitative analysis involves the investigation of the coefficients and the significance of the variables incorporated into the tested pricing models. The Bodoff (2009) model and the Lane and Mahul (2008) model (when tested with single-peril bonds data) provide results which show positive coefficients in front of the incorporated TRS parameters (i.e. the additional dummy variables). The same results are obtained after testing the Lane and Mahul (2008) AB model. Further, positive coefficients are also observed when testing the Papachristou (2009) model. We also ran a slightly modified regression of the Lane and Mahul (2008) AB model, which included an additional dummy variable, namely the “Single Peril Indicator”. This variable reflects single peril bonds and the additional effect that peril diversification brings to the model. The results of this model show that the “No TRS Indicator” has a negative coefficient.

The positive coefficients, obtained through almost all tested models, mean that the “Safer TRS” and the “No TRS” structures exert upward pressure on the bonds’ spread. This result is contrary to that which was expected at the outset of this research. Our hypothesis was built on theory which assumes that the “Safer TRS” structures or the complete elimination of credit risk by

removing the TRS counterparty will reduce the risk load to investors, therefore the premiums over the risk they take should decrease.

However, only one of the tested models showed a negative coefficient, and only for the “No TRS” variable. Moreover, its probability was proven to be insignificant. These results were obtained through the Lane and Mahul (2008) AB model, which includes a “Single Peril Indicator”. When testing the same model without the “Single Peril Indicator” variable, all coefficients obtained were positive. A possible explanation of this difference is that the added “Single Peril Indicator” has absorbed an excess effect, which has flawed the explanatory power of the variables in the other models. It is worth noting that the “No TRS” parameter is a feature of bonds which are more transparent than those with a “Safer TRS” structure. Also, the “No TRS Parameter” was the first variable which reflected the purification of the pricing model, obtained after adding the “Single Peril Indicator”. However, this is an assumption which cannot be proven with absolute certainty because the variable’s probability is not within the significance range. We believe that the reliability of this version of the Lane and Mahul (2008) model could be improved by testing it with a larger data sample or by including additional purifying variables. However, the main aim of this study is not to construct a catastrophe bonds pricing model for crisis-affected markets; therefore we recommend this as a topic of future research.

Further, the results of the conducted tests show that the “Safer TRS” variable lies within the pre-determined significance range, while the “No TRS” indicator does not. This means that catastrophe bonds’ spread is more sensitive to the “Safer TRS” parameter. This variable has a larger effect on bonds’ prices at the moment than the “No TRS” parameter. A possible interpretation of this result is that issuers prefer bonds’ structures which are not significantly different from the previously established ones. Also, investors might prefer bonds with known, existing structures, which were improved after the influence of the credit crisis. Furthermore, since the “No TRS” structure is an innovation in the ILS market, a longer time period might be necessary in order for it to be established and accepted as a reliable feature of catastrophe bonds.

Overall, the results we expected were proven only to the extent that one of the incorporated dummy variables (i.e. the “Safer TRS Indicator”) is significant. However, both variables show

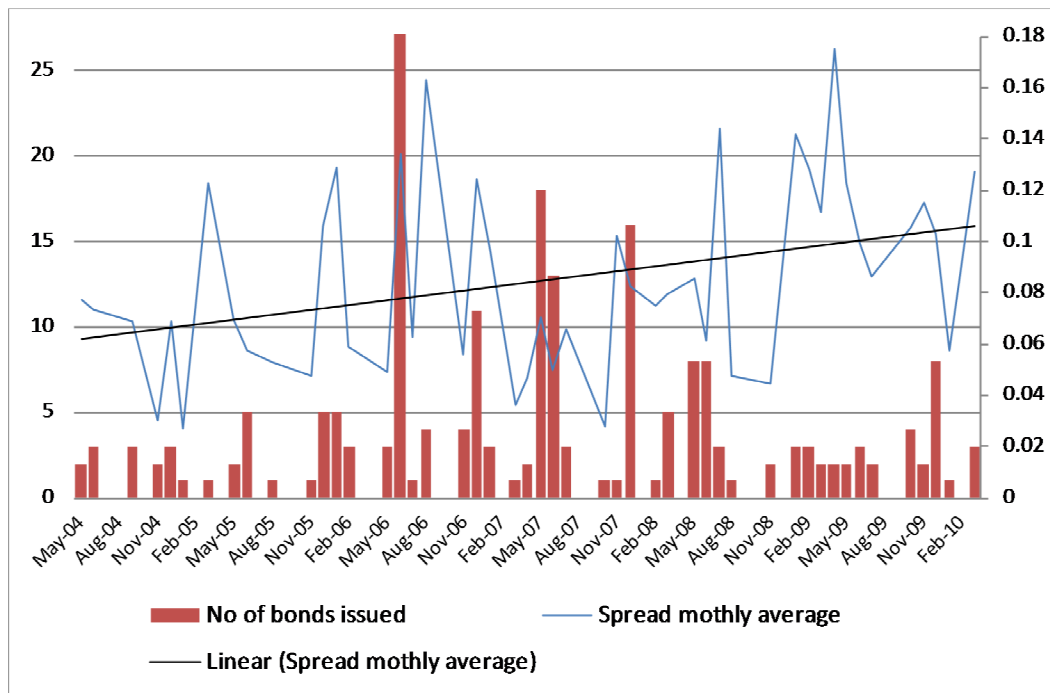
positive coefficients, which is in contrast to our expectations. This means that hypothesis (H_0) was rejected by the research.

We believe that these results might have been flawed by the excessive effects of the global financial crisis and the fluctuations in the ILS market. Before the crisis hit in 2007, the financial markets worked under well-established economic principles. However, after 2007 their efficiency rapidly decreased and the validity of major economic laws significantly deteriorated. We believe that the crisis effects exert additional pressure, which affects bonds' prices. This effect should be incorporated in pricing models which test data obtained after 2008. Thus, in order to purify the existing models, an additional variable, which would absorb the "crisis" effect should be incorporated in the models. Another possibility would be to exclude the data obtained during the crisis-affected period. However, in this research this would not be an appropriate measure since all bonds with changed structure (issued after 2008) would be left out of the model; thus the main aim of the study would not be accomplished.

To conclude, the qualitative analysis of the obtained results shows that the explanatory power of the incorporated dummy variables is reduced due to the effects of the credit crisis. As described in Chapters 1 and 2, the ILS market was also affected by the global financial crisis, despite its stable performance throughout the years. Following the collapse of Lehman Brothers in 2008, the number of newly issued catastrophe bonds' sharply decreased. Even so, the overall ILS market experienced a quick recovery and new risk capital began to be issued at beginning of 2009. However, investors in catastrophe bonds saw these securities as riskier than before and required higher premiums. Thus, in 2009 many catastrophe bonds' funds had to sell the bonds on the secondary markets (Munich Re, 2010). At the same time, investors were believed to have taken advantage of this distressed selling, which consequently inflated the spread of bonds (Torchia, 2009). Since the secondary market for catastrophe bonds reacted slowly to the recovery of the ILS, this led to a market overhang and decrease in demand from the secondary market during this year (Schmutz and Dubinsky, 2009). This was the main cause for the excess capacity in the primary catastrophe bond market. In order to clear the abundant supply and attract more secondary investors, the market reacted by increasing bonds' spreads (Graph 5.1) The effects of this phenomenon have not yet vanished completely and even though spreads started declining in

the end of 2009, they are still above pre-Lehman's levels (Guy Carpenter & Company LLC, 2010).

Graph 5.1: Bonds issuance and monthly spread average



It is expected that the catastrophe bond market will continue to recover in 2010. The main drivers behind this trend are the growing investor base, increasing demand in the market as well as the structural improvements in catastrophe bonds (RAA, 2010). This positive perspective is supported by catastrophe bonds' spreads which have started declining and are expected to soon reach those of traditional reinsurance packages (Guy Carpenter & Company LLC, 2010). Another factor which plays a role in the market recovery is the 2010 US hurricane season, which is expected to be more severe than the one in 2009. This would mean an increase in the amount of risk capital issued (Hills, 2010).

With the effects of the global crisis slowly vanishing, the catastrophe bonds' prices are also declining. The credit risk involved has significantly decreased after the structural improvements introduced in the beginning of 2009. We believe that the safer TRS structure, which lowers the risk load for investors, is also one of the major drivers behind the decline in spreads. We also expect that the pricing models tested under these assumptions will prove this statement if tested

again with data that is completely unaffected by the crisis effects experienced in the period 2008-2010. This will be a topic of future researches and we expect these to prove the presence of negative coefficients for the dummy variables reflecting the changed structure of catastrophe bonds.

Our findings show significant results and therefore we believe they have contributed to the development of the catastrophe bond theory and provided a different perspective for future studies in the field of catastrophe bond pricing. This thesis can be value-adding to researchers in the area of bonds' pricing, to consulting companies dealing with catastrophe bonds issues, to catastrophe bonds' issuers interested in accurate issuance timing of the bonds, to rating agencies which incorporate credit risk as a part of their methodology for rating catastrophe bonds and to readers who have a keen interest in catastrophe bond theory and pricing models.

6. CONCLUSIONS AND FURTHER RESEARCH CHAPTER

In this chapter we present the conclusions we have reached after analyzing the results of the pricing models. Also, several areas of potential future research in the field of catastrophe bonds will be outlined.

In this research we analyzed the development of catastrophe bonds during the last decade and outlined the main factors which affect bonds' prices. In the last five years we have observed new trends which affected the structure of catastrophe bonds. The major event which marked the beginning of these changes was the collapse of Lehman Brothers in 2008. This financial institution acted as a TRS counterparty for several catastrophe bonds and precipitated their failure or rapid decrease in value. Contrary to what was claimed by analysts prior to this event, catastrophe bonds were proven to carry a certain amount of credit risk. This instigated several changes in the structure of these bonds. After 2008, the collateral investments of the TRS counterparty were replaced with safer ones, including government-backed securities, monetary funds' investments or tri-party repurchase agreements. Other bonds were constructed without the use of a TRS counterparty at all.

Our hypothesis was that the structural change in catastrophe bonds, which was observed after September 2008, would exert a downward pressure on spreads since the risk exposure for investors would be reduced. After carrying out this research we can present our main findings:

- 1) Catastrophe bonds' spreads are significantly affected by the safer TRS structure introduced after September 2008;
- 2) Structures which do not involve a TRS counterparty do not show significant influence on bonds' spreads for the time period investigated in this research;
- 3) Contrary to our expectations, the changes in bonds' structure show a positive effect on bonds' spread. This was proven by all tested pricing models, except for the Lane and Mahul (2008) AB model, which includes a "Single Peril Indicator".

Thus, we can answer our research question by stating that under the present market conditions, the "Safer TRS" structure has a significant impact on catastrophe bonds' prices. Even though the

tested models show a positive coefficient for this variable, we believe that this is an additional effect brought in by the global financial crisis and that our hypothesis can be proved in a future research when the effects of the crisis will have vanished completely. As described in Chapter 5, spreads were artificially inflated by investors taking advantage of the unfavorable market conditions, as well as by the excess supply in the primary market which was not met by the demand in the secondary market. We assume that the additional crisis effect is the cause of the positive sign in front of the coefficients of the dummy variables reflecting the change in structure in the tested pricing models.

6.1. Future Research

We believe that the investigated topic is a matter of future interest and we recommend several areas of further research:

- 1) A purification of the tested pricing models is necessary in order to catch and present the additional effect on bonds' prices brought in by the global financial crisis. A variable which reflects and absorbs this effect should be incorporated in the model. This would give a realistic view of the effect that the structural change has on bonds' prices;
- 2) Another improvement would be the test of the pricing models with a larger data sample, which would include catastrophe bonds issued after 2010, i.e. after the effects of the crisis have vanished;
- 3) We aim at further developing the Papachristou (2009) pricing model since we believe that the variables incorporated in it are the most accurate determinants of catastrophe bonds' prices. Also, we aim at testing the model with a different data sample and investigate the impact of the other characteristics of the bonds (i.e. single and multi-peril bonds) on their pricing;
- 4) An interesting area of research would be the secondary catastrophe bonds' market and the pricing principles which are relevant there. Such a research would be possible when this market develops further and more information about the trading of bonds becomes available. A time series analysis of the prices of catastrophe bonds on the primary and secondary markets would add to the existing theory of the ILS market.

- 5) It would be valuable to see whether the safer TRS structure introduced after 2008 would remain a long-term catastrophe bonds' feature or whether it is a temporary effect of the credit crisis, which will disappear when investors' preferences for risk increase.

We would be grateful if our research has contributed to the development of the catastrophe bond theory and we encourage any further studies that would add to the existing knowledge of this quickly-developing area of finance.

6.2. Acknowledgements

We would like to thank our advisor prof. Lars Oxelheim for his help and guidance during the development of our research. We are grateful to Marcus Thorsheim and Dimitris Papachristou for their valuable ideas and constructive comments about our work. Moreover, we would like to express our deep gratitude to our families and friends for their continuous support during the implementation of this study.

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APPENDIX

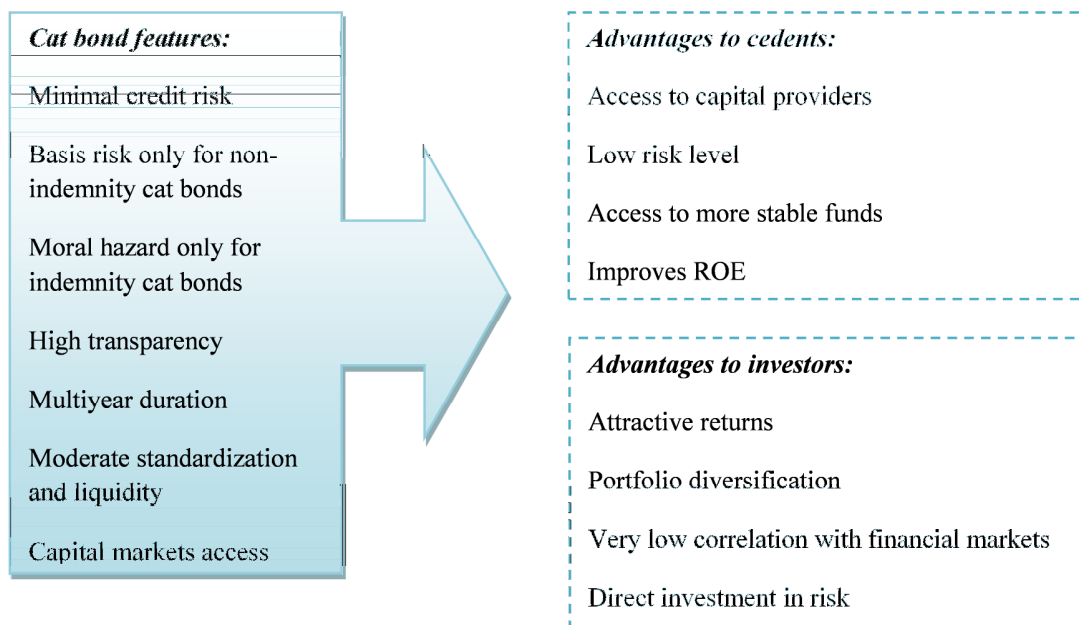
I. The ILS Market and catastrophe bonds

Insurance and reinsurance companies manage to raise capital by involving in securitization transactions and other alternative risk transfer deals. This provides them with the opportunity to use this capital to reimburse losses if necessary, while simultaneously mitigate risk by transferring it to the markets. (Cummins, 2008)

The mechanism of raising funds has several main roles. It is a way to fill in the financial and capital gaps left after the occurrence of a catastrophic event, to smooth the cyclicity of insurance markets and to increase the competitiveness of bonds spreads. (IAIS, 2009)

The catastrophe bond market, as one of the most important parts of the ILS market, is characterized by a number of attributes which make it attractive to both cedents and investors.

Figure I/1: Cat bonds features, advantages and disadvantages



Source: Cummins and Weiss, 2009

Source: Lane, 2010

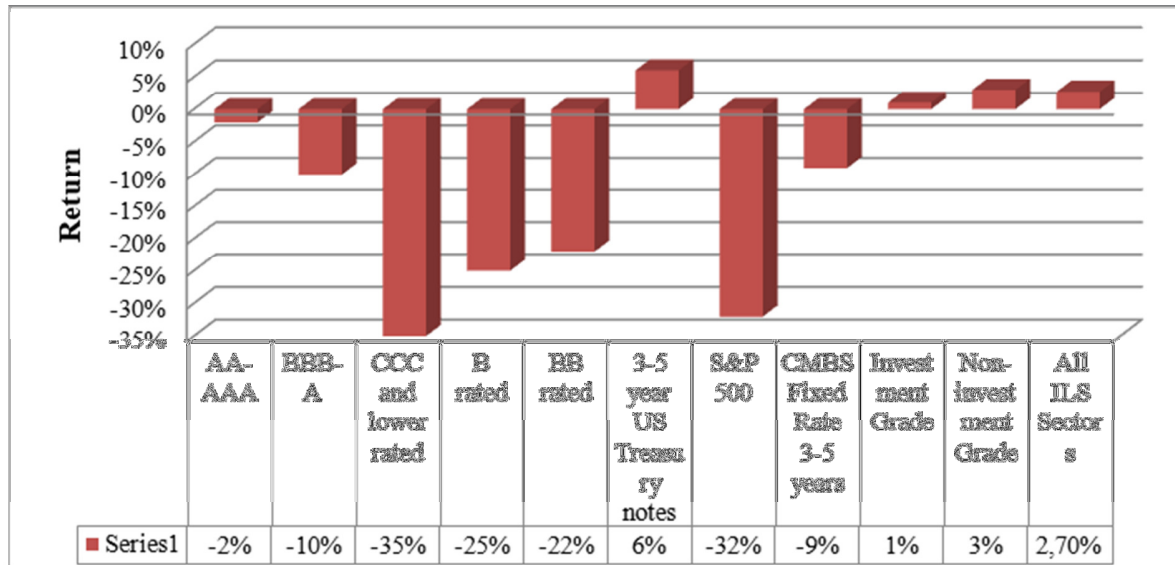
Catastrophe bonds' liquidity level is generally higher than that of other ILS instruments (sidecars, ILWs, options, swaps, etc.) (Cummins and Weiss, 2009). During the past two years, the liquidity level of catastrophe bonds has improved due to the increasing volume of collateral investments in money market funds. However, these are still not considered to be liquid financial instruments.

Despite the increase of natural disasters, and therefore higher risk exposure, catastrophe bonds market has experienced continuous growth and development. There has been a constant flow of new entrants, growth in the amount of risk capital issued by a single sponsor, and an increase in bonds' duration (IAIS, 2009). The number of issuances is evenly spread between insurers and reinsurers. Some of the most popular issuers are USAA, Swiss Re, Munich Re, SCOR, Allianz, etc. There is a limited number of transactions initiated by state or higher international structures (e.g. Cat-Mex 2006) (IAIS, 2009). Investors in this type of securities include institutions like catastrophe bond funds, pension funds, hedge funds and others (Zolkos, 2006).

Despite the experienced growth and relatively low correlation, this market was also affected by the financial crisis which started in 2007. The effects started to be felt in the end of 2008 after the collapse of Lehman Brothers. Liquidity levels went down and capacity in the market shrunk leading to almost no new transactions in the several months following the Lehman Brothers bankruptcy (AON Benfield, 2009).

However, the ILS market recovered relatively quickly and proved that liquidity was available even in such unstable situation. The catastrophe bond market also showed positive results, improved performance and increasing confidence among investors, which led to improvements in capacity. The returns observed in 2008 are shown on the Graph below. Together with US treasury notes, AA-AAA rated, investment and non-investment grade assets, the ILS instruments are the only ones showing positive returns in the financial turmoil experienced in 2008 (AON Benfield, 2009).

Graph I/1: ILS market returns



The test of the financial crisis led to certain changes in catastrophe bonds, the most significant of which involved higher transparency and safety levels. This improved structure will lead to investors seeking better diversification by investing in bonds with higher expected loss and higher return levels (AON Benfield, 2009).

So far, the ILS market instruments' level of utilization remains low which is due mostly to the fact that these are relatively new types of transactions. There has been a small number of completed deals which compete with the stable and long established traditional reinsurance market. However, the ILS market share and the risk capital issued are constantly growing which shows general stability when tested in the conditions of a severe global financial crisis (IAIS, 2009). With the improvement of the current market situation, alternative risk transfer instruments have the opportunity of occupying a larger part of investors' portfolios and become more of a traditional than exotic form of investment (Ferguson, 2008).

II. Mechanics of the catastrophe bond structure

One of the most important parts of the catastrophe bond structure is the SPV. It is set by a sponsor who enters into a reinsurance contract. According to the contract, the SPV provides the sponsor with contingent loss payments if the catastrophe bond is triggered by a pre-determined trigger event. In return, the sponsor provides the SPV with premium payments until the catastrophe bond matures (Bruggeman, 2007). The setting of this structure is done with the help of a modeling company, which gives advice and directions on the trigger mechanism and the risk calculations. Prior to issuing notes to investors, the cat bond is rated by a rating agency which bases its calculations on the data provided by the modeling company. After the cat bond is rated, the SPV issues notes to the investors through an underwriter. Proceeds from the cat bond issuance are placed in a custodian account (or collateral trust account). The SPV later enters into a total return swap deal with a TRS counterparty. This counterparty reinvests the proceeds in secure and high-quality investments (Fritsch and Laplante, 2008). The TRS counterparty in return guarantees the timely payment of a LIBOR rate (minus TRS premium) to the SPV. The SPV receives the LIBOR rate from the TRS counterparty and premium from the sponsor. These inflows are directly transferred to the investors as interest payment (Fritsch and Laplante, 2008). If a pre-determined event takes place and the bond is triggered, the sponsor receives the funds determined by the contract and can cover the incurred losses (Bruggeman, 2007). In order to pay the sponsor, the TRS counterparty sells the collateral assets and irrespectively to the liquidation price returns the full amount to the SPV (Towers Perrin, 2009). The SPV, according to trigger type and the contract conditions, splits the payment between the sponsor and the investors. In a typical structure, full recovery is guaranteed to the sponsor and if any funds are left after covering the losses, they are returned to the investors as part of their initially paid principal (Cummins, 2008). Also, investors receive back their principal and interest (LIBOR plus premium) when the bond matures provided it has not been triggered (Bruggeman, 2007).

III. Insurance Market Cycles

The insurance market cycle is determined by two important factors, namely capital and investment returns (Tobin, 2007). However, new trends have been experienced recently. Nowadays factors like regulatory control, improved risk management, increased transparency and the continuing consolidation among the biggest players in the insurance market lead to increased market stability. Simultaneously, companies' performance becomes less dependent on the market cycle (Tobin, 2007).

Usually, the most unfavourable market conditions are experienced after a major catastrophic or a man-made event occurs, sometimes followed by a crisis or a depression period. In the beginning of the 1990s such an event was hurricane Andrew, later followed by the terrorist attacks on 11th September 2001 and hurricanes Katrina, Wilma and Rita in the first decade of the 21st century (Tobin, 2007). The main characteristics of the soft and hard market are presented below.

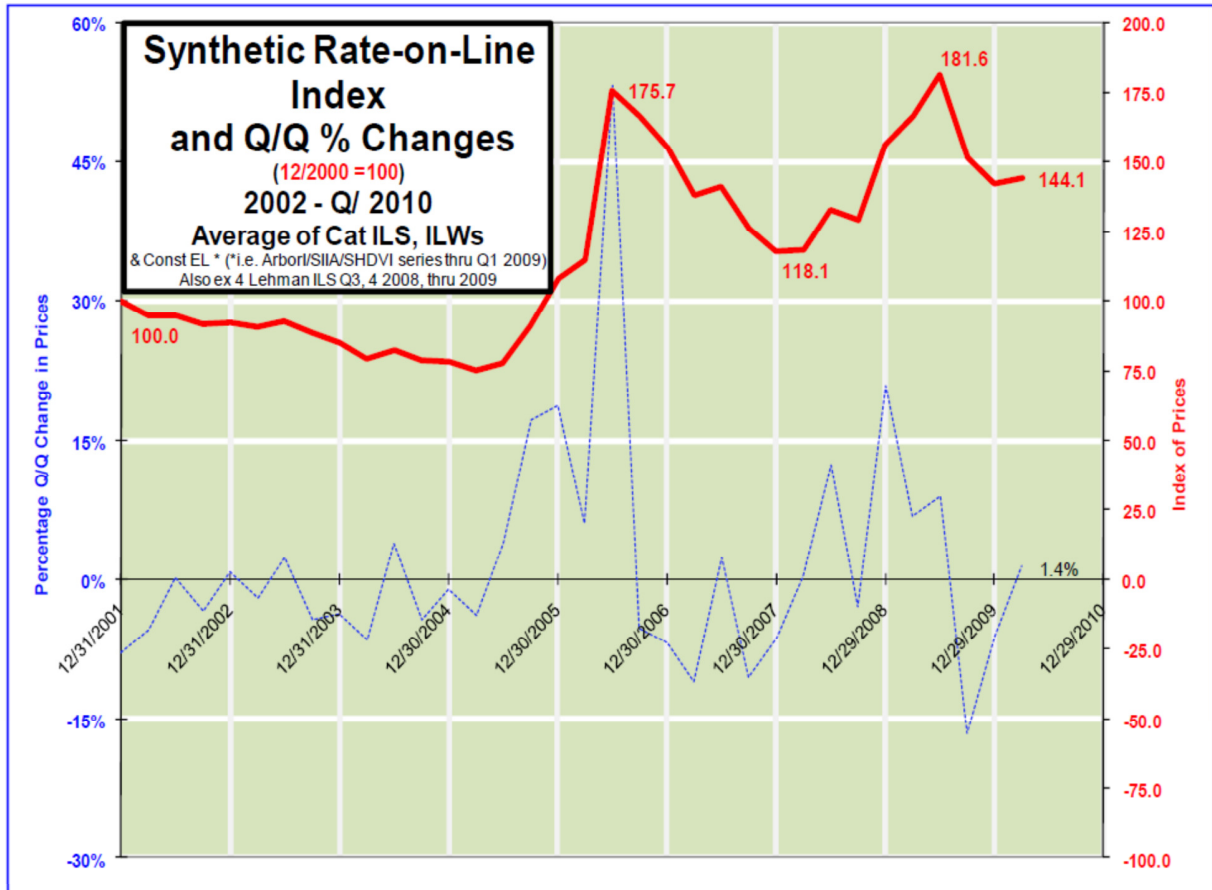
Table III/1: Soft and hard market

Soft Market	Hard Market
Increased competition	Less market participants
Increasing number of market participants	Strict underwriting requirements
Decreasing spreads	Increasing premiums
Excess capacity	Capacity shortage
Innovative structures	

Source: Tobin, 2007

IV. Market cyclicality index (ROL)

Graph IV/1: Market cyclicality index ROL



Source: Lane Financial LLC, 2010

V. Original models regression results

Table V/1: Summary of the original Bodoff (2009) model regression results

Peril	Zone	Years	Market Condition	# of Observations	R Square	Adjusted R Square
All	All	All years	Full cycle	115	87.4%	87.0%

Peril	Zone	Years	Market Condition	Parameter Name	Parameter Value	Standard Error	Confidence Interval (95%) Lower Bound	Confidence Interval (95%) Upper Bound
All	All	All Years	Full Cycle	Constant _{All} %	2.35%	0.25%	1.85%	2.85%
All	All	All Years	Full Cycle	Additional Constant _{Peak} %	1.28%	0.27%	0.76%	1.81%
All	All	All Years	Full Cycle	Additional Constant _{Diversifying} %	-1.09%	0.35%	-1.79%	-0.39%
All	All	All Years	Full Cycle	Loss Multiplier _{EQ}	1.60	0.10	1.40	1.81
All	All	All Years	Full Cycle	Loss Multiplier _{wind}	2.29	0.10	2.10	2.48

Table V/2: Summary of the original Lane and Mahul (2008) model regression results

**Table 2. Catastrophe Risk Pricing – Model (2)
Since Inception (1997-Q1 2008)**

	Coefficients	Standard Error	t Stat	P-value
Intercept	0.00194012	0.009581203	0.202492	0.839700601
Expected Loss	2.051656829	0.084239213	24.35513	2.88432E-67
Cycle Index	0.033209231	0.010112302	3.284043	0.001173341

Multiple R = 0.8517

No intercept

Intercept	0	#N/A	#N/A	#N/A
Expected Loss	2.052184059	0.084034015	24.42087	1.38768E-67
Cycle Index	0.035168649	0.0029309	11.99927	2.11937E-26

Multiple R = 0.9404

Recent Issues (2003-Q1 2008)

Intercept	-0.00140586	0.010650567	-0.13199	0.895134073
Expected Loss	2.333766308	0.091786229	25.42611	3.76097E-61
Cycle Index	0.030405597	0.010596176	2.869488	0.004609275

Multiple R = 0.8898

No intercept

Intercept	0	#N/A	#N/A	#N/A
Expected Loss	2.332482952	0.091019005	25.62633	8.57089E-62
Cycle Index	0.02907543	0.003266839	8.900171	6.08881E-16

Multiple R = 0.9035

Table V/3: Summary of Papachristou (2009) Model

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%

Source: Papachristou (2010)

Table V/4: Coefficients and standard errors of the linear terms

Factor	Level	Estimate	Standard Error	t-Value	Pr(> t)
Trigger	Indemnity	0.0819	0.0437	1.8732	6.33E-02
Peril/Territory	Multi inc. US Hurr.	0.1174	0.0390	3.0111	3.13E-03
Peril/Territory	US EQ	-0.1392	0.0444	-3.1384	2.11E-03

Source: Papachristou (2010)