12-6-2007

Analysis of Pricing and Reserving Risks with Applications in Risk-Based Capital Regulation for Property/Casualty Insurance Companies

Chayanin Kerdpholngarm

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The author of this dissertation is:

Chayanin Kerdpholngarm
114/189 Navongprachapattana rd.
Srigun Donmeung
Bangkok, 10210
Thailand
Chay09@gmail.com

The director of this dissertation is:

Dr. Shaun Wang
Department of Risk Management and Insurance
35 Broad Street, Robinson College of Business
Atlanta, GA 30303

ANALYSIS OF PRICING AND RESERVING RISKS WITH APPLICATIONS IN RISK-BASED CAPITAL REGULATION FOR PROPERTY/CASUALTY INSURANCE COMPANIES

BY

CHAYANIN KERDPHOLNGARM

A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree

Of

Doctor of Philosophy

In the Robinson College of Business

Of

Georgia State University

GEORGIA STATE UNIVERSITY
ROBINSON COLLEGE OF BUSINESS
2007

ACCEPTANCE

This dissertation was prepared under the direction of Chayanin Kerdpholngarm's Dissertation Committee. It has been approved and accepted by all members of that committee, and it has been accepted in partial fulfillment of the requirements for the degree of Doctoral of Philosophy in Business Administration in the Robinson College of Business of Georgia State University.

H. Fenwick Huss, Dean
Robinson College of Business

DISSERTATION COMMITTEE

Dr. Shaun Wang, Chairman

Dr. Robert Klein

Dr. William Feldhaus

Dr. Jean Kwon

Acknowledgements

First, I would like to express my gratitude to my advisor, Shaun Wang, for his continuous support. He is responsible for inspiring me in this topic and helped me sought out my ideas with simple but straightforward approaches. His patience and guidance assisted me to overcome many crisis situations and finish this dissertation.

A special thanks goes to my committee member, Robert Klein, who has been always there to listen and to give advice. I am deeply grateful to him for the long discussions that brought out the good ideas in me. I am also thankful to him for helping me complete the writing of this dissertation as well as the challenging research that lies behind it.

I also would like to thank the rest of my thesis committee: Jean Kwon, who asked me good questions and William Feldhaus who reviewed my work on a very short notice. I am indebted to Martin Grace who taught me how to ask questions and express my idea. He also supported and encouraged me since the beginning of my Ph.D. program.

Considerable acknowledgment and appreciation is devoted specifically to Robert Faber and Karen Pachyn who have provided me the insightful comments since the early discussions on this topic. Their experience in insurance industry helps me understand what happens in the real worlds. I am also greatly thankful to them for reading my reports and providing the peer reviews.

I want to thank Piyanut Itarut for providing me with endless encouragement and for being a very best friend. I must also thank Andreas Milidonis for lending me his ears and helping me think thoroughly. Also thanks to the karaoke folks for keeping me in good spirit and being fun to be with.

Most importantly, my deepest gratitude is to my parents, Sanae and Anchalee, whose unconditional love, concern, and support endowed me strength to complete this dissertation. Especially through the hard times, I thank my parents and my sister, Wannasiri, who have always been there when I need comfort.

Finally, thank you again to all those people who have made this dissertation possible.

ABSTRACT

Analysis of Pricing and Reserving Risks with Applications in Risk-Based Capital Regulation for Property/Casualty Insurance Companies

BY

Chayanin Kerdpholngarm

December 7th, 2007

Committee Chair: Dr. Shaun Wang

Major Academic Unit: Risk Management and Insurance

The subject of the study for this dissertation is the relationship between pricing and reserving risks for property-casualty insurance companies. Since the risk characteristics of insurers differ based on their structure, objectives and incentives, segmenting the insurers into subgroups would allow for a better understanding of group-specific risks. Based on this approach to analyzing insurer financial risks, we find that, in a given accident year, the pricing and reserving errors are positively correlated, especially in long-tailed lines of business. Large insurers, stock insurers, and multi-state insurers, in general, exhibit a strong correlation between accident-year price and reserve errors. However, only size of insurers appears to be a factor that influences the interaction between price changes and the calendar year loss reserve adjustments. Furthermore, we find that the pricing risk and reserving risk are marginally more homogenous within a market segment when size, type and number of states are employed as criteria for market segmentation, hence insurance regulators should consider the refined market segments for the RBC formula. The empirical results also indicate that, in general, Chain-Ladder reserving method likely contributes to loss reserve errors when there is a change in the loss development pattern and the magnitude of the errors is worse for large insurers. Finally, we find that our proposed measurement method for the product diversification benefit provides support for the notion that the diversification benefit on the incurred losses increases with the number of lines in the portfolio. Yet, the diminishing returns tend to decrease the diversification benefit on the incurred losses for insurers that write the business in more than six of the selected lines. To the contrary, our proposed measure does not provide clear evidence that writing business in many product lines increases the product diversification benefit with respect to adverse loss development. We do find that the diversification benefit for both incurred losses and loss development is higher for larger insurers. Hence, for risk management and regulatory purposes, a stronger case can be made for considering firm size than product diversification.

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CHAPTER 1

1. Introduction

1.1. Background and Motivation

The subject of the study for this dissertation is the relationship between pricing and reserving risks for property-casualty insurance companies. As will be explained, estimates of historical losses are an important input in the pricing of many property-casualty insurance lines. In long-tail lines, initial estimates of unpaid losses (i.e., loss reserves) are particularly subject to error and subsequent revision as reported claims are paid or adjusted, additional claims (arising from policies issued in prior years) are reported, and new information pertinent to reserve estimates becomes available. The risk associated with reserve errors would be expected to be closely linked with the risk associated with pricing errors depending on the line of insurance and insurer characteristics. Further, the link between reserve and pricing errors has important implications for firm risk management and regulation. This dissertation hypothesizes and tests this relationship empirically using alternative models and methods and examines the consequences of its findings for firm and market behavior, insurer financial risk management and insurance regulation.

Reserve and pricing errors appear to be tied to the phenomenon know as the "underwriting cycle." It is well-known that the property-casualty insurance industry, especially for long-tailed lines of business, experiences alternating periods of "soft markets" and "hard markets". In soft markets, supply expands and prices fall as insurers seek to increase the business they write (and/or retain the business they have written) in the face of falling market prices. Empirical data suggest that prices fall below costs in soft markets, resulting in low or negative profits for insurance firms. In hard markets, supply contracts and insurers raise their prices to levels that at least achieve profits or rates of return equal to the cost of capital. Hence, the risk of under-pricing appears to vary across different phases of the underwriting cycle. This is one of several aspects of the reserve-pricing error relationship examined in this dissertation.

Based on theory and empirical evidence, we argue that the risk of underestimating reserves for unpaid losses is associated with the risk of under-pricing. Under-estimation of loss reserves will cause total losses incurred by insurers to be underestimated and profits and surplus to be overstated. These errors can have further implications for insurers' financial and market decisions. Importantly, insurers' estimates of their historical losses play a significant role in their calculation of the prices they should charge in the future. Hence, underestimation of unpaid losses attributable to prior periods can lead to under-pricing of insurance contracts in future periods.

Most of the academic research on the underwriting cycle has sought to find "rational" economic explanations for the phenomenon, e.g., changes in interest rates, loss shocks, data reporting lags, etc. (see, for example, Doherty and Garven, 1992). [1] However, these studies tend to focus on drivers of pricing risk while ignoring the interaction between pricing and reserving risks. As estimates of historical losses are a major input in the calculation of insurers' prices for future periods, it is reasonable to surmise that reserving errors are correlated with pricing errors. Lack of knowledge about the interaction between these risks hampers an insurer in making appropriate decisions and consequently could aggravate the overall risk of the firm. Developing a better understanding of the interaction among these firm risks contributes to a better

[1] Klein (2004) provides a summary review of theoretical and empirical research on the underwriting cycle.

understanding of firm risk management as well as the dynamics of the underwriting cycle.

Additionally, the link between pricing and reserving errors has implications for the financial regulation of insurers. In theory, regulators monitor and seek to limit insurers' financial risk (i.e., the risk of default or financial impairment). Regulators seek to accomplish this objective through various means, including financial reporting requirements, measurement and analysis of insurers' financial performance, condition and risk, capital standards, and intervention with insurers that are in financial distress. All of these activities are affected by reserve errors and their consequences for pricing errors.

Recently, the insurance industry has recognized that a behavioral approach is an important key to effective risk assessment and risk management. Consequently, the National Association of Insurance Commissioners (NAIC) and rating agencies have been incorporating an Enterprise Risk Management (ERM) initiative into their Risk-Based Capital (RBC) requirements. ERM also is an important component of the Solvency II regulatory standards being developed for insurance companies in the EU. The ERM, in one respect, can be thought of as the interaction among various forces and market participants. Wang and Faber (2006) defined enterprise risk management as "*the discipline of studying the risk dynamics of the enterprise … and how players' actions influence the behaviors of the risk dynamics…*" This definition supports the notion that the behavior of insurance participants is important to risk evaluation.

The recognition of such a behavioral impact on enterprise risk can help provide a baseline for examining the underwriting cycle phenomenon. Insurers may respond differently to the market environments that vary across the cycle. During soft markets, price competition is intense and underwriters strive to increase the amount of business and premiums they write. In so doing they reduce prices and relax their underwriting standards to acquire more business. However, this can result in inadequate premiums relative to the actual costs that insurers should expect to incur, resulting in causing high loss ratios when actual costs become apparent. Contrary to what happens in the soft markets, price competition lessens during hard markets. Insurers increase prices and underwriting rules are tightened. Losses (i.e., low or negative profits) from inadequate prices during soft markets are followed by relatively high profits earned in hard markets.

Another interesting market process that tends to correspond to the underwriting cycle is the so-called "reserving cycle" phenomenon. The reserving cycle refers to the cyclical pattern of understatement and overstatement of loss reserves by insurers. It arises from inaccurate estimations of loss reserves, whether deliberately or not, by insurers. Based on a review of industry aggregate data, the reserving cycle appears to track the underwriting cycle.

Among academic researchers, there are different opinions about the causes of reserve errors and their link to pricing errors. Many researchers may believe that reserve errors (and price errors) are inadvertent and unintentional (e.g., Wang and Faber, 2006).[2] Some researchers, however, suggest that reserves may be intentionally manipulated to change reported financial results and also support certain business decisions, such as setting prices (e.g., Gaver & Paterson, 1999), tax planning, and smoothing of performance. For example, according to this view, insurers may intentionally set lower reserves to justify lower prices and set higher reserves to justify higher prices. However, a relationship between reserving errors and pricing

[2] While many researchers have sought to develop rational economic explanations for insurers' reserve and price calculations and the underwriting cycle, it is apparent that insurance practitioners believe that there is a significant behavioral component to these phenomena. A review of insurance trade press articles yields numerous practitioner assessments that conclude that insurers are deliberately under-pricing and failing to enforce stringent underwriting standards during soft markets.

errors does not depend on insurers' intent – one would expect to observe such a relationship regardless of whether there is deliberate manipulation or not.

Not only do reserving and pricing (underwriting) risks vary over time, they also likely differ across types of insurers. For instance, publicly traded stock companies that face pressure to increase earnings, either from shareholders or from managers who are compensated based on profits, would be expected to act differently than mutual companies. Stock insurers have an incentive to manipulate their reported financial results in order to please their shareholders (Grace and Leverty, 2005). One way of achieving this is to manage loss reserves to smooth earnings. However, adverse effects from these manipulations, once recognized, can potentially cause trouble for insurers – they may be ultimately compelled to report "adverse" loss development and lower their reported earnings.[3]

In theory, government regulation should prevent insurers from misstating their financial condition and incurring excessive financial risk. The current RBC formula in the US, however, does not consider the relationship between reserving and pricing errors and how these risks may vary over time and among insurers. The same regulatory requirements and measures are applied to all insurers regardless of their organizational form and market conditions. In addition, the NAIC RBC formula does not recognize the interaction between pricing risk and reserving risk. Indeed, it assumes the two risks are independent. These limitations of the RBC formula can distort the calculation of insurers' capital requirements and potentially influence their financial risk management.

[3] Considerable time may pass before insurers are compelled to increase their loss reserves for prior years and suffer the consequences of historical under-reserving. Increases in an insurer's loss reserves for prior years are reflected in the calendar-year financial results when the reserves are adjusted. Schedule P in insurers' regulatory financial statements shows their premiums and losses on a calendar-accident year basis, i.e., losses are reported for the year in which they are incurred.

Insurance regulators in other jurisdictions have started to recognize the significance of individual insurer risk characteristics and are attempting to incorporate them into their capital formula. During the course of the development of the Solvency II Directive in the European Union (EU), an important issue has been raised regarding the capital requirements that will be imposed on small and medium-sized insurers. According to the Solvency II proposals, small companies may be subject to multiplicative size-factors that increase the amount of required capital required for pricing risk and reserving risk. However, this approach is unfavorable to small niche companies that seem to have more stable results.[4]

The underwriting cycle's impact is also reflected in the currently proposed Solvency II capital requirement. The expected profits or losses from business written in the following statement date are treated as an allowance in the capital standards.[5] However, the expected profit allowance is simply the average of profitability in the previous three-to-five-year period. At the turn of the market cycle, this method can produce a reduction in capital requirements in softening markets and an increase in capital requirements in hardening markets. However, this treatment of the underwriting cycle is inappropriate for the cycle's turning periods.

Taken together, this discussion indicates that the topic of this dissertation is interesting and important for several reasons. First, it deals with important elements of decision-making in insurance firms. Second, it has significant implications for the assessment and management of insurers' financial risk. Third, it is very relevant to the financial regulation of insurance companies, including but not limited to regulatory

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[4] In the initial development of the NAIC's RBC formula, a component that would increase RBC charges for small companies was eliminated because of concerns about strong opposition from small insurers as well its failure to distinguish among small insurers according to the stability of their earnings.

[5] See Klein and Wang (2007) for an overview of Solvency II proposals and the process for their adoption and implementation.

capital requirements. Finally, it offers potential insights into factors affecting insurance market conditions and the underwriting cycle – a phenomenon that continues to intrigue researchers and plague market participants.

1.2. Contribution

This dissertation focuses on the interaction between pricing and reserving risks, and proposes a practical approach to refine the RBC formula for property-casualty insurers that reflects this interaction. We suggest that refined segment classification based on the risk characteristics of insurers is the key to an appropriate capital requirement. Since the risk characteristics of insurers differ based on their structure, objectives and incentives, segmenting the insurers into subgroups would allow for a better understanding of group-specific risks and support more refined risk management strategies and regulatory capital requirements. Based on this approach to analyzing insurer financial risks, we focus on four important questions.

The first question is whether the reserving risks of insurers change with varying market conditions during the underwriting cycle. Fitzpatrick (2004) provides an explanation of a behavioral theory of the underwriting cycle in which he opines that the underwriting cycle is specific to each insurer and market sector. The insurers who cut prices to expand their business dominate the market pricing action except when past pricing problems (i.e., inadequate prices) are recognized. In this study, we characterize structures, objectives and incentives in terms of their size, type, specialist expertise, and "locality".

The NAIC RBC formula applies a covariance adjustment which is equal to the square root of the sum of squares of each risk category.[6] The risks, including pricing

[6] See section 3.2. for more details.

and reserving risks that are subject to square root adjustment, are assumed to be substantially uncorrelated. However, we observed that pricing and reserving risks are highly correlated. The lack of a proper correlation adjustment in the RBC formula combined with the fact that pricing and reserving risks comprise 80 percent of the aggregate industry RBC raises serious questions about the calculation of insurers RBC requirements.[7] Changes in the RBC formula that would consider the interaction of reserving and pricing risks would improve its accuracy and effectiveness.

The second question considers whether the underwriting risks of insurers are affected by company characteristics. Insurers vary in terms of their structure and objectives and this could cause their risk levels to vary. Wang and Faber (2006) for example, observed that large stock companies, compared with mutual insurers, have more pressure on earnings and have greater discretion in estimating their reserves. Therefore, they are more susceptible to pricing and reserving risks. In this paper, insurers are categorized according to their risk characteristics to further test this proposition. Specifically, in the empirical analysis of a given line of business, a market is segmented by size, type, multi-lines, and multi-regions. The underwriting risks associated with these characteristics will then be discussed accordingly.

The third question is whether actuarial reserving models contribute to the reserving risks. To investigate this question, we apply the classical chain ladder method to project incurred losses. The actuarial estimates will be compared with the actual results to gauge the accuracy of the actuarial models. In fact, the actuarial reserving models are simple and do not reflect the risk characteristics such as line-specific and firm's size-specific features. Therefore it is interesting to examine how well the actuarial methods can estimate the loss reserves in each market segment. The

[7] Risk-Based Capital: Overview and Instructions Forecasting, Property and Casualty 2006.

evidence of varying accuracy among classes (e.g. size of company) of insurers would support the argument that the actuarial reserving model may not work well with the class of insurers whose risk is complex and/or subject to drivers other than the insured loss per se.

The final ultimate question is whether insurance regulators should consider the refined market segments by insurers' firm structure and objectives for the RBC formula. To answer this question, we conduct tests using credibility theory to investigate the implication of refined segments relative to industry-wide regulation. In particular, we apply credibility theory to test whether the underwriting risks of insurers are homogenous for an entire industry or if they are segment-specific. Our scope of analysis will go further than simply the size of a company as proposed in Solvency II; we also segment the market by type of company, specialist expertise, and the geographic distribution or business.

We find that, in a given accident year, the pricing and reserving errors are positively correlated, especially in long-tailed lines of business. The results imply that under-estimation (over-estimation) of loss reserves, whether it is deliberate or not, will cause total losses incurred by insurers to be underestimated (overestimated), and thus the prices to be understated (overstated). In addition, we learn that the pricing in an accident year is associated with the loss reserve adjustment that occurred in the same year. [8] The results suggest that insurers increase (reduce) loss reserves as prices are rising (decreasing) and vice versa.

We also find that in a given accident year, large insurers, stock insurers, and multi-state insurers, in general, exhibit a strong correlation between price and reserve errors. However, when we focus on the timing of price changes and loss reserve

[8] Accident-year data ties incurred losses (and the associated premiums earned) to the year when losses are incurred.

adjustment, only size of insurers appears to be a factor that influences the interaction between price changes and loss reserve adjustments. Furthermore, we apply credibility theory to test whether segmenting the insurance market by size, firm structure, number of lines, and number of states written is an effective method for grouping the pricing and reserving risks. We find that, in general, the pricing risk and reserving risk are marginally more homogenous within a market segment when size, type and number of states are employed as criteria for market segmentation. In contrast, we do not find that the number of lines of business is an effective criterion for segmenting the pricing risk and reserving risk.

The empirical results also indicate that, in general, the classical actuarial reserving method such as the Chain-Ladder method likely contributes to loss reserve errors when there is a change in the loss development pattern and the magnitude of the errors is worse for large insurers.

Finally, we find that our proposed measurement method for the product diversification benefit provides support for the notion that the diversification benefit on the incurred losses increases with the number of lines in the portfolio. Yet, the diminishing returns tend to decrease the diversification benefit on the incurred losses for insurers that write the business in more than six of the selected lines. To the contrary, our proposed measure does not provide clear evidence that writing business in many product lines increases the product diversification benefit with respect to adverse loss development. We do find that the diversification benefit for both incurred losses and loss development is higher for larger insurers. Hence, for risk management and regulatory purposes, a stronger case can be made for considering firm size than product diversification.

The remainder of the paper is organized as follows. Section 2 reviews the extant literatures on underwriting cycle, reserving cycle, and their interaction. Section 3 explores underwriting risks in the context of behavioral theories of finance/economics. Section 4 contains background information on the NAIC and rating agencies' approach for premium and reserve risks. Section 5 lays out the hypothesis construction. Section 6 describes our dataset and the variables used in the analysis. It also explains the methodologies we use for testing our hypotheses testing. Section 7 presents and discusses our empirical results. Section 8 summarizes our results, presents our conclusions, and further discusses their implications.

CHAPTER 2

2. Literature Review

2.1. Underwriting Cycle

The property-casualty insurance industry is well known for its pattern of price movement, the so-called "underwriting cycle". The underwriting cycle refers to the rising and falling pattern of prices, and therefore pricing risks, and the availability of insurance contracts. In soft markets, the insurance supply is abundant with lower prices and relaxed underwriting standards. Increased switching of insurance carriers by customers and less refined risk assessment in underwriting can be expected in this period. In hard markets on the other hand, the insurance supply is tightened, as reflected by the increase in prices and stricter underwriting standards. The severe conditions of the hard market can dismay both insurance buyers faced with higher prices and the decreased availability of insurance.

The key drivers found in the literature on the underwriting cycle phenomenon are supply shifts (capital constraints), volatility of losses, solvency constraints, interest rates, market imperfection, imperfect knowledge of the risk and correlation of underwriting performance to volume at times, and the behavioral aspects of insurers' pricing and coverage decisions. Many studies explicitly or implicitly assume a pricing model in testing hypotheses regarding the underwriting cycle. The pricing models are based on loss uncertainty, insurer capital and economic factors.

Understanding the insurance pricing model provides insights into the factors insurers consider in setting prices. Researchers then apply the knowledge about these pricing factors in their analysis of the underwriting cycle. The literature uses alternative pricing models including the financial model, the capacity constraint model, the financial quality model, the option pricing model, the actuarial model, the economic model, and the behavioral model. Each model has unique assumptions and implications about pricing factors. Their implications differ in terms of short-run and long-run profitability. It is shown that all alternatives are relevant to the existence of the underwriting cycle, yet in distinct aspects.

Choi, Hardigree and Thistle (2002) present the alternatives of the insurance pricing model that appear in the underwriting cycle research. Not taking into account the behavioral model, they found that in general these pricing formulas have the same form, i.e., the expected loss plus a short-run deviation from the long-run equilibrium. More details about all alternative models for the underwriting cycle study will be given in the following subsections.

2.1.1. Actuarial Model

The actuarial pricing models are based on the premium principle. The principle states that premiums are determined according to the targeted probability of default. That is, the risk premium charged by the insurer is the fund that allows the insurer to maintain a predetermined default probability. There are two major pricing models based on this principle: the standard deviation premium model and the utility premium model.

a) *Standard Deviation Based Model*

In this model, the policy premium is equal to the actuarial fair price, plus a standard deviation based loading. The explicit formula is:

$$P = \mu_L + \alpha \cdot \sigma_L$$

where P = premium; μ_L = expected present value of losses; α = safety loading; σ_L = standard deviation of losses.

b) *Zero-Utility Model*

The principle underlying this model posits that insurers set prices in a utility maximizing framework (Bowers et al, 1986; Bühlmann, 1970; and Gerber, 1979). The premium charged must be adequate to compensate the insurer for holding risks. Explicitly, the premium must be set high enough so the insurer derives as much utility from being in the market as not being in the market.. A simple example of the premium formula based on this principle is:

$$P = \mu_L + \lambda \cdot \sigma_L^2$$

Where P = premium; μ_L = expected present value of losses; λ = the risk aversion parameter. The zero-utility principle assumes a perfectly competitive market. The risk premium increases with the variance of risk and decreases with the amount of surplus in the short-run. The participation constraint is binding in the long run.

2.1.2. Financial Models

The financial insurance pricing models were first introduced through the concept of Insurance Capital Asset Pricing Model (ICAPM) developed by Cooper (1974), Biger and Kahane (1978), Fairley (1979), and Hill (1979). The ICAPM is the combination of balance sheet and CAPM rate of return on the insurer's equity. The result is as follows:

$$E(\tilde{r}_u) = -k\, r_f + \beta_u [E(\tilde{r}_m) - r_f]$$

where $E(\tilde{r}_u)$ = expected underwriting return; $E(\tilde{r}_m)$ = expected return on the market portfolio, r_f = risk-free rate of interest; $\beta_u = Cov(\tilde{r}_u, \tilde{r}_m) / Var(\tilde{r}_m)$ = the beta of underwriting profits; k = the liabilities-to-premiums ratio.

Myers and Cohn (1987) combined ICAPM with the Discounted Cash Flows (DCF) by arguing that *k* in ICAPM is an approximation of the DCF approach. Their multi-period pricing model is:

$$P = L\sum_{i=1}^{n}\frac{C_i}{(1+r_L)^i} + \frac{r_f \cdot z \cdot E}{1-z}\sum_{i=1}^{n}\left[\frac{1-\sum_{j=0}^{i-1}C_j}{(1+r_f)^i}\right]$$

Where P = premium paid by policyholders for insurance coverage; L = total amount of losses under the policy; C_i = the proportion of losses paid at time i; r_L = loss discount rate; r_f = risk-free rate of interest; z = tax rate for investment and underwriting income; E = investment and underwriting income.

Basically, the price according to the financial pricing model can be expressed as the expected present value of claims plus policy expenses.

The financial pricing model assumes a perfect capital market and a perfectly elastic supply in the short run. In particular, capital markets adjust quickly after loss shock. The underwriting profits are founded on the assumption that there is no default risk to the insurer. Some studies in the literature imply this pricing model in studying the underwriting cycle, especially in the effect of price regulation (Venezian, 1985; Cummins and Outreville 1987; Tennyson, 1993; Gron, 1994). By assuming that insurers price their product based on the financial model, there exists evidence that regulatory lag such as prior approval can produce cyclical patterns even in a rational expectation setting.

2.1.3. Capacity Constraint Model

Stewart (1984) and Bloom (1987) developed two informal capacity-constraint models. They formalized the idea that "lack of capacity" causes underwriting cycles.

Both models depend upon the shifting of insurance supply curves to explain the underwriting cycle. In contrast to the financial model, capacity constraint models are based on the assumption that the capital market is imperfect (Doherty and Garven, 1992; Cummins and Danzon, 1992; Winter 1988, 1991a., 1994; Doherty and Posey 1993; Gron 1994; Froot and Stein, 1998). However, the zero default probability is implied in this model. The entry and exit costs for capital are deterrents of insurer bankruptcy, and the industry is hypothesized to survive through the period of the soft market.

Assuming that insurance firms are risk neutral, the capacity constraint model theory illustrates the cycle phenomenon via the capital process. The high cost of raising new equity externally implies that firms accumulate surplus internally and hold that excess capacity to remedy the unexpected need of new equity in the future. The high prices that appear during the hard market partially come from the firm's surplus accumulation scheme. However, the period of hard market ends when enough capital has been accumulated in the industry. According to capacity constraint theory, supply is scarce when there is loss shock or an incident that depletes capital. In the short-run, capital shortage and the expensive cost of raising new equity externally shift the supply curve to the left which consequently increases the price. Nonetheless, the surplus will be recovered through the profit gained from the high prices in the hard market. The industry capacity will accumulate and the surplus curve will shift back to the "normal" level in the long-run.

Evidence of capacity constraint theory was found in the literature. Doherty and Garven (1992) examined the relationship between interest rates, insurer capital structure, and insurance pricing as drivers of underwriting cycles. They showed that changes in interest rates simultaneously affect the insurer's capital structure and the equilibrium underwriting profit. They also found that insurance prices are inversely related to interest rates, which is consistent with the capacity constraint hypothesis. Cummins and Danzon (1992) suggested that the hard market arises from the need of capital to recuperate from depletion after loss shock. However, new capital will continue flowing into the market, and in the long run the capital supply will shift back to the "normal" state. Similarly, Gron (1994) documented that the sharp fall in capacity supply causes increases in future profitability in the short-run. Nevertheless, the financial models yield better predictions for prices in the long-run. Froot and Stein (1998) presented a study on the effects of capital shocks to insurers. Their model implies that the insurance price is a function of its capital. Due to the costs of raising external capital, the firm may have to reject profitable investment opportunities. They also suggest options for risk management: (i) holding capital ex ante, which is costly due to tax and agency costs, (ii) engaging in costly hedging (reinsurance) transactions, and (iii) adjusting the exposure through investment policies.

2.1.4. Financial Quality Model

The financial quality model is an extension of the capacity constraint model. Assuming that a firm has an optimal capital structure, this model suggests that default risk is endogenous and affects insurance prices in the long-run (Harrington and Danzon 1994; Cagle and Harrington 1995). The model incorporates the idea that insolvency risk depends on the amount of an insurer's capital due to the uncertainty of losses. Similar to the capacity constraint model, shocks to the surplus shift supply in the short-run. While capacity constraint theory views the price of insurance as a function of market surplus, the financial quality theory considers it as a function of the firm's surplus. According to the financial quality theory, demand shifts in response to loss shock to insurers, yet the effect of the demand shift is less than the effect of the supply shift. The increase in prices after surplus shock is expected only in the short-run. Prices however are expected to be positively dependent upon the firm's surplus in the long run when the supply has adjusted to the normal level.

High levels of surplus, or financial quality, raises customers' confidence; they therefore are willing to pay more. Cummins and Danzon (1997) applied this model type in their research. Imposing a specific capital market imperfection, they hypothesized that in order to meet target leverage ratios, insurers charge new policyholders higher premiums after the adverse loss shock. The market imperfection in consideration is that the benefit to financial quality, resulting from the added capital from the new and renewal policies, is diluted by the liability from the existing polices. In other words, the new policyholders who pay higher premiums do not receive the full benefits in terms of the financial quality for which they pay. The old policyholders, on the other hand, gain benefits from less insolvency risk, but pay no additional premiums. The authors' findings suggest that the insurers' price increasing and reserve strengthening during the liability crisis period (1984-1985) corresponded to the surplus level. In addition, they argued that price regulation can cause the insurance availability crises and can impede the price adjustment to the normal level.

2.1.5. Option Pricing Model

The insurance option pricing model developed from the thought that insurance coverage can be expressed as risky debt. Payments under primary insurance policies are triggered by changes in the value of insured assets. The option pricing model recognizes the default risk of insurers which can be expressed as a put option on assets of the firm.

Assuming that claim costs can be approximated by a Brownian motion process, the insurance policy is a call option spread, paying

$\{Max[0, Y - M] - Max[0, Y - U]\}$ at maturity, where Y = losses, U = maximum limit, and M = fixed retention amount. The Black-Scholes approach is then applied in calculating the formula of premiums.

A crucial application of option modeling in the insurance literature is the insolvency risk analysis (Sommer, 1996; Cummins and Danzon, 1997; Phillips, Cummins, and Allen, 1998). The policy pricing is established on the put-call parity formula:

$$A = C(A, L, \tau) + \left\lfloor Le^{-r_f \tau} - P(A, L, \tau) \right\rfloor$$

where A = the value of firm assets; L = the value of firm liabilities; C(A,L,τ) = a call option on asset A, with striking price L, and time to maturity τ; P(A,L,τ) = a put option on asset A, with striking price L and time to maturity τ.

The basic concept of the option pricing model is that policy price is equal to the expected present loss plus insolvency put which is the option on the assets of the insurer. The option pricing model and the financial quality model are similar in that insurance coverage can be thought of as risky debt. In contrary to the financial quality model, the price from option modeling would fall as surplus decreases, both in the long-run and short-run. Cummins and Danzon (1997) extended the basic option model to the case of multiple liabilities. Their empirical tests provided evidence that the price of insurance is inversely related to insurer default risk, and that prices declined in response to the loss shocks of the studied period. Phillips, Cummins, and Allen (1998) proceeded a similar analysis on multiple-line insurers. Their empirical findings were consistent with the option model hypotheses: prices varied across firms depending upon overall-firm default risk and the concentration of business among subsidiaries. However, within a given firm, prices did not vary by line after controlling for line-specific liability growth rates.[9]

2.1.6. Behavioral Model

The behavioral model is an important theory which is a major focus of this research. Unlike economic models, the behavioral model explains the underwriting cycle based on the principle that insurers view the market from their own standpoints. Their differing perceptions of the market result in varying insurance prices. Essentially, the behavioral model is founded on the thought that "Insurance supply is as psychological as it is financial" (Stewart, 1984).

Stewart (1984) claimed that the underwriting cycle is perpetual to some extent because of the "lack of information" and "lack of coordination" among insurers. Individual insurers cannot know the precise amount that they should supply. Furthermore, individual insurers have different information and different cost structures, and therefore different perceptions and expectations of future profits or losses development. Each insurer's unique perceptions prevent the market from reaching equilibrium in which there is no cycle in the long-run.

Fitzpatrick (2004) published a keynote paper on the behavioral aspect of underwriting cycles. The main idea of his paper is that the underwriting cycle is a consequence of the interactions between market participants. He summarized that the underwriting cycle is unique for a single insurer and market sector, and is at root the result of managerial judgments. Competition for revenue and market share, compensation structures, and game power among various participants within the insurance companies are the behavioral factors that drive the underwriting cycle. He

[9] The authors use loss reserve weighted average of the industry-wide growth rates by line as a proxy for line-specific liability growth rates.

concluded that underwriting results are based on three factors: “(i) underwriters’ motivation from financial reward and fear of losing employment, (ii) internal agency influences, and (iii) pressures from insurance agents and brokers on the pricing behavior of insurers.”

Feldblum (1999) pointed out that competitive strategy is a cause of the underwriting cycle :

> “Insurer strategies during profitable years drive rates down;
> changed strategies during poor years push rates up,”

The pricing strategy of an insurer can change the market price. For example, an insurer who has profitable years may offer low prices and consequently gain business. Due to the competitive nature of the insurance market, peer insurers would have to lower their prices in order to sustain their businesses, which eventually drive down the market price.

In general, insurers determine prices according to two alternatives of pricing strategy: maintaining market share and maintaining profitability. Since the insurance market is competitive, insurers who decide to maintain market share would manage their underwriting so as to afford pricing at such lower, competitive rates (Fitzpatrick, 2004). Moreover, Wang and Faber (2006) discovered that maintaining market share can increase the premium inadequacy. They conducted simulation tests and found that if insurers kept the aggregate premium constant while reducing premium rates and increasing the number of policies, the pricing risk would increase dramatically.

On the other hand, if the insurers decide to maintain profitability, their pricing would be calculated from the associated risks. This pricing strategy might result in relatively high prices. By paying attention to the profitability per unit exposure, the insurers can have more confidence in the adequacy of their premiums. Unfortunately, the insurers that seek to maintain profitability are likely to charge high prices relative to their competitors, especially when the market price is low. These high prices can cause them to lose market share to their competitors. The decrease in portfolio size will affect the risks of overall firm. Therefore the insurers who choose either of these strategies should consider pricing risk in both exposure unit and portfolio as a whole.

The optimism of insurers also influences insurance pricing cycle (Winter, 1988; Gron, 1989, 1990; Harrington and Danzon, 1994; Feldblum, 1999; Bulow and Klemperer, 2002; Fitzpatrick, 2004; Conger and Wolstein, 2004; Wang and Faber, 2006). The optimism of an insurer denotes the insurer’s "attitudes," "expectations," and "perceptions." Winter (1988, 1989) and Gron (1989, 1990) addressed these issues in explaining the timing and length of the high-price phase. Feldblum (1999) found that an individual insurer’s degree of optimism may increase or decrease in different years. Conger and Wolstein (2004) conducted a survey of actuaries and underwriters in the property-casualty industry where they found that actuaries and underwriters do exhibit overconfidence about their knowledge, implying the existence of a relationship between the degree of optimism and price adequacy.

In view of moral hazard or “winner’s curse”, an insurer may intentionally appear “optimistic” and under-price insurance contracts in the current period in order to increase market share. This action intensifies price competition in the market (Harrington and Danzon, 1994; Browne and Hoyt, 1995; Fitzpatrick, 2004; Baker, 2005). The inadequate premiums could later bring the insurers difficulty when liquidating their provisions. Harrington and Danzon (1994) developed and tested hypotheses based on this rationale using data from the general liability industry. They found evidence that supports the moral hazard hypothesis. Their results also imply that applying regulatory discipline to insurers who charge low prices and who possess high default risks would improve market price stability.

Finally, the interest rate also plays a role on the behavior of insurers. Insurance companies invest part of their premiums as reserves in “incurred but not reported” (IBNR). Surprisingly, Fitzpatrick (2004) found that investment income from such investment often surpasses profits from underwriting. He observed that given insurers’ concern over stability of returns, investment returns can be a significant driver of the underwriting cycle. When the interest rate increases, the insurers can continue to write at low prices (which extends the soft market period) even if faced with negative underwriting margins. On the other hand, a decrease in the interest rate can pressure insurers to increase premium rates in order to compensate for their losses of investment income, and thus contributing to the arrival of the hardening period.

2.2. Reserving cycle

Reserving is a key risk that affects insurers’ balance sheets and can have adverse effects on insurer capital. The estimation error of loss reserves is persistent and seems to have a cyclical pattern. We call this cyclical pattern of loss reserve error the “reserving cycle”.

Explanations for loss reserve mis-statements have received extensive interest from researchers (Anderson, 1973; Smith, 1980; Stanard, 1985; Weiss, 1985; Grace, 1990; Beaver and McNichols, 1998; Beaver, McNichols and Nelson 2003; UK working party, 2003; Grace and Leverty, 2005; Wang and Faber, 2006). Significant discussion in the literature exists on the causes of loss reserve mis-statement. The studies are based on two major subjects: (i) imperfect actuarial reserving techniques and (ii) loss reserve manipulation by insurers.

2.2.1. Actuarial Reserving Model Risk

Insurers apply actuarial reserving methods to project the frequency, severity and timing of claims. There are a number of projection techniques available to estimate loss reserves, such as the chain ladder, the Bornhuetter-Ferguson model, and the Taylor separation method. However, the actuarial methodology itself can be a source of loss reserve inaccuracy because the actuarial methods are based on past experiences which may not correctly represent current information.

Studies have found that actuarial reserving models are likely to institute time-dependent patterns into loss reserve estimation (Stanard, 1985; UK working party, 2003; Wang and Faber, 2006). Stanard (1985) conducted a simulation test of prediction errors of four simple loss reserve estimation techniques: the age-to-age factor method, modified Bornhuetter-Ferguson model, adjustments to total known losses, and the additive model. The theoretical and simulated results suggested that the age-to-age factor method yields biased estimates and is inferior to the three other methods. Schiegl (2002) used Monte Carlo simulation to create a run-off table. His results show that the Chain-Ladder reserves and Monte Carlo simulated reserves are deviated statistically.

A UK working party (2003) confirmed the existence of the reserving cycle in the UK from 1985 to 2001. One of their hypotheses stated that the reserving cycle is a consequence of errors resulting from actuarial reserving methods. By comparing the incurred loss derived from the different actuarial methods, i.e., Paid Chain-Ladder, Incurred Chain-Ladder, and Incurred Bornhuetter-Ferguson, they found that all of the methods produced a reserving cycle in marine and liability, but weak evidence of the cycle in the property line.

Wang and Faber (2006) proposed similar hypotheses. They illustrated plots of estimated reserve derived from popular actuarial reserving methods such as the Chain-Ladder method. Using a sample of insurers, their results showed that the selected actuarial reserving models did not perform well with any company characteristics. In particular, they found that the Chain-Ladder method worked quite better for small companies compared to large companies. In liability lines, the Bornhuetter-Ferguson reserving method tended to provide under-reserving in the early years if the price was underestimated, which again could aggravate the reserving risk. This implies that the actuarial reserving method exacerbates the reserving cycle if the underwriting cycle effect is not recognized.

2.2.2. Loss Reserve Manipulation

Another hypothesis regarding loss reserve errors is that the loss reserve is in some way manipulated by insurers. On the basis of insurers' behaviors and the market atmosphere, researchers have proposed seven crucial drivers to explain the existence of these errors (Anderson, 1973; Smith, 1980; Weiss, 1985; Grace, 1990; Cummins and Grace, 1994; Penalva, 1998; Beaver and McNichols, 1998; Gaver & Paterson, 1999; Beaver, McNichols and Nelson, 2003; Grace and Leverty, 2005). These drivers are income smoothing incentives, economic environments, tax-saving incentives, regulatory solvency constraint, price regulation, and growth incentives.

Documented cases have shown examples where insurers have advertently manipulated loss reserves with the intention of smoothing the reported underwriting results (Anderson, 1973; Smith, 1980; Weiss, 1985; Grace, 1990). Smith (1980) and Beaver and McNichols (1998) found evidence that discretionary loss reserve accruals are positive-serially correlated. Such time-dependency implies that loss reserves do not accurately reflect all information. Beaver, McNichols, and Nelson (2003) extended those studies and documented that property-casualty insurers showed tendencies of income smoothing through loss reserves. They found evidence that loss reserves are managed across the entire distribution of earnings and that small profit firms understate loss reserves relative to highest earning firms. Results also suggested that public and mutual companies manage loss reserve while private companies do not.

Loss reserve manipulation motivated by tax reductions has been widely discussed in the literature. Weiss (1985) and Grace (1990) stated that the IRS has monitored loss reserves to prevent such misbehavior. Grace (1990), Cummins and Grace (1994) and Penalva (1998) found evidence of a relationship between loss reserve errors and tax minimization involving the use of loss reserves to reduce insurers' tax liability. Gaver and Paterson (1999) provided evidence that incentives to manage taxable income remained stable even in a changing regulatory environment. Similarly, the incentive of loss reserve manipulation owing to tax reduction has been found among UK insurers (Diacon, Fenn, and O'Brien, 2003).

Furthermore, Petroni (1992), Penalva (1998), Gaver and Paterson (1999, 2004), and Nelson (2000) found evidence in the property-casualty industry that loss reserve understatement is more prevalent among financially weak insurers than financially healthy ones. Beaver, McNichols, and Nelson (2003) used the revised estimate for the unbiased expectation of losses to calculate discretionary loss reserve. They documented that both financially distressed and financially healthy insurers understated loss reserve accrual through loss reserve management. The loss reserve understatement however, is more pronounced in the sample of healthy insurers.

Regulatory solvency requirements can also produce an incentive to manage loss reserve. Gaver and Paterson (1999) found that the Risk-Based Capital solvency requirements in 1992 weakened the incentives to under-reserve due to solvency margins improvement. According to Gaver and Paterson (2004), insurance companies manage loss reserves to avoid regulatory intervention. This reserve manipulation was done to achieve less than four IRIS ratios[10] violation and provide some time for them to mend their financial conditions. Nelson (2000) indicates that state price regulations trigger loss reserves understatements. His results suggest that insurers in states with prior approval under reserve by discounting in order to afford charging the competitive rates.

Grace and Leverty (2005) integrated various theories of reserve manipulation incentives as had been proposed in the literatures. In contrast to previous studies, their results indicate that the motivation of reserve errors does not come from the avoidance of regulatory ratio violations. Managerial quality as measured by revenue efficiency does not adequately explain the reserve errors. The authors also suggested that insurers are likely to overstate reserves in the regulated lines since insurers increase their loss reserves to attain profitable rates. In addition, they found that IBNR, which are difficulties in estimation, are not the sources of reserve manipulation.

2.3. Underwriting Cycle vs. Reserving Cycle

The reserving cycle appears to move together with the underwriting cycle. This observation encourages an idea concerning the correlation between pricing risk and reserving risk. The UK working party (2003) and Wang and Faber (2006) provided evidence that a tendency exists for insurers to overstate loss reserves when

[10] The Insurance Regulatory Information System (IRIS) is set of financial ratios has been used by National Association of Insurance Commissioners (NAIC) since the middle 1970s. The IRIS ratios are used for determining whether a firm needs a solvency scrutiny. Most researchers suggest that an insurer is financially weak if four or more ratios are outside the proper bounds.

underlying loss ratios are low and to understate the reserves when underlying loss ratios are high. This finding comes as no surprise because loss reserves and premium rates tend to be theoretically related. In theory, loss reserve takes free capital out of the market, meaning that insurers lose some opportunities to write business because they have to use some of their capacities for reserving. This reduction in capacity results in a lower supply of insurance, and by law of demand, higher prices. Furthermore, redundant reserves in current years cause a release of reserves that flows into surplus years later. Consequently, loss reserve errors may cause insurers to adjust their rates in the future (Ho, 1999). The releases of loss reserves, especially in the soft market, can lead to lower rates. On the other hand, targeted premium rates can be a cause of the reserve errors. Insurers may "cook" their loss reserve books in order to justify the targeted premium rates (see, for example, Nelson, 2000). The empirical evidence of loss reserve manipulation as a consequence of incentives of smoothing earnings is consistent with the co-movement pattern underwriting cycle and reserving cycle.

Wang and Faber (2006) made a similar discussion about under-reserving as being more of a consequence of financial status rather than as a cause. They indicated that adverse reserve developments could be a consequence of under-pricing, motivated by market competition and/or optimism. When prices are incorrectly estimated, reserves are calculated as if the prices were correct. Hence, when insurance contracts are under-priced, reserves are under estimated as well. When the hard market begins, insurance prices improve and insurance companies possess the funds for loss reserve revision.

2.4. NAIC Risk-Based Capital Model

Beginning in the early 1990s, NAIC adopted a formula for determining the minimum capital requirement needed by an insurance company to help regulators with solvency issues. Nonetheless researchers have found that the RBC system itself is imperfect and could create incentives for excessive risk-taking by insurers (Cummins, Harrington, and Klein, 1991; Cummins, Harrington, and Niehaus, 1993a; Madsen, 2002; Wang and Faber, 2006). Three key limitations of NAIC RBC standards are:

- The NAIC capital charge is derived from book valuations of asset and liabilities, and uses a one-year time frame.
- It is simple and does not deal well with diversification.
- The model is quite static and is a lagging indicator.

Since financial-based information is used in calculating capital charge, it may be biased due to the statutory effect. In addition, an insurance company's credibility when reporting the factual data to regulators is questionable. The financial information reported to regulators includes actuarial opinion and independent auditor review. However, as both are hired by the insurance company, and the information is provided by the company, the analyses are possibly biased in favor of the insurer. A possible bias is that the analyses yield results that justify the risk-based capital system. The insurance regulator uses the information and analyses received from the company in the RBC calculations. Since the information applied might be biased, the results of capital charged will then also be biased. Even though the actuarial opinion is reported, the regulator does not have the resources to review and thoroughly scrutinize the data. Therefore the current RBC system seems to be "garbage in garbage out".

Madsen (2002) suggested that the NAIC's RBC itself can encourage insurer misbehavior. The purpose of the study was to examine the effects of asset allocation for property-casualty insurance on the RBC requirements. Loss reserves and premiums written play a key role in the RBC formula in the sense that the lower loss reserves and premiums written imply a higher capital-to-asset ratio, which is an NAIC solvency measure. He found evidence that an insurer is in fact focused on satisfying traditional regulator measures and that shareholder value can be destroyed in both the short-term and long-term.

Hodes, Neghaiwi, Cummins, Phillips, and Feldblum (1996), followed by Hodes, Feldblum, and Neghaiwi (1999) discussed the use of financial models employed by the NAIC for property-casualty insurance companies. The results showed that dynamic financial models play an important role for companies that write long-tailed lines of business which have fluctuating rate adequacy, severe competition and volatile consumer bases.

Wang and Faber (2006) recognized the flaw in the risk-based capital framework in terms of its lack of premium and reserve adequacy adjustment. They proposed risk capital factors that instill the downside premium and reserve deficiency risk. This implementation is illustrated by U.S. private passenger auto liability and commercial auto liability lines. The risk capital factor based on their calculation is higher for commercial lines than personal lines, and much higher for commercial auto fleet compared to non-fleet. Insurers therefore must charge higher risk margins for lines that have higher premium deficiency risks.

Researchers are also interested in the effectiveness of capital requirement and predictive power of solvency screening systems in property-casualty insurance (Grace, Harrington, and Klein, 1995, 1998; Cummins, Grace, and Phillips, 1997).

Grace, Harrington, and Klein (1995) provided evidence that using the Financial Analysis Solvency Tools (FAST) score is a superior means to identify financially distressed insurers than using the ratio of an insurer's RBC to its actual surplus. They also found that including the RBC ratios in the insolvency prediction models in which the FAST score is embedded does not significantly increase prediction power. Cummins, Grace, and Phillips (1997) also found similar results. They compared the insolvency explanatory power of three approaches: RBC, FAST, and Cash flow simulation. Their results also indicated that the FAST system is superior to the RBC. The cash flow simulation however, can add dynamicity and dominates the ratio-based system of FAST and RBC.

CHAPTER 3

3. Underwriting Risk and Theory of Behavioral Finance/Economics

The economic models conventionally assume that people are rational in the sense that they have coherent preferences and should make decisions in a specified fashion. In reality, the decision makings usually involve with the complicated situation, confusion, and emotional conditions which can lead the people to deviate from the rationality. That is, Kahneman and Tversky (1973) proposed the Prospect Theory to study such "irrational" behaviors in managing risk under uncertainty. They posit that deviations from rationality stem from emotion and perception. Moreover, the difference states of emotion and perception can make people to concentrate on each component of a problem separately rather than looking at the whole picture, so-called "mental accounting". Failure to recognize that the aggregate is a result of interaction among its components leads to the deviations from rationality.

The Framing Effect states that people decision making depends upon the setting of problems. People exhibit risk-aversion when a choice is presented in one setting and display risk-lover when the same choice is framed in a different manner. For example, people are willing to take a risk when the problem is framed in view of gain and to avoid the risk when the same problem is framed in form of loss. Prospect Theory explains such asymmetry of decision making that people are not risk-averse, yet they are loss-averse. It is not the uncertainty that people try to avoid, rather they dodge from losing. He noted that people reveal a tendency to look at problems in pieces rather than in the aggregate.

Based on the economic model of irrationality and the belief that investors do not always rationally trade off risk and return, researchers introduced a field of study called “behavioral finance” to analyze investors’ behaviors. The investors sometimes behave in a way that consistent with the rational models but sometimes their actions are influenced by distinctive perceptions and emotional impulses. These rational and irrational behaviors are commonly observed in a capital market and are widely discussed in behavioral finance literatures. Since underwriting risks in the insurance industry are partially a product of insurers’ behaviors, we thus relate the theory of behavioral finance with the insurers’ underwriting conducts.

Underwriting cycle is a phenomenon that is partly driven by insurers’ psyche. During the soft markets, insurers plunge into the low premium rate despite their reckoning that profit is not quite there. The unprofitable periods often persist until the most rational insurers exhaust their patience or when insurers are no longer able to survive with such low prices. Thus the hard markets arrive.

We can view the cycle in a way that insurers overestimate insured risks some time and underestimate part of the time but do not overestimate or underestimate all of the time. Edward Miller (1977) reports that the difference in behavior depends on the amount of gain. Investors prefer the occasional large gains to the consistent small winnings. His findings can apply to the low price phenomenon in the insurance market. Insurers gamble by bearing loss during the soft market with the hope to gain large profit when the market turns to hard period. Large profits that they could gain in the future encourage them to gamble and face the underwriting loss in the soft market.

Another reason for usual under-pricing in the soft market is that charging relatively high price will cost them the market share. Mental accounting and fear of losing their customers and revenue persuade them to concentrate on the market share rather than overall risks to the company. The loss-aversion regarding the market share leads insurers to take risks by adhering to unprofitable prices in the fond hope that some day the market will recover and make them whole. The focus on revenue can blind them from realizing the effect from the underwriting risk on other risks that could aggravate the risks of company as a whole. Besides, Shefrin and Statman (2000) report that the human psyche is split into short-term and long-term perspective. Peoples' response is a consequence of weights assigned on future and immediate gratification. Since insurers, especially stock insurers, face the compulsive revenue and market share competition, they tend to appreciate satisfaction today more than the long-term value.

In the context of overconfidence, experience, expertise, and learning do not eliminate biases from rational decision making. People tend to overestimate their intelligence and experience while believing that they usually display rationality. Daniel, Hirshleifer, and Subrahmanyam (1998) proposed a theory of securities market under- and overreactions based on investor overconfidence about the precision of private information; and biased self-attribution[11]. Their empirical results indicate that overconfident investors overweigh the private information relative to the public signals, resulting in overreaction to the stock price.

The errors in pricing and reserving can be partly a result of overconfidence. If an insurer begins with unbiased estimate of insured risk, new public information about the risk on average is considered as vindicating its private information. The insurer then updates the confidence in her ability in a biased manner. In particular, it would earn more confidence in the private signal to which she overreacts in the future. The overconfidence will continue until new public information (market price) invalidates the private information and the insurer gradually agrees with the

[11] According to attribution theory (Bem (1965)), people overweight events that vindicate their judgments and blame the events that disapprove their judgments on external noise or sabotage. Self-attribution bias occurs when people attribute successful outcomes to their own skill but blame unsuccessful outcomes on bad luck.

fundamentals. Thus, biased self-attribution implies short-run overconfidence that causes a lag response to the fundamental prices and extends the period of soft or hard markets. In contrary, the reversal of reaction will arrive in long-term and the insurer adjusts insurance price according to the realization of true risks.

In conclusion, behavioral finance fields of study apply psychology to better understand economic decisions. It helps analyze the underwriting cycle phenomenon in respect to rationality or lack of rationality in insurers' response to market prices. The principle increasingly becomes the theoretical basis for the underwriting cycle and provides an explanation for the market behaviors that had been mysterious to researchers.

CHAPTER 4

4. Review of Premium and Reserve Risks under NAIC and Rating Agencies Approaches

In 2004, the International Association of Insurance Supervisors (IAIS) released a draft of a global framework for insurer capital requirement, known as Solvency II. Solvency II aims to place the regulatory capital requirements of each company against its individual risk profile. This will encourage companies to implement their own internal risk models, enhance risk management, and be prudent about the strategy and operations of their business.

In the United States, the NAIC has been employing the risk-based capital (RBC) to access the financial strength of insurers, and when needed, has the power to take prompt corrective action (The baseline of the NAIC risk-based capital requirement will be discussed in the following subsection). Rating agencies also contribute to risk-based capital calculation. For example, S&P applies its capital adequacy ratio (SPCAR) to analyze an insurer's financial condition. The components of SPCAR are almost identical to those found in the NAIC RBC formula except that the S&P approach includes a risk charge for guarantee fund assessments. Similarly, A.M. Best introduced Best's Capital Adequacy Ratio (BCAR), which is the ratio of the adjusted surplus to the net required capital for insurance companies. Both SPCAR and BCAR adjust surplus to an economic basis.

Looking more closely at the BCAR model for underwriting risk, the loss and loss-adjustment-expense reserves and net written premium risks are considered in gauging a company's underwriting exposure. For reserving risk, A.M. Best emphasizes the adjusted reserve leverage and stability in loss development as a measure of reserving errors. In general, BCAR assigns significant weight on a company's adjusted reserves, which emphasizes reserve adequacy and discounted reserves. In contrast to the NAIC risk-based capital, the size of the company and the risk inherent are also regarded in the formula. In addition, the required capital for premium written risk for each line of business integrates the line-specific risks, the company's profitability and the company's size. The model also includes an underwriting cycle adjustment in pricing risk.

The following subsections introduce the baselines of capital requirement for property-casualty insurer in the U.S. and worldwide. More details about the NAIC basic capital formula for underwriting risk will be given to better understand regulator practice.

4.1. Solvency II – Capital Requirements for Non-Life Insurers

In the proposed Solvency II, the methodology for RBC requirements aims to place the regulatory capital requirements of each company against its individual risk profile. This will encourage companies to implement their own internal risk model, enhance risk management, and be prudent about the strategy and operations of their business.

Solvency II also considers some key issues which relate to the idea of our thesis. The issues involve class (line) segmentation, size of company, and the underwriting cycle effect in capital calculation.

(i) The class segmentation is based upon classes of business specified in the EU Insurance Accounts Directive.[12]

[12] Tilinghast (Towers Perrin), 2006: "The current suggested class segmentation is based upon the 11 classes of business specified in the EU Insurance Accounts Directive. The classes are accident and

(ii) Small companies are penalized by size-factors that increase the amount of capital required if the amount of expected business written in a particular line of business is less than a specified amount.

(iii) The underwriting cycle is captured in the solvency capital requirement (SCR) calculation through the expected profits or losses allowance in the year following the valuation date. However, the proposed adjustment is inappropriate during turning points of the underwriting cycle.

Some countries have included the Solvency II principles into their frameworks. We will look at the frameworks for non-life insurance in Switzerland and the U.K. as they embrace some interesting issues related to our study.

In Switzerland, the reserving risk and current year risk are quantified individually for non-life insurance. For each line of business, claims in the current year are modeled based on parametric and stochastic internal data. The reserving risk is estimated using a shifted lognormal distribution. In the U.K., the Enhanced Capital Requirement (ECR) is comprised of capital charges on asset risk, pricing risk, and reserving risk. The capital requirement is derived from equalization reserves, a long-term reserve that an insurance company keeps in the event of an unexpected catastrophe. In addition, the U.K. takes into account the effect of the underwriting cycle in valuing the underwriting risk. The market underwriting cycle is modeled by the AR2 process.

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health, motor-third party liability, motor other classes, marine, aviation and transport (MAT), fire and other damage of property, third-party liability, credit and surety, legal expenses, assistance, miscellaneous non-life insurance and inwards reinsurance."

That U.S. regulator will look at the EU's Solvency II as a prototype for future supervision if the industry is not known. All in all, NAIC and EU insurance regulators have very similar frameworks. The former president of the NAIC, Alessandro Iuppa stated in a public hearing on Solvency II (June, 2006) that “The NAIC reiterates many of the fundamental themes of Solvency II – many of which resonate with the work being done at the NAIC and at the IAIS.”

4.2. NAIC Risk-Based Capital Formula

The risk-based capital formula reflects the financial soundness of an insurance company. The common risks identified in the NAIC property-casualty models include asset risk-affiliates (risk of default of assets for affiliated investments), asset risk-other (risk of default for debt assets and loss in market value for equity assets), credit risk, and underwriting risk. In addition, the risk-based capital for property-casualty also includes the risk of reserve deficiencies by considering an insurer’s excessive growth since companies that grow rapidly are likely to understate loss reserves.

Like banking regulations, the NAIC applies factor-based regulatory capital requirements. Except for affiliate equity investment risk and off-balance sheet risk, which seems to be uncorrelated with the others, the NAIC formula incorporates the dependence structure between these risk categories by applying covariance calculations. This adjustment reflects the fact that the cumulative risk of several independent items is less than the sum of the individual risks and therefore reduces the risk-based capital amount.

The total required capital for property-casualty is:

$$RBC_{NL} = R_0 + \sqrt{R_1^2 + R_2^2 + R_3^2 + R_4^2 + R_5^2}$$

R_0: Insurance affiliate investment and (non-derivative) off-balance-sheet risk

R_1: Investment asset risk – fixed income investments

R_2: Investment asset risk – equity investments

R_3: Credit risk (non-reinsurance plus half reinsurance credit risk)

R_4: Loss reserve risk, one half reinsurance credit risk, growth risk

R_5: Premium risk[13], growth risk

We focus here on the capital formula for underwriting risk charges for they are the dominant portions of the risk-based capital formula and relevant to our thesis. Feldblum (1996) provided a summary of the NAIC risk-based capital formula for which we use as reference.

4.2.1. Reserving Risk

Not attempting to measure the reserve adequacy, the reserving risk charge in risk-based capital formula serves to measure the vulnerability of loss reserves to adverse developments. The calculations are performed separately by individual companies (not company group), Schedule P line of business, and statement data.

The reserving risk charge is comprised of industry-wide and company-specific components. For each company, the adverse loss development ratio is calculated as:

$$\begin{aligned} \text{Adverse Loss Development ratio} &= \frac{\text{Adverse loss development}}{\text{Loss reserve}} \\ &= \frac{\text{Ultimate} - \text{Initial incurred losses}}{\text{Incurred losses} - \text{Paid losess}} \end{aligned}$$

For each line of business on a certain statement date, individual company ratios are averaged (unweighted) to determine the average industry-wide ratio. Furthermore, for

[13] In this paper, we refer to premium risk and loss reserve risk as pricing risk and reserving risk respectively.

each line of business, the *implicit interest margin*, or the difference between the discounted and undiscounted value of reserves, is calculated. The discounted loss reserves are determined using the method employed by the IRS with a flat 5% discount rate. The final capital charge of carried reserves is then determined as:

*Final Charge = (1 + company RBC percentage) * implicit interest margin*

where the *company RBC percentage* is calculated from industry-wide and company-specific adverse loss development.

Finally, the risk-based capital formula judgmentally allocates parts of reserving risk across lines. The basis for this is the relationship of aggregate industry reserves by line of business to the sum of aggregate industry reserves for all lines of business.

4.2.2. Written Premium Risk

As defined by Feldblum (1996), the written premium risk is “the risk that the company’s future business will be unprofitable, and that the company will have to cover underwriting losses with surplus funds.” Like the reserving risk charge, the written premium risk charge is comprised of average industry and company experience. For each line of business, the investment income adjusted average loss and loss adjustment expense ratios by accident year for the past ten years are applied as a measure of premium risk. For a company in a given line of business, the figure is therefore multiplied by the written premium in the most recent calendar year to obtain the capital charge for written premium risk.

The overall capital charge for underwriting risk also takes into account some other factors. For example, the reserving risk (written premium risk) is adjusted to offset loss-sensitive business, claims-made business, loss (premium) concentration factor, and growth charge for reserving risk (premium risk).

CHAPTER 5

5. Hypotheses Construct

A major interest of our study is to investigate how the pricing risk and reserving risk are correlated and how insurers' the interaction differ according to insurer risk characteristics which is classified by firm structure, line of business, and product and geographical diversification. The hypotheses will be laid out in the same order with the questions we posed in the introduction section.

One of the foremost forces of the lack of certainty inherent in pricing is the insurers' expectation on the risks. Insurers who are more optimistic will charge lower prices than those who are less optimistic. The "optimism" can also be influenced by the insurers' incentives to engage in price competition. The management compensation which is often tied to volume, and expense management[14] can motivate the insurers to be more optimistic towards the claim costs so that they can offer the competitive prices[15]. In a competitive market such as insurance industry, the market price therefore is driven down to the price offered by the most optimistic insurers which eventually leads to the soft market period. The insurers that charge higher than the market price will lose market share. In order to keep their customers, they will adjust their prices to the competitive levels even if the prices can be unprofitable.

Moral hazard is another driver of pricing risk. The limited liability of insurance companies protects shareholders from losing more than the value of their shares and can lead insurance companies to take the risky step of selling insurance

[14] Expense management requires branches to maintain an acceptable expense ratio which forces premium volume to remain at least constant. The objective to maintain the premium volume can have an effect on the price, given that the insurance industry is competitive.
[15] Our interviews with Chief Actuary Executives confirm that management appears to be optimistic about the written risks so that the company can afford the competitive rates.

below cost in order to increase market share. In addition, state insurance guarantee funds protect insurance sellers and buyers from the consequences of under-pricing. It can encourage insurance buyers to willingly buy a policy from the company that charges a low price.

A driver of reserving risk that has been widely discussed in insurance literatures is that the loss reserve is in some way manipulated in accordance with incentives of smoothing earnings. The empirical findings of the income smoothing through loss reserve combined with the notion that the underwriting cycle and the reserving cycle move together (UK working party, 2003; Wang and Faber, 2006), we hypothesize that the pricing risk and reserving risk have a causal relationship. In a one-period time frame, insurers tend to overstate loss reserve when price is high in order to justify the targeted premium rate, and tend to understate the loss reserve when the underlying price is low. In conclusion, under-pricing will ultimately lead to adverse reserve development while over-pricing will finally lead to favorable reserve development.

Theoretically, pricing risk and reserving risk are directly correlated. Insurers have to work with immature loss data (upper triangle) to estimate the insured losses and set the prices accordingly. Thus, underestimation of ultimate losses will lead to under-pricing. On the other hand, for long-tailed lines, such as workers' compensation and other liability at the end of the first year, only a small percentage of losses have been reported. As a result, insurers use the estimated loss ratio to set reserves. Hence, under-pricing will lead to under-reserving which will show upward reserve development. That is, the incorrect estimates of insured losses will ultimately be shown in the form of loss reserve development.

The risk of underestimating reserves for unpaid losses also is associated with the risk of under-pricing. Under-estimation of loss reserves will cause total losses incurred by insurers to be underestimated and profits and surplus to be overstated. These errors can have further implications for insurers' financial and market decisions. Importantly, insurers' estimates of their historical losses play a significant role in their calculation of the prices they should charge in the future. Hence, underestimation of unpaid losses attributable to prior periods can lead to under-pricing of insurance contracts in future periods.[16]

Therefore, the hypothesis about relationship between pricing risk and reserving risk is as follows:

Hypothesis 1: For a given accident year, the accident-year loss ratio and ultimate loss development are positively correlated.

Basically, we hypothesize that insurance prices and loss reserves are interactively determined at the underwriting point in time. The knowledge of the causal relationship between pricing and reserving will provide ideas about the leading indicators of the underwriting and reserving cycle which will be helpful for building the forward-looking RBC models.

Based on historical data, it appears that the gross loss ratio of small insurance companies, including captives and risk retention groups, are lower than that of large companies. An explanation is that large insurers are likely to price risks on a fleet

[16] In practice, pricing is generally done rather independently of the reserving process. The actuaries doing the pricing will use historical data, but it is generally broken down in finer detail than that used by the reserving actuaries. The pricing actuary needs to look at everything by state, territory, class, etc. The reserving actuary generally sets reserves on a more summarized level. The reserving actuary is free to use whatever methods he/she feels are appropriate to set the reserves. The pricing actuary may be constrained in how he/she arrives at the rates for those lines of business for which rates need to be filed by state insurance department requirements. Nevertheless, since both pricing and reserving actuaries use the similar loss data in their calculation and both of them are under the same market pressure, we still expect that pricing and reserving errors will be correlated.

basis and to resort to experience ratings. Unfortunately, underwriters and actuaries are not likely to see the loss and loss development which consequently limits their experiential knowledge (Wang and Faber, 2006). The lack of knowledge leads to a higher swing of individual loss ratio and loss development for large insurers. Since insurers who are deficient in expertise are likely to miscalculate the insured losses which affect both pricing risk and reserving risk, we expect that large insurance companies, who mostly use experience-based rating as their pricing basis, will show a stronger correlation between loss ratios (price) and loss development (loss reserve error).

According to the above discussion, we form a hypothesis as follows:

Hypothesis 2: The degree of interaction between pricing and reserving risk differ by size of company owing to portfolio size and experiential knowledge, and the interaction is more apparent in large insurers.

The distinct underwriting behavior is also hypothesized for different types of insurers, including publicly traded stock insurer, stock insurer, mutual insurer, risk retention group, reciprocal insurer, and alien subsidiary. Each type of insurance company possesses their own risk characteristics. Furthermore, pricing strategy is a key factor of premium inadequacy; we expect that companies whose pricing strategy is to maintain market share are more exposed to the pricing risk.[17] The aim to maintain market share can impose an insurer to manage its earnings through loss reserve practice, which as a result enhances the correlation between prices and loss reserve adequacy.

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[17] Wang and Faber (2006) conducted a simulation test and documented that if an insurer keep the aggregate premium the same while reducing premium rate and increasing number of policies, the underwriting risk increases dramatically.

Publicly traded stock insurers are more subject to earnings tension than other types of insurers due to the pressure from shareholders and the management compensation that ties to the firm profitability. The management of publicly traded stock insurers therefore focuses on short-term interest. Since publicly traded stock firms are concerned more with earnings combined with extensive reserve options, they are likely to maintain the market share and are more subject to pricing risk and reserving risk. Besides, senior executives who are focused on revenue and market share prefer to use capital to maintain revenue and market share in a soft market than giving dividends to shareholders or holding it in an investment account. As the underwriting results of this type of insurer can be more volatile than for other types of insurers, we expect that the publicly traded stock insurers will display a relatively high correlation between loss ratio and loss development.

Unlike publicly traded stock insurers, mutual insurers, which are owned by policyholders, are not dedicated to making profits in the form of dividends. Their final objective is to achieve the best possible returns and services for their member-policyholders. Without the pressure from shareholders and profit-based compensation, the underwriting results of mutual insurers should be more stable than those of the publicly traded stock insurers. According to Mayers and Smith (2000), mutual companies have limited ability to raise capital and are less likely to write the risky lines. They find that mutual insurers have superior underwriting than the stock companies who own the short-term growth and earnings pressures. Harrington and Danzon (2000), on the other hand, points out that capital limitation of mutual companies raises disadvantages when competing with stock companies.

However, mutual insurers may also have an incentive to compete for market share. The rationale for this claim is that a mutual insurer tends to pay just enough of a dividend to current policyholders, but using most of the capital to cut prices in order to get new policyholders and to discourage existing policyholders from future price shopping (Baker, 2005).

A risk retention group (RRG) is a type of insurance company formed for special purposes. The RRG is owned by its policyholders. Membership is often limited to people whose businesses share the same liability risks. The risk pool of this kind of company is comprised of similar risks and there exists little risk diversification. Risk Retention Groups in general are thinly capitalized. Thus they are not well cushioned in the event of a shortfall in loss reserves.[18] Based on these reasons, we may see a high fluctuation of underwriting results in RRGs.

The reciprocal insurer is "an unincorporated group of individuals, called subscribers, who mutually insure one another, each separately assuming his share of each risk." The purpose of a reciprocal insurer is to minimize insurance costs with potential savings through safety programs (Reinmuth, 1964). Regarding reciprocal insurers, Norgaard (1964) stated that "these individuals generally are above average in property housekeeping, in their loss ratios, and in their desire to lower cost through safety." According to his statement combined with the objectives, we speculate that underwriting results of reciprocal insurers should be in good condition.

The last type of insurers considered in this paper is the alien subsidiary. Even though the alien insurers operate in the U.S., they view the U.S. market from an external standpoint. They are subject to the policies of their parent companies located abroad who own different economic features. Our hypothesis is thus based on the notion that the alien insurers might behave differently from domestic insurers.

[18] Information from The Auto Club website, available at http://www.theautoclub.com/warranty/rrg_vs_insurance.jsp

Focusing on interaction between pricing risk and reserving risk, we expect that the correlation between loss ratio and loss development will vary according to insurers' type-specific underwriting behaviors. Our hypothesis about underwriting risks according to type of company is:

> *Hypothesis 3: The correlation between insurers' pricing and reserving risks differs by firm structure of company on account of their individual objectives and incentives; the interaction is more apparent in publicly traded stock insurers.*

The specialist expertise of an insurance company more or less depends on the number of lines of business written. The insurers that write business in one or a few lines have more experience and knowledge about the losses, whereas the multiple-line companies undergo a "diminishing of knowledge" due to diversification. In other words, the multiple-line insurers may have more difficulty in recognizing underwriting risks in a certain line because the diversification effect thwarts the insurers from seeing the real risks of each line of business, and there is a lag time before the lack of knowledge shows up in loss ratio. However, writing business in a small number of lines may lessen the benefits gained from diversification. The portfolio theory which is fundamental to property/casualty business modeling underlines the diversification benefits from risk pooling. The number of lines written also implies risk diversification of the company's portfolio. While the multiple-line insurers to some extent lack expertise, they potentially gain the benefits of diversification. Nevertheless, our hypothesis is based on the premise that the diminishing of knowledge can simply create more risk than the diversification offset.

Similarly, the number of states written indicates the degree of specialist expertise and geographic diversification. The insurers that write business in one or a few states have more geographical expertise about risks than the insurers that have business in many states. However, the insurers who operate in many states can gain the benefits of geographic diversification.

We speculate that the writing business in many lines of business can be both beneficial and detrimental to the underwriting risks, and the link between pricing risk and reserving risk. Thus, our hypothesis about insurers' geographic expertise and diversification is:

Hypothesis 4: Interaction between pricing risk and reserving risk differ by number of lines and/or number of states written owing to the specialist expertise and risk diversification.

In the context of interaction between pricing risk and reserving risk, the price level can be a consequence of loss reserve adjustments in a multi-period time frame. The reserve redundancy accumulated in the current year will cause a release of loss reserves that flows into the surplus some time in the future. The increase in surplus enables the insurers to reduce their premium rates afterward. On the other hand, the reserve insufficiency in the current year leads to high price in the future so that the insurer can afford the fund for loss reserve correction. Hence, the loss ratios level can be a consequence of reserve overstatement (understatement), and the reserve inadequacy (redundancy) from the previous years can affect the level of premium rates in the current year.

Since the time lag of the inadequacy/redundancy to take an effect on pricing is unknown, we instead analyze the casual relationship in form of timing of loss reserve adjustment. Suppose that redundancies of loss reserve in the past years take an effect in the current period. The release (accrual) of loss reserves will be shown by decreases (increases) in loss reserves of the past-year policies, or favorable (adverse) loss reserve adjustment. Loss reserves have a direct impact on the surplus account. Since the surplus determine prices, according to law of demand, the loss reserve amount tend to play an important role in pricing decisions. On the other hand, loss reserve errors can be a result of manipulation of the timing of loss recognition. The over-reserves from prior high rate years can be used to subsidize underwriting results when the prices are low. Therefore, a favorable loss adjustment is expected to be observed with a low price while an adverse loss reserve development should be observed with a high price.

In the other direction, an increase in prices can lead to an increase in loss reserves. Whence premium rates rise, the funds obtained from higher prices can be used to correct the reserves that were underestimated in the past years. Thus high prices can lead to adverse reserve adjustment (increase in loss reserve), particularly in the case of insurers that entered the hard market in relatively strong financial condition.

According to the discussion above, we speculate that there is link between price level and the decisions for loss reserve adjustment, i.e., we expect to see the favorable (adverse) loss reserve adjustment in low (high) rate year. Since we use loss ratio as a measure of insurance price, the greater the loss ratio implies the lower in price. Therefore the negative sign of the correlation between price level (accident-year net loss ratio) and reserve adjustment (one-calendar-year loss development) is expected.

Hypothesis 5: For a given year, the accident-year loss ratio and one-calendar year loss development are negatively correlated.

Furthermore, we also speculate that the decision of loss reserve adjustment is more related to change in prices rather than from the price level. Under the same rationality for hypothesis 5, we expect that the negative (positive) loss reserve adjustments occur as prices are decreasing (increasing).

Hypothesis 6: For a given year, change in accident-year loss ratio from prior year and one-calendar year loss development are negatively correlated.

In the long-tailed line of business such as liability insurance, it is especially difficult to estimate the reserve by relying on the actuarial reserving model. Applying mathematical and statistical modeling to estimate losses, the actuaries can produce errors in the loss reserve estimation which inherently affect premium rates. The actuarial reserving models are based on historical data and the assumption that loss development patterns are similar to those in the prior years. Forecasts for the insured losses thus solely mirror the historical information but fail to reflect factors that can influence the losses in the upcoming period. For example, suppose that incurred losses decreased for the past five years and begins to increase in this year. To project the incurred losses for the forthcoming year, the actuarial models speculate that the losses would be decreasing as observed in the recent years. Failing to recognize the reversal in loss development pattern, the predicted losses therefore are undervalued and lead to further reserve take down. Likewise, if the incurred losses were rising in the past years and falling in the current year, the actuarial methods would yield the overestimation of the incurred losses and lead to further reserve accrual.

Nevertheless, not only does the actuarial estimate depend on the direction of the movement of the losses in prior years, it also depends on the rate of the growth of incurred losses. Therefore, we may observe the overestimation of losses in the year that loss changes from being decreasing to be increasing if the rate of the increase of loss in the current period is lower than the net increase rate of loss in the past nine years. As a result, both loss overestimation and underestimation can be observed regardless of change in the direction of the incurred losses.

The incurred Chain-Ladder method will be taken as the representatives of the traditional actuarial reserving models. The errors created by the selected actuarial models will be compared among different company sizes. The philosophy behind this is that large insurers, whose behavioral matters are more complicated, are inclined to settle loss reserves away from the actuarial estimates.

Hypothesis 7: The loss reserve error is partly a consequence of the limitations of the actuarial reserving model. The effect of the model risk is more pronounced for large insurers.

Finally, as we theorize that insurers' underwriting risks differ by the company's risk characteristics, introducing these behavioral guidelines should enable an effective approach for risk assessment. As the current RBC formula estimates the required capital from the combination of industry-wide and company-specific risks, we thus suggest that refining market segments by risk characteristics should allow for better RBC requirements.

Hypothesis 8: Building the refined market segments into the NAIC RBC formula for underwriting risk will allow for better risk *assessment, and therefore increase the accuracy of capital requirement.*

According to the discussion for hypothesis 4, we examine the potential for underwriting risks to "average out" when viewed as a portfolio. By writing the business in more than one line of product, an insurer can gain benefits from diversification, a reduction in risk of the overall portfolio (e.g., Markowitz, 1952). Within the insurance industry, product lines are indicated by the type of risk coverage, such as workers' compensation insurance, auto insurance, homeowners insurance, etc. Therefore the risks in a portfolio of diverse insurers will be less than the risks inherent in writing only one line of product, given that the risks of the various lines are not directly related.

Though the portfolio theory highlights the diversification benefits from risk pooling across geographic regions and across products, it tends to overestimate the benefit from diversification. Indeed, the diversification can prevent large multiple-line insurers from understanding the real characteristics of the individual underwriting risks. The difficulties to recognize the real risks as a result lead to the failure in establishing the effective management.

Hypothesis 9: Diversification benefit increases with the number of lines of business. On the other hand, the lack of knowledge by writing many product lines can reduce the benefit from diversification.

In summary, we propose that pricing risk and reserving risk interact with each other, and the degree of interaction varies according to company-specific risk characteristics. In addition, we aim to find a support for the hypotheses that the portion of the underwriting risks could stem from the unique risk characteristics in each market segment. Therefore, it is important for regulators to understand these learnings for the further RBC model development.

CHAPTER 6

6. Dataset and Methodology

6.1. Dataset and Definitions

In our empirical analysis, we utilize U.S. property/casualty insurance data over the sample period 1991-2004. The financial data is taken from annual financial statements reported to the NAIC. The types of insurance companies are obtained from Best's key rating Property/Casualty. NAIC and Best's key rating datasets are merged by NAIC company codes, and only insurance companies that are present in both databases will be included in our samples.

In our study of pricing and reserving risks, we focus on liability insurances because losses are difficult to estimate and the underwriting cycle is more evident in the liability lines. Specifically, a longer tail magnifies the uncertainty of pricing risk since liability claim costs is more difficult to predict the farther into the future. In addition, a longer tail magnifies the uncertainty of reserving risk as the assumptions used in calculation tend to change over time which could subsequently lead to a dramatic need for reserve adjustments, especially when future claim cost seem to be more expensive than what had been projected.

The liability lines of business considered in this thesis are workers' compensation, other liability, commercial and multiple peril, commercial auto liability, private passenger auto liability, medical malpractice, and product liability. However, we include homeowners as a sample for property line. The homeowners market is driven by natural catastrophe and is also used as a benchmark for the analysis.

We apply some sample selection criteria to exclude insurance companies whose written premium is less than $1 million in the selected line. We browse the data list to identify and remove the insurance companies that are out of business and are not continually writing the business. The companies whose data are available for less than ten years are also excluded. Thus our final sample contains insurers who do the business consistently and who are actively involved with the market.

We also classify the insurers by the average of accident-year direct and assumed (inclusive of reinsurance) earned premium. Small, midsize, large, and giant insurers are defined as the companies whose average of earned premium are less than 25^{th} percentile, between 25^{th} and 75^{th} percentile, between 75^{th} percentile, and greater than 95^{th} percentile, respectively.

We use the accident-year direct and assumed loss ratio as a measure of pricing risk. The direct loss ratio is chosen for this study so that we can disregard the reinsurance effect because some companies may have better risk management through the reinsurance instrument.[19] Furthermore, the accident-year loss ratio is applied in the study instead of the calendar year loss ratio for the reason that the accident-year loss ratio contains the information about losses and premiums of the policies that occur in that year. The calendar year loss ratio, in contrast, is based on an accounting perspective. Not only does it reflect information about the contracts that are written in a calendar year, the calendar year loss ratio also contains information about activities of the policies that were written in previous years. For example, the loss ratio in calendar year 2000 includes the information of accident years 1991-2000 that could have transactions going on in year 2000. Selecting accident year in lieu of calendar

[19] The analysis of correlation applying direct loss ratio and net loss ratio provides the similar results in term of both signs and magnitudes of the correlations.

year eliminates the information from the previous accident years that could mislead our analysis.

Furthermore, the reserving risk is evaluated by accident-year loss reserve development which is defined as:

$$Loss\ development = \frac{Ultimate\ Incurred\ Loss - Initial\ Incurred\ Loss}{Ultimate\ Incurred\ Loss}.$$

We also define the one-calendar year loss development which will be used in our study. The one-calendar year loss development represents the total loss reserve adjustment accounted for in a given accident year. In order to standardize the loss development, we define the calendar year loss development as the loss adjustments occurred in a given accident year as percentage of earned premium of the policies written in the same year.

$$One\ CY\ Loss\ development = \frac{One\ year\ loss\ development\ in\ a\ given\ accident\ year}{Earned\ \ premium}$$

6.2. Vector-Autoregression (VAR) Analysis of Pricing and Reserving

The robustness test of interactions between pricing and reserving risks will be performed via the so-called vector autoregression (VAR) methodology. The VAR technique allows us to examine the dynamic interactions between insurance price (loss ratio) and loss development. Though it does not imply any causal conclusion about insurance price and loss development patterns, it does allow us to observe the correlation between the two series in the current period when the time series effects are eliminated.

For a given line of business, we conduct the VAR analysis using panel data and follow the steps employed by McCarty and Schmidt (1997). Assume an autoregressive lag length *p*, and estimate the following equations by ordinary least squares (OLS):

$$L_t = c_1 + \sum_{i=1}^{p} \alpha_i L_{t-i} + \sum_{i=1}^{p} \beta_i R_{t-i} + u_t$$

$$R_t = c_1 + \sum_{i=1}^{p} \gamma_i L_{t-i} + \sum_{i=1}^{p} \omega_i R_{t-i} + \upsilon_t$$

where

L_t = Loss ratio of accident year t

R_t = Loss development of accident year t

$$= \frac{Ultimate\ Incurred\ Loss - Initial\ Incurred\ Loss}{Ultimate\ Incurred\ Loss}$$

and c_1, c_2 are constant terms; α, β, γ, and ω are coefficient terms.

However, while the parameters of the VAR show the effects of past loss development (loss ratio) on present loss ratio (loss development), they do not show the effects of an increase in current loss ratio on current loss development and vice versa. In order to delve within the current period for the correlation, we look at the correlation matrix of the error terms vector. If the error terms are positively correlated, then both variables tend to move together; if negatively correlated, those two variables tend to move in the opposite directions. If the correlation is zero, then the two variables are not related. The positive correlation would be consistent with the hypothesis about correlation between pricing risk and reserving risk, that is, increases (decreases) in price raise (reduce) the loss reserve.

Not only can the VAR technique test for the correlation between loss ratio and loss development in the current period, this technique can control for economic drivers that could have a significant effect on the two time series. In our analysis, we control for size of company (premium earned), interest rates (market yield on U.S. Treasury securities at 5-year constant maturity, quoted on investment basis), premium growth (percentage of increase in direct premium written), and percentage of premium written in commercial lines.

6.3. Greatest Accuracy Credibility Theory

Credibility theory (Whitney, 1918) is the branch of insurance mathematics that explores the experience rating formula based on weighted averages of both individual and segment estimates of the individual risk premium. The theory has been developed and applied in wide-ranging independent topics beyond the branch of risk theory.

The classical credibility theory is a weighted average of the form

$$\overline{m} = z\hat{m} + (1-z)\mu \ , \tag{6.1}$$

where $0 \le z \le 1$; $\overline{m}$ = credibility estimate; $\hat{m}$ = base statistic (or natural estimator based on individual data); μ = complement of credibility (or other information); z is the credibility associated with the base statistic.

A variety of arguments have been used for developing the value of z. One of the most important is the *Greatest Accuracy Credibility Theory*. The objective of this theory is to estimate $m(\theta)$ with some function $\breve{m}(X)$ of the individual data. In insurance mathematics, the Greatest Accuracy Credibility's goal is to find the best estimator of the linear form

$$\breve{m} = a\hat{m} + b,$$

where $\hat{m}$ is some estimator based on the individual data, and a and b are constants. The best estimator is determined by minimizing the mean squared error (MSE)

$$E[(m(\theta) - \breve{\mathrm{m}}(\mathrm{X}))^2].$$

The greatest accuracy break-through was introduced by Bühlmann (1967, 1969). Bühlmann credibility minimizes the square of the errors between the estimate and the true expected value of the quantity being estimated. This model considers a non-parametric model specifying that, conditional on a set of parameters, Θ, the random variables $X_1,\ldots, X_n$ have the same mean, $\mu(\theta)$, and variance, $v(\theta)$, and are independent and identically distributed.

Define

$$m(\theta) = E(X_j \mid \Theta = \theta)$$

and $$v(\theta) = Var(X_j \mid \Theta = \theta).$$

where $m(\theta)$ is referred to as the hypothetical mean and $v(\theta)$ is referred to as the process variance. Substituting

$$\hat{m} = \overline{X} = \frac{\sum_{j=1}^{n} X_j}{n},$$

which is the best linear unbiased estimator (BLUE) of $m(\theta)$, Bühlmann derived the credibility formula as follows:

$$\overline{m} = z\overline{X} + (1-z)\mu \ , \tag{6.2}$$

where $$\mu = E(X_j),$$

$$z = \frac{n}{n+k}, \tag{6.3}$$

and $$k = \frac{E[\Pr ocess Variance]}{Var[Hypothetical\ Means]}.$$

The credibility factor z is referred to as the Bühlmann credibility factor. The Expected Value of the Process Variance and the Variance of the Hypothetical Means are each calculated for a single observation of the risk process.

6.3.1. Bühlmann-Straub Model

The Bühlmann model in the previous section is based on assumption that the random variables $X_1,\ldots, X_n$ are independent and identically distributed. and do not allow for variations in exposure or size. Bühlmann and Straub (1970) extended the Bühlmann model by relaxing the i.i.d. assumption and letting the conditional variance take the form:

$$Var(X_j \mid \Theta = \theta) = \frac{v(\theta)}{p_j},\ j=1,\ldots,n$$

where p_j is the amount of risk exposed.

The motivation was that X_j is the loss ratio in year j, which is the total claim amount divided by the amount of risk exposed. In our study, we define the loss ratio, $X_{j,}$ as the ratio of accident-year incurred losses and loss expenses to earned premiums and define p_j as the earned premiums.

Applying algebraic work, Bühlmann and Straub derived the credibility formula which has the form as in (5.1) with

$$\hat{m} = \frac{\sum_{j=1}^{n} p_j X_j}{\sum_{j=1}^{n} p_j},$$

where
$$z = \frac{\sum_{j=1}^{n} p_j}{\sum_{j=1}^{n} p_j + k}, \qquad (6.4)$$

and
$$k = \frac{E[v(\theta)]}{Var[m(\theta)]}.$$

6.3.2. Error in Credibility Estimates

Like other statistical models, the credibility model may possess prediction errors. (The prediction error is the squared difference between the credibility weighted prediction and the actual results.) The error of the predictor may arise from the process error and the bias of the complement. If the complement of the credibility is accurate in its own right, the resulting estimate will be more accurate. Therefore, the choice of complement is crucial for accuracy of prediction.

The mean squared error (MSE) of the greatest accuracy credibility estimator is a function of the constants *a* and *b*. Applying this, one arrives at the optimal estimator which is known as *linear Bayes* (LB) estimator

$$\overline{m} = E(m(\Theta)) + \frac{Cov(m,\hat{m})}{Var(\hat{m})} \times (\hat{m} - E(\hat{m})) .$$

To measure the accuracy of the LB estimator, the MSE which is known as LB risk is derived and is expressed in the explicit formula as

$$\overline{\rho} = Var(m) - \frac{Cov^2(m,\hat{m})}{Var(\hat{m})} ,$$

where m is the actual value of observation.

The LB risk for the Bühlmann model and Bühlmann-Straub model have the same form of

$$\overline{\rho} = (1-z)\, Var(m(\Theta)) ,$$

where z is as defined in (6.3) and (6.4) respectively.

We apply the credibility theory in quantifying the homogeneity of the underwriting risks within market segments. The Bühlmann-Straub model is selected as a methodology for explaining the choice complements of credibility and comparing the effectiveness of the various models due to its capability to reflect variations in exposure or size. In particular, we investigate the accuracy of loss ratio and loss development credibility estimation using the industry and market segments as choices of complement of credibility.

Since we have the data available for year 1991-2004, we apply the data up to year 2003 in estimating the credibility parameters and predicting the risk of year 2004. The estimates of the risk will then be compared with the actual data in 2004. The error from the estimation is the difference between the credibility estimates and the actual risk in year 2004. The mean of squared error is regarded as a measure of the accuracy of model predictions. To support our hypotheses, the credibility model that uses segment-specific risk as complements of credibility must give a better prediction relative to the model that uses the industry-wide risk.

Two Bühlmann-Straub models will be exercised for this analysis. Everything else is the same; the first model uses the industry loss ratio as the complement of credibility while the second model employs the market segment loss ratio as the choice of complement of credibility. The credibility estimates derived from the first model, for which we will refer to as the "industry model" hereafter, are based on the assumption that the risk is a combination of the company-specific risk and the industry-wide risk. On the other hand, the second model presents the idea that the risk is dependent upon the company-specific risk and the segment-specific risk. The explicit forms of the two models can be shown as follows.

Model 1: $\overline{m} = z\hat{m} + (1-z)\mu_1$

Model 2: $\overline{m} = z\hat{m} + (1-z)\mu_2$

where μ_1 is the industry-wide risk and μ_2 is the segment-specific risk.

Comparing the accuracy of the credibility estimates between the two models will provide evidence about the homogeneity of risk in the industry and the market segment. If the risk is more homogenous within market segments than within the whole industry, the mean squared errors derived from the second model should be less than that derived from the first model.

According to our study, we will perform the analysis in both pricing risk and reserving risk. In the pricing risk framework, we define the variables in the equations as follows.

$$X_j = \frac{Company\ loss\ ratio\ in\ year\ j}{Industry\ loss\ ratio\ in\ year\ j}$$

$$\mu_1 = \frac{Industry\ loss\ ratio\ in\ year\ j}{Industry\ loss\ ratio\ in\ year\ j} = 1$$

$$\mu_2 = \frac{Market\ segment\ loss\ ratio\ in\ year\ j}{Industry\ loss\ ratio\ in\ year\ j}$$

$$p_j = Earned\ Premium\ in\ year\ j$$

In the credibility analysis for reserving risk, we apply loss reserve development, which is defined by the ratio of the adverse loss development to the ultimate incurred losses, as a proxy for reserving risk. The variables in the credibility model for reserving risk are defined as follows.

$$m_j = \frac{Company\ loss\ development\ in\ year\ j}{Industry\ loss\ development\ in\ year\ j}$$

$$\mu_1 = \frac{Industry\ loss\ development\ in\ year\ j}{Industry\ loss\ development\ in\ year\ j} = 1$$

$$\mu_2 = \frac{Market\ segment\ loss\ development\ in\ year\ j}{Industry\ loss\ development\ in\ year\ j}$$

$$p_j = Premium\ in\ year\ j$$

The errors of credibility estimations will be calculated, and the results will imply the justification of our hypothesis that the underwriting risks are more uniform within market segments than within the overall market.

6.4. Actuarial Reserving Model

We employ the Incurred Chain-Ladder reserving method for examining the actuarial model risks. The Chain-Ladder method is a widely used method for loss reserve estimation (Radtke and Schmidt, 2004). The method uses historical cumulative incurred losses by accident year and develops those actual losses to estimate ultimate losses based upon the assumption that the actual losses will develop to estimated ultimate cost in a manner that is analogous to those in the prior years. This method is selected for our analysis due to its simplicity and its popular usage in loss development estimations.

Consider the loss development triangle from Schedule P, part 2 in an annual statement (see Table 1). Let $\{S_{i,k}\}_{i,k\in\{0,1,\dots,n\}}$ be a family of incurred loss random variables. We interpret $S_{i,k}$ as the incurred losses of accident year i and development year k. $S_{i,k}$ is observable for calendar year $i+k\le n$ and unknown for calendar year $i+k>n$. According to Schedule P part 2, we have n = 10.

For $i\in\{0,1,\dots,n\}$ and $k\in\{0,1,\dots,n\}$, define the *individual development factor* of accident year i and development year k:

$$F_{i,k}=\frac{S_{i,k}}{S_{i,k-1}}.$$

For $i,k\in\{0,1,\dots,n\}$ such that $i+k\le n$. Let

$$S^{CL}_{i,n-i}=S_{i,n-i}\ ,$$

$$F_k^{CL} = \sum_{j=0}^{n-k} \frac{S_{j,k-1}}{\sum_{h=0}^{n-k} S_{h,k-1}} F_{j,k} \ ,$$

and
$$S_{i,k}^{CL} = S_{i,k-1}^{CL} F_k^{CL} \ ,$$

where F_k^{CL} and $S_{i,k}^{CL}$ are called the *chain-ladder factor* of development year *k* and the *chain-ladder predictor* of the aggregate incurred loss $S_{i,k}$ for accident year *i* and development year *k*, respectively.

The actuarial reserve errors are calculated for each individual insurer. The Chain-Ladder estimate error is defined as:

$$Chain\,Ladder\,reserve\,error = \frac{(Incurred\ Loss\ as\ of\ 2004 - Ultimate\ Chain\ Ladder\ Incurred\ Loss)}{Earned\ \mathrm{Pr}\,emium}$$

6.5. Proposed Measure to Diversification Benefit

This study offers a method for evaluating the product diversification benefit for pricing risk and reserving risk. Instead of merely using the historical years, our approach instills the predictive assessment for diversification benefit. The accident-year net earned premium and net incurred losses are employed in the calculation in accordance with the net premium written that is used in BCAR model. In addition, we include eight major lines of business in the measurement to avoid the unremitting data in some minor lines. The lines of business included in the measurement are workers' compensation, other liability, commercial multiple peril, commercial auto liability, private passenger auto liability, medical malpractice, product liability, and homeowner insurance. Given that the premium volume in the lines that are excluded is quite small, we hope that dropping these lines will not considerably affect the measurement.

6.5.1. Diversification Benefit on the Underwriting Losses

In calculating the diversification benefit, we assume the latest year earned premium as the premium to be earned in the upcoming years. The loss ratio patterns are assumed to be approximately analogous to those in the historical years. For each line of business, the projected future losses are estimated from the latest-year earned premium and the loss ratios in the historical years. In particular, the projected losses are equal to the latest-year premium multiplied by the historical loss ratios. The standard deviation of the projected losses is then calculated for each individual line. The standard deviations from individual lines are thus added up as if the losses of each line of business are independent. To calculate the diversification benefit, we apply the same steps of calculation in the portfolio level. For each company, we aggregate the latest-year earned premium and incurred losses in every line of business and exploit them in the loss projection. Then the diversification benefit is defined by the difference between the standard deviation of the aggregate projected loss and the summation of the standard deviation of individual lines. The explicit form of diversification benefit can be written as:

$$Diversification\, benefit = 1 - \frac{\sigma_{Aggregate\ projected\ loss}}{\sum_i \sigma_{projected\ loss\ in\ line\ i}}.$$

An insurer who writes business in only one line of business will have zero diversification benefit, according to the formula.

6.5.2. Diversification Benefit on Loss Development

In addition to the analysis of diversification benefit on the underwriting losses, we are interested in investigating whether such benefit also has positive effect on the reserving risk. Indeed, we expect to see the lower risk of the loss development in the multiple-line insurers relative to the single-line insurers. Analogous to the incurred loss projection, we assume the latest-year ultimate incurred loss as of year 2004 as the ultimate incurred loss to be observed in the forthcoming years. The ultimate loss development pattern, which is defined by the ultimate incurred loss minus the initial incurred loss, is postulated to be similar to those in the historical years.

For each line of business, the projected future initial incurred losses are estimated based on the above assumptions. The projection of the amount of the adverse/favorable loss development is then derived from the difference between the latest year ultimate incurred loss and the projected initial incurred loss. Similar to the steps for evaluating the diversification benefit on the incurred loss, the standard deviations of the projected loss development are calculated for each line of business and are summed up as if they were independent to each other. The diversification benefit is defined as the difference between the standard deviation of the aggregate projected loss development and the standard deviation of the summation of the projected loss development.

$$Diversification\ benefit = 1 - \frac{\sigma_{Aggregate\ projected\ loss\ development}}{\sum_i \sigma_{projected\ loss\ development\ in\ line\ i}}$$

According to the formula, the single-line insurers will gain zero diversification benefit on loss development.

CHAPTER 7

7. Empirical Results

Table 2 provides descriptive statistics on the loss ratios of each line by year for the years 1991-2004. The mean of loss ratios suggest a tendency of changes in prices from year to year. The patterns of loss ratios tend to be unique for each line of business. In general, the price patterns in long-tailed liability lines such as workers' compensation are gradually changed, i.e., the loss ratios increase and decrease in a slow manner. Prices in homeowners, however, tend to move up and down more frequently than the prices in liability lines. This could be because prices in homeowners tend to adjust quickly in response to the natural catastrophe events.

In the following subsections, we analyze the empirical results of pricing and reserving risks and their interactions. The plan of the analysis is as follows. Section 7.1 discusses the findings of relationships between pricing risk and reserving risk. Section 7.2 presents the credibility estimations of pricing and reserving risk and their implication regarding the homogeneity of underwriting risks within the insurer categories. Section 7.3 discusses the reserve errors that are generated by the Chain-Ladder reserving method. Based on our proposed methods, section 7.4 analyzes the results of product diversification benefit on the incurred losses and on the loss development.

7.1. Correlation Analysis of Pricing Risk and Reserving Risk

The objective of this analysis is to test the hypotheses that pricing and reserving risks are correlated and that the correlations vary by firm categories, i.e., firm size, organization structure, product diversification, and geographic diversification. The relationships are measured in three different ways: (i) the correlations between accident-year loss ratios and accident-year loss development, (ii) the correlations between accident-year net loss ratios and one-calendar-year loss development, and (iii) the correlations between changes in accident-year net loss ratio and one-calendar-year loss development. The correlations between accident-year loss ratios and accident-year loss development provide insight of whether the risk of underestimating (overestimating) reserves for unpaid losses is associated with the risk of under-pricing (over-pricing). The correlations between accident-year net loss ratios and one-calendar-year loss development determine whether the insurers tend to adjust the loss reserves in relation to the current price levels. The correlations between changes in accident-year net loss ratio and one-calendar-year loss development measure the concurrency of the timing of price changes and loss reserve adjustments.

Furthermore, we categorize the insurers by four characteristics, i.e., firm size, firm structure, product diversification, and geographic diversification. We expect that the relationships of pricing and reserving risks are different according to different risk characteristics in each category.

The plan of this section is as follows. Section 7.1.1 discusses the findings of the relationships between pricing risk and reserving risk using the industry aggregate data. Section 7.1.2 examines the relationships between pricing risk and reserving risk based on the mean correlations derived from the company data. Sections 7.1.3-7.1.6 present the price-reserve correlations in relation to firm size, firm structure, product diversification, and geographic diversification respectively.

7.1.1. Correlation analysis of industry aggregate pricing and reserving risks

In this subsection, we discuss the industry aggregate relationships of pricing and reserving risks. We observe the patterns of pricing risk and reserving risk which are shown by the plots of (i) accident-year loss ratios against the accident year loss development, (ii) accident-year net loss ratios against the one-calendar year loss development, and (iii) change in net loss ratios against the one-calendar year loss development. Note that the definitions of the variables are provided in section 6.1.

According to the industry aggregate plots of accident-year loss ratios against accident-year loss development for the eight selected lines of business (see figure 1.1a-1.8a), we see that both series tend to follow the same pattern. The patterns of accident-year loss ratio and accident-year loss development have almost the same shape in workers' compensation, other liability, commercial auto liability, and product liability industry. The similar patterns of the two series are also presented in private passenger auto liability, commercial and multiple peril, and medical malpractice industry. Homeowners industry, however, does not show this tendency. The accident-year loss development is very small in this line because claims are usually settled within one or two years. The prices, on the other hand, are more volatile as the losses in homeowners are driven by natural catastrophe events.

Focusing on liability lines of business, we measure the relationship between accident-year industry loss ratios and loss development through their correlations. Since the pricing and reserving cycles seem to be unique for each line of business, we investigate the correlations between accident-year loss ratios and loss development separately by lines of business. Even though homeowners insurance does not display a cyclical pattern of loss development, we include this line in our study as an example of property line of business and as a benchmark for the analysis in the other selected lines.

Table 3 shows the correlations between the accident-year aggregate loss ratio (direct and reinsurance assumed) and accident-year loss development in the eight major lines of business. The results suggest that the two variables are positively correlated with a higher magnitude in the liability lines than in the property lines such as homeowners. This is not surprising because liability lines have a long tail, and their losses are more difficult to initially estimate in the early years of the loss development process. The difficulty in accurately estimating insured losses affects both pricing risk and reserving risk, and their interaction.

Lines of insurance differ in terms of how quickly claims are settled and losses are paid. This affects how quickly insurers can develop accurate estimates of the losses they will ultimately have to pay. Lines with longer loss developments periods or that are subject to factors that can significantly change the losses that insurers will be required to pay would be expected to be more prone to loss reserving errors.

Following this reasoning, we can see that the correlations between loss rations and loss development are weaker in commercial multiple peril (CMP) and private passenger auto liability (PPAL). The weaker correlation observed in private passenger auto liability may be due to the fact that PPAL losses tend to be more stable and less subject to reserve and pricing errors. The correlation in CMP, which includes both liability and property coverages, may be weakened by its property coverage component for which losses are paid more quickly than for liability coverages.

For a short-tailed property line such as homeowners insurance, we also see that price-reserve correlation is low and not statistically significant. Homeowners claims are paid relatively quickly but this line is subject to loss shocks arising from weather-related perils and natural disasters. Hence, homeowners loss ratios can be relatively volatile from year to year but this volatility is due to highly variable losses rather than errors in estimating reserves for unpaid claims.

Next, we analyze whether the loss reserve adjustments is related to the price level at an industry aggregate level. In other words, we explore the correlations between industry accident-year net loss ratio and industry one-calendar-year net losses and loss expenses development (see the definition in section 6.1). Note that the accident-year net loss ratio and net one-calendar-year loss development are chosen for the analysis instead of the direct and assumed loss ratio and loss development due to the data availability. Hence, the result we obtain from the correlation analysis is after the effect from the reinsurance management.

Figures 1.1a-1.8a illustrate the industry aggregate plots of accident-year net loss ratios against one-calendar-year loss development for the eight selected lines of business. However, the figures do not graphically show a high correlation between the two series. In product liability industry, the one-calendar year loss development is very volatile and it appears to be independent of the net loss ratio. The one-calendar year loss development in homeowners market, however, is almost flat and tends to be unrelated with the net loss ratios. The smooth pattern of one-calendar year loss development in homeowners could be because claims are settled and losses are paid quickly.

In order to measure the relationship between prices and loss reserve adjustments in a given year, we examine the industry aggregate correlations between accident-year net loss ratio and one-calendar-year loss development as shown in table 4. Interestingly, the correlations are low in most of the lines with exception of commercial multiple peril and other liability. In addition, the signs of correlations vary by lines of business. The industry aggregate data shows the negative correlations in the industry of commercial multiple peril, other liability, workers' compensation, and product liability. The positive correlations observed in the industry of commercial auto liability, medical malpractice, and private passenger auto liability reject our hypothesis that the adverse loss reserve adjustments tend to occur when prices are high. However, it offers new insight that calendar year loss development behaves very differently from the accident-year loss development. Furthermore, it supports indirectly the notion that insurers can manipulate their booked reserves in the timing of recognition of accident-year profits/losses (knowingly or unknowingly) by bowing to other pressures.

Even though we do not find consistent evidence of the relationship of prices and one-calendar year loss development among lines of business, we speculate that the calendar year loss reserve development can be more related to the change in price rather than the price level per se.

We investigate the coincidence of the timing of price changes and loss reserve adjustments. Figures 1.1b-1.8b illustrate the industry aggregate plots of change in accident-year net loss ratios against one-calendar-year loss development for the eight selected lines of business. The plots indicate that, at an industry aggregate level, the change in accident-year net loss ratios tend to be negatively correlated with the one-calendar year loss development in workers' compensation, other liability, commercial auto liability, and medical malpractice. The negative correlations imply that insurers are likely to adjust the loss reserves and change the prices at the same time. In contrast, the accident-year net loss ratios and one-calendar year loss development do not track in commercial multiple peril, private passenger auto liability, product liability, and homeowners. The stable one-calendar year loss development in commercial multiple peril and homeowners could be due to the property coverage component in which claims are settled quickly. In product liability industry, the one-calendar year loss development is very volatile compared with the change in net loss ratio.

Table 5 exhibits the correlations between change in price and one-calendar-year loss development using the industry aggregate data. Consistent with our expectation, changes in accident-year loss ratio and one-calendar-year loss development are negatively related in all of the selected lines. In addition, they are highly correlated in commercial auto liability, other liability, medical malpractice, and workers' compensation, yet they are not strongly correlated in commercial multiple peril, private passenger auto liability, product liability, and homeowners.

Nonetheless, the correlation analysis using the industry aggregate data may show misleading results as it merely offers the sketch of the interaction between pricing and reserving risks. For more concrete evidence, we extend the investigation the interactions between pricing and reserving risks by analyzing individual company data as will be discussed in the section 7.1.2.

7.1.2. Correlation analysis of pricing and reserving risks based on the company data

For the analysis of the relationship between pricing and reserving risks based on the company data, the correlations between the two risks are calculated for each company, and the means of the correlations are used in analyzing the results.

Per tables 3.1-3.8, the results indicate that the correlations between accident-year loss ratios and loss development are positive and significantly different from zero in every selected line of business, affirming the interaction between pricing risk and reserving risk; this is especially true in commercial lines such as workers' compensation, other liability, and medical malpractice. The results imply that the under (over) pricing leads to the under (over) reserving and vice versa. Yet, the usage of company data in the analysis yields the lower correlations relative to the usage of aggregate level data.[20]

Furthermore, we expect that the accident-year net loss ratios and one-calendar-year loss development will show the negative correlations, based on the reasons that the over-reserves from prior high rate years may be used in low rate years to subsidize underwriting results. Hence, we expect to observe the low prices in the years that there are releases of loss reserves. Similarly, we hypothesize that, in the high rate years, the insurers can afford to correct the loss reserves. The funds obtained from high prices can be used to correct the reserves that were underestimated in the past years. Thus high prices can lead to an increase in reserves.

Tables 4.1-4.8 illustrate the correlations between accident-year loss ratios and one-calendar year loss development by lines of business. The mean and median of the correlation are close to zero in all lines of business. In contrast to what we find in the other liability aggregate data, the correlation between the two series derived from the company data is also close to zero. The signs of the correlations, however, are different among lines of business, providing no clear relationship of prices and loss reserve adjustments.

We can offer behavioral explanations for the observations of low or positive correlations between calendar year loss development and accident-year loss ratios. The pricing and loss reserve adjustment decisions can be influenced by the current surplus amount which could be funded from external sources. An insurer may choose to correct its previous underestimated reserves and charge the low prices when it has enough funds to do so. On the other hand, prices and reserve account may be used as

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[20] The lower correlations observed in the correlation analysis that is based on the company data could come from the reason that, in comparison to the company loss ratios and company loss development, the industry loss ratios and industry loss development tend to be more stable. The more variability in the company loss ratios and loss developments could affect the correlation analysis in the way that it weakens the observed correlations between the two variables.

a source of funds when the insurer is short of surplus. As a result, the price and loss reserve may increase at the same time.

Next, we examine the correlations between change in accident-year net loss ratio and accident-year loss development using the company data. Since increase (decrease) in loss reserves reduce (increase) the surplus amount which can lead to increase (decrease) in the insurance prices. Also, when prices increase, the insurers gain fund and may use this fund to revise the reserves account. Therefore, we expect to observe lower (higher) prices together with the favorable (adverse) loss reserve adjustments. This insight leads us to the following investigation of the impact of calendar year loss development on the changes of accident-year loss ratio.

We observe the correlations between changes in accident-year net loss ratio from the prior year and one-calendar-year loss development using the company data. Consistent with our expectations, the change in accident-year net loss ratio and one-calendar-year loss development are negatively correlated in all of the selected lines (see tables 5.1-5.8). However, the degrees of the correlations are much lower when the company data is used instead of the aggregate data.[21]

Comparing the results of the three different correlations, we see that they are not similar. This is not surprising since the three correlations have different meanings (the implications of the three correlations are provided at the beginning of section 7.1). For instance, the correlations between change in net loss ratio and one-calendar-year loss development (table 5.1-5.8) test the timing of changes in prices and reserve

[21] The considerable differences in the magnitudes of the correlations derived from the industry aggregate and company data could be due to the definitions of the one-calendar-year loss development (see section 6.1). According to the definition of one-calendar-year loss development, the loss development is weighted by the earned premium. Since the industry earned premiums are huge relative to the amount of calendar year loss development, the "one-calendar-year loss development" is substantially compressed. The noises created by the company data is also offset when the industry aggregate data is used. On the other hand, the difference between company earn premium and calendar year loss development is smaller than that of the industry level. Therefore, the "one-calendar-year loss development" is not materially compressed. The "one-calendar-year loss development" also contains noises when the company data is used in the analysis.

adjustments while the correlations between accident-year loss ratio and one-calendar-year loss development (table 3.1-3.8) do not consider the time scale effect.

One might argue that one year may be too short to observe the correlations between pricing risk and reserving risk. The underlying reasoning is that there is a time lag between loss reserve adjustments and the shifts of underwriting policy. In the period of softening market, insurers' change of underwriting policy is a more gradual event. Particularly in large companies, it can take 12 months for insurers to really begin to shift underwriting policy after the release/accrual of reserves in the previous year. However, the shift in underwriting policy can occur more rapidly in hardening market since often the insurers respond to a clear event (e.g. loss shock). Consequently, the inter-period interactions between pricing risk and reserving risk may exist. In addition to the investigation of pricing risk and reserving risk in the one-period framework, we explore the relationships of the previous year reserving risk and the current year pricing risk. We rationalize that the release (accrual) of loss reserves in the previous year can lead to the decrease (increase) in price in the current year.

The results of interactions between accident-year net loss ratio and one-year lag of the one-calendar-year loss development reject our expectation that the pricing risk and reserving risk are well correlated in the two-year timeframe. In fact, the correlations are low and indeed close to zero. We also calculate the correlations between one-year lag of net loss ratio and one-calendar year loss development but the correlation is also very minuscule. For example, in other liability industry, the average of correlations between change in net loss ratio and one-year lag of one-calendar year loss development is 0.1%, and the average of correlations between one-year lag of change in net loss ratio and one-calendar year loss development is only 1.2%.

7.1.3. Correlation analysis of pricing risk and reserving risk with respect to the firm size

This section tests hypotheses about the relationships between pricing risk and reserving risk whether it is different by sizes of insurers. We examine how the price-reserve correlations vary by insurer size (as shown in Tables 3.1-3.8). Since large insurance companies tend to write broader and more diverse market segments and set prices using experience ratings, we expect that they will show a positive and strong correlation between pricing and reserving risks. The reasoning underlying this expectation is that insurers with larger and more diverse books of business will be less informed about factors or developments that will affect the ultimate incurred losses for different market segments within their portfolios of exposures. This, in turn, may lead to pricing errors that are linked to errors in estimating unpaid losses. Small local insurers, on the other hand, are not experience rating. They tend to write narrower market segments, which gives them an informational advantage in accurately estimating reserves and setting prices. Therefore we expect the small insurers to have a weaker correlation between pricing and reserving risks.

Table 3 shows the correlations, at an aggregate level, between accident-year loss ratios and accident-year loss development for small, midsize, large, and giant insurers for the eight selected lines of business (see section 6.1. for the definitions of sizes of insurers). Consistent with our expectations, small companies, in general, exhibit low correlations in comparison to large and giant insurers.

CMP and WC are two lines where we do not see this tendency. Large and giant companies do not have a significant correlation in commercial multiple peril. In WC, the correlation is not substantially different among the different insurer size categories. It could be that regulation in this line has a similar impact on every insurer and this leads to less variation in their correlations between loss ratios and loss development.

For the other liability lines, the correlation analysis suggests that accident-year loss ratios and ultimate loss development are generally correlated and their relationship differs by insurer size.

We extend the investigation of correlations between pricing risk and reserving risk by analyzing individual company data. Tables 3.1-3.8 illustrate the correlations between accident-year loss ratios and accident-year loss development. The results support our hypothesis that the magnitudes of the correlations vary by size of companies. In every selected liability lines, we find that large and giant insurance companies have higher correlations in comparison to that of the small insurers. The implication of this result is that the less information about losses and the usage of experience rating in large companies strengthen the interaction between pricing and reserving errors. However, homeowners and private passenger auto liability insurers do not show that the correlations are considerably different among the different sizes of companies. An explanation of this result is that the loss development is small for every size of homeowners writers due to the quick claim settlement and loss payment. In private passenger auto liability, the losses tend to be well understood and both small and large insurers are less subject to the pricing and reserving errors.

Next, we explore the interactions between loss reserve adjustments in a given year and the same year prices. In contrast to the findings in the analysis of accident-year loss ratios and ultimate loss development, the industry aggregate data shows that small companies have higher correlations between changes in accident-year loss ratio and one-calendar year loss development in commercial multiple peril, other liability, product liability and homeowners (see table 5). Moreover, the small companies in product liability have positive correlation. The midsize companies, on the other hand, have stronger correlation than the other sizes in medical malpractice and workers' compensation. Only commercial auto liability shows that large insurers have the larger magnitude of the correlation than the smaller sizes of insurers.

We further observe the correlations between changes in loss ratio from the prior year and one-calendar year loss development by analyzing the company data. Tables 5.1-5.8 present the negative correlations in most of lines of business. In contrast to the results derived from the industry aggregate data, small companies in product liability have a negative correlation, but not significantly different from zero, between changes in accident-year net loss ratio and one-calendar-year loss development. The homeowner insurers, however, do not show that the correlations vary by sizes of the companies.

With the exception of the commercial multiple peril, the results based on the company data suggest that large and giant companies display a stronger correlation in comparison to the smaller insurers, implying that large and giant companies tend to increase their loss reserves while raising the prices. In commercial multiple peril, the midsize companies have the greatest correlation.

These findings suggest that the correlations between change in accident-year loss ratio and calendar-year loss development vary by line of business and company's characteristics. Nevertheless, the insurers with any company's characteristics tend to increase (decrease) price while accruing (releasing) the reserves, which is consistent with our hypothesis.

7.1.4. Correlation analysis of pricing risk and reserving risk with respect to the firm structure

The relationships between pricing risk and reserving risk are also expected to be related to insurer's incentives with respect to organization structure. In particular, we expect that the stock and publicly traded stock insurers will display a higher correlation between pricing risk and reserving risk than the other types of companies. We leave the alien insurers out from the discussion as they may experience the non-domestic influences. We also do not discuss the results from the types with few companies because the results could be misleading.

Consistent with our hypothesis, tables 3.1-3.8 exhibits higher correlations between accident-year loss ratios and accident-year loss development in the publicly traded stock insurers and/or stock insurers in most of the selected lines. Disregarding the alien insurers who tend to have special behaviors in accordance with the influences from their parent companies, the publicly traded insurers and/or stock insurers have higher correlations than the other types of companies in every line of business. The result in medical malpractice and product liability, in contrast, suggests that mutual insurers and stock insurers have roughly the same correlations (within reasonable range of sampling error). Note that per tables 3.1-3.8 the order of correlations of risk retention group, reciprocal, and alien companies are not consistent among lines of business. An explanation for the arbitrariness could be the limited number of samples in these types of insurers. Another explanation might be that these insurers have other characteristics and behaviors that are not fully captured by our classification by size and type of insurer, and those insurers may employ different strategies for different lines of business. In summary, the results indicate that stock insurers, especially publicly traded companies, have stronger correlations between accident-year loss ratios and accident-year loss development than the other types in most of the lines of business, implying that the earning pressure in the stock insurers fortify the correlations between pricing risk and reserving risk.

Exploring the interactions between changes in price and loss reserve adjustments with respect to the firm structure, we find that stock insurers show a significant and strong interactions between change in price and loss reserve adjustment in other liability and commercial multiple peril. That is, the increase in accident-year loss ratio is likely to be observed with the increase in one-calendar-year loss development in these lines of product. Mutual insurers, nevertheless, have the strongest correlations in workers' compensation, private passenger auto liability, commercial auto liability, medical malpractice, product liability, and homeowners market. The results do not show clear evidence that the timings of loss reserve adjustment and the shift of underwriting policy vary according to the firm structure.

7.1.5. Correlation analysis of pricing risk and reserving risk with respect to product diversification

Product diversification is another factor we expect to have influence on the relationships between pricing and reserving risks. The insurers who write business in one or a few lines are likely to have more specialist expertise for the business they are doing. The contrary goes for the multiple-line insurers. In comparison to the single-line or few-line insurers, the insurers who write business in several lines tend to be more subject to pricing and reserving errors due to the less knowledge about the risks of the coverages. Consequently, we hypothesize that the correlations between pricing risk and reserving risk are greater in multiple-line insurers.

Tables 3.1-3.8 demonstrate the correlations between pricing risk (accident-year loss ratios) and reserving risk (accident-year loss development) according to product diversification, which is presented by number of lines written. The multi-line writers tend to exhibit higher correlations between accident-year loss ratio and the accident-year loss development in commercial casualty lines such as commercial auto liability, workers compensation, and product liability. However, we do not see this tendency in the other lines of business. Therefore, the results suggest that the price-reserve correlations are not subject to the number of lines written.

Next, we analyze the interactions between changes in price and loss reserve adjustments with respect to the number of lines written. Per tables 5.1-5.8, we observe that the simultaneous occurrence of price increments (decrements) and one-calendar year adverse (favorable) loss development is more pronounced in multi-line insurers in commercial multiple peril, commercial auto liability, product liability and homeowners. In contrary, the correlations between change in net loss ratios and one-calendar year loss development are higher in mono-line or few-line insurers than the multi-line insurers in workers' compensation, private passenger auto liability, and medical malpractice. In other liability, the correlations are quite close among different classes of the number of lines. The different results among lines of business provide weak evidence that the interactions between changes in price and loss reserve adjustment vary by the number of lines of business.

7.1.6. Correlation analysis of pricing risk and reserving risk with respect to geographic diversification

Similar to the analysis of pricing risk and reserving risk associated with the number of lines of business, we speculate that the same rationality works for the geographic diversification. That is, the insurers who write business in one or a few states are likely to have more specialist expertise for the business they are doing. On the other hand, the insurers who write business in several states tend to be more subject to pricing and reserving errors due to lack of the expertise. Hence, we hypothesize that the multiple-state insurers have the higher price-reserve correlations.

The results in tables 3.1-3.8 suggest that the insurers who write in multiple states tend to have higher correlations between accident-year loss ratios and accident-year loss development than the mono-state writers; this is true for commercial multiple liability, other liability, private passenger auto liability, workers compensation, and product liability. The commercial auto liability, medical malpractice and homeowners, however, do not have this tendency. Therefore, the results do not propose strong evidence that the pricing risk and reserving risk differ by geographic diversification.

Considering the interactions between changes in price and loss reserve adjustments with respect to the number of states written (see tables 5.1-5.8), the results suggest that the companies who write business in single and/or a few states have stronger correlations between price changes and one-year loss development in medical malpractice, private passenger auto liability, workers' compensation, and homeowners. On the other hand, the hypothesis is supported in other liability, commercial multiple peril, commercial auto liability, and product liability. The multiple-state insurers in these lines show the stronger correlations between changes in net loss ratio and one-calendar-year loss development. The different results among lines of business imply the influence of geographic diversification and expertise on the interactions between changes in price and the loss reserve adjustments are different by line of business.

7.1.7. Vector Autoregression Analysis of Pricing Risk and Reserving Risk

As researchers have found evidence that insurance price in property/casualty industry is AR(2) and that some economic factors have influence on pricing risk, we are interested in investigating the correlation pricing risk and reserving risk if the time series and some relevant economic factors that affect both pricing risk and reserving risk are controlled. We select lag two (p=2) in our VAR analysis corresponding to literatures and statistical concerns.

The economic variables that are controlled in the VAR analysis are size of company (earned premium), interest rates (market yield on U.S. Treasury securities at 5-year constant maturity, quoted on investment basis), premium growth (percentage of increase in direct premium written), and percentage of premium written in commercial lines. The percentage of premium written in commercial lines is included as the exogenous variable for the reason that these lines tend to be significantly subjected to market competition, and their prices are more volatile than personal lines.

Due to the limited data, we do not run the VAR models separately by the insurers' risk characteristics, e.g., firm size, firm structure, number of lines, and number of states.

According to the reasons given in section 6.2, we focus on the correlations of the error terms derived from the VAR analysis. The positive correlations of the error terms means that, in a given year, the increases (decreases) in pricing risk raise (reduce) the loss reserving risk after time series effect are controlled.

Table 6 exhibits the residuals correlations derived from VAR analysis for eight selected lines of business. We perform the VAR analysis using three models. Model 1 studies the correlations between accident-year loss ratios and ultimate loss development. Model 2 studies the correlations between accident-year net loss ratio and one-calendar-year loss development. Model 3 studies the correlations between change in net loss ratio and one-calendar-year loss development.

The correlations of the residuals in model 1 have the sign that consistent with our hypothesis: accident-year loss ratios and ultimate loss development in a given year are positively correlated. In exception with commercial multiple peril and homeowners in model 1, the correlations between pricing risk and reserving risk are significantly different from zero, affirming that pricing risk and reserving risk are related. The insignificant correlations between accident-year loss ratio and accident-year ultimate loss development in commercial multiple peril and homeowners could be due to that the pricing errors of the property coverages are more related to the natural losses rather than the reserving errors.

It is not surprising that the correlations of accident-year loss ratio and accident-year ultimate loss development that are derived from the VAR model, in general, are lower than the simple correlations in tables 3.1-3.8. The lower correlations imply that the time series effect and the selected economic factors have an effect on price-reserve correlations.

On the other hand, the correlations between prices and loss reserve adjustments in a given year are ambiguous once time series effect and some exogenous variables are taken care of. In particular, although they are all significantly different from zero, the correlations between accident-year net loss ratio and one-calendar year loss development and the correlations between change in net loss ratio from prior year and one-calendar year loss development have mixed signs among lines of business. That is, in a given year, it is not clear that how the accident-year net loss ratio and change in net loss ratio relates to one-year loss development after controlling for the effect from time series and some exogenous variables.

7.2. Credibility Theory and Analysis of Underwriting Risk

A major hypothesis that is previously posed is that the underwriting risks to some extent are a consequence of the insurers' behaviors and risk characteristics. However, the risk characteristics of the insurers can be practically homogeneous within the market segments, which is defined in term of firm size, firm structure, product diversification, and geographic diversification, rather than within the whole industry. Unfortunately, the current regulatory risk-based capital models for underwriting risks rely on company-specific risk and industry-wide risk. If the underwriting risk structure is more uniform within market segments than within the overall market, considering the refined segment in the regulatory models will improve the accuracy of the risk assessment.

7.2.1. Segment Specificity of Pricing Risk

Tables 7.1-7.8 illustrate the mean of squared errors and median of squared errors for the models with different choice of complements of credibility. The choices of complements of credibility are defined according to the definitions for market segmentation. More specifically, in each line of business, the market is segmented by size, type, number of lines, and number of states of the insurers. We will discuss the results from each model according to its choice of complement of credibility.

First, we compare the accuracy of the credibility estimates of the model that use industry loss ratio as the complement of credibility with the models that utilize the loss ratio of each size segments. The mean squared errors in tables 7.1-7.8 imply that, having the industry model as a benchmark, the pricing risk appear to be size-specific for large and/or giant insurers in most of the lines of product such as commercial multiple peril, commercial auto liability, private passenger auto liability, workers' compensation, product liability, and homeowners. Commercial multiple peril and product liability also show that the pricing risk is analogous among small insurers. Furthermore, the results in medical malpractice and other liability market suggest that the pricing risk is more homogeneous within small and midsize insurers than within the overall industry.

Next, we delve into the uniqueness of pricing risks within market segments by type of the company. Except for the other liability industry, publicly traded insurers show the type-specific pricing risk in every line of business. This is consistent with the hypothesis that the earning tension can bring about the special pricing risk for the publicly traded companies. Stock insurers also tend to have the distinctive pricing risk in commercial multiple peril, commercial auto liability, private passenger auto liability, workers' compensation and product liability. As we expected, alien insurers exhibit the distinctive pricing risk from the domestic insurers in almost every line of product. Nonetheless, the type specificity of pricing risk is not evidently shown for mutual, reciprocal, and risk retention group insurers because the results among lines of business are mixed.

When the market is divided into groups of mono-line, few-line and multiple-line insurers, the homogeneity of pricing risk within these groups in comparison to the whole industry, varies among lines of business. In commercial multiple peril, homeowners, medical malpractice, private passenger auto liability, and workers' compensation, the model that uses the mono-line or few-line insurers loss ratio as the complement of credibility provides a better estimation than the industry model. That is, mono-line or few-line insurers exhibit the group-specific pricing risk in these lines of business. On the other hand, the pricing risk seems to be specific in the multiple-line segment in some lines of product such as commercial auto liability, other liability, and product liability.

Finally, we question about the pricing risk being unique from the whole industry when the market is segmented by the number of states in which the insurers do the business. We find that multiple-state insurers have the distinctive pricing risk from the overall industry in all lines of business. Besides, medical malpractice and product liability show that pricing is segment-specific for mono-line insurers.

In conclusion, the results basically suggest that using the combination of company owned risk and the market-segment risk in predicting the pricing risk for an insurer can improve the accuracy of the prediction, especially when the market is characterized by firm size, organization structure, and number of states.

7.2.2. Segment Specificity of Reserving Risk

Based on the same rationality in the pricing risk analysis, we perform the credibility theory to find supports for the hypothesis that the refined segment can improve the accuracy of the reserving risk prediction. Since there are some outliers in the credibility estimation, we will base our analysis on the median of the squared errors so that the misleading effect from the outliers can be eliminated.

In comparison to the industry model, tables 8.1-8.8 suggest that employing the market segmentation by firm size can provide a better prediction for the reserving risk in all lines of product. The medians of the squared error indicate that the reserving risk appears to be size-specific for large, and giant insurers in all lines of business. This finding supports our hypothesis that the lack of knowledge about the risk can cause the large insurers to display distinct reserving risk from the overall market. The midsize insurers seem to have the size-specific reserving risk features in commercial auto liability and workers' compensation. Only product liability shows that reserving risk is size-specific for the small insurers.

Furthermore, we study the appropriateness in using the types of companies as a principle for the reserving risk classification. With the exception of the commercial auto liability, the reserving risk of publicly traded insurers tends to be type-specific, which is consistent with the hypothesis. Moreover, the reserving risk seems to be unique within the group of stock insurers in commercial multiple peril, other liability, private passenger auto liability, and workers' compensation. For the other type of insurers, however, there is no clear evidence that the reserving risk is type-specific as the results are mixed across lines of business.

Considering the market segmentation by number of lines, the result implies that reserving risk is segment-specific for multiple-line insurers in commercial multiple peril, commercial auto liability, medical malpractice, other liability, and workers' compensation. The mono-line or few-line insurers tend to have the group specific reserving risk only in medical malpractice market. Nevertheless, there is no evidence that the reserving risk is segment specific in many lines such as homeowners, product liability, and private passenger auto liability.

Lastly, we find that the reserving risk is segment specific when the market is segmented by number of states. The credibility results imply that the multiple-state insurers exhibit the unique reserving risk compared with the risk in the overall industry in every line except for homeowners and medical malpractice. The mono-state or few-state insurers appear to have the distinct reserving risk in homeowners and medical malpractice. Generally, we find that segmenting the market by number of states would enhance the accuracy of the reserving risk prediction.

7.3. Actuarial Reserving Model Risk

Figures 2.1-2.2 illustrate the aggregate incurred loss estimates of workers' compensation market according to Chain-Ladder and Bornhuetter-Ferguson methods.

The plots in figure 2.1 represent the reversal direction of loss development and the failure to recognize such information in the actuarial reserving models. More specifically, the incurred losses were favorably developed during year 1992-1996 but began to increase in year 1996. However, the Chain-Ladder and Bornhuetter-Ferguson assume that incurred loss would remain decreasing just like before 1996. As a result, the actuarial estimates yield the underestimated forecast of losses. This idea is clearly shown in figure 1.1 in which actuarial estimates are materially deviated from the actual losses since 1996.

Similarly, the loss reserve error created by the actuarial reserving models is demonstrated in figure 2.2. The incurred loss was rapidly growing during year 1996-2000, and though it keeps on increasing, the growth rate diminished in year 2000. Unfortunately, the Chain-Ladder and Bornhuetter-Ferguson approaches expect that the incurred loss would be decreasing at the same growth rate of years prior to 2000. Consequently, the incurred losses are actuarially overestimated in this scenario.

Based on the individual company data, we demonstrate an empirical analysis of actuarial reserving model risk. The Chain-Ladder method, which is popularly used for loss reserve estimations, is chosen as a representative of the traditional actuarial reserving model.

In addition, the insurance companies are also characterized by size of the insurers. As pointed out by Wang and Faber (2006) who applied some selected insurers as an example, the Chain-Ladder estimation error is likely to be pronounced in large insurers and this method seems to work well with the small insurers. Accordingly, we speculate that Chain-Ladder method could be a source of loss reserve errors and can create the unfavorable errors especially for the large insurers. Other than using some selected insurers as a sample, we investigate the actuarial estimate errors of every insurer. We also group the insurance companies by size of their premium using each line of business for comparison of the effectiveness of the Chain-Ladder method on different size of insurers. Mean and median of the errors are presented for each class of insurers, and we will base our analysis on the median of the errors for the outlier effect exclusion.

Applying the Chain-Ladder method, we project the incurred loss for accident-year 1996, 1999, and 2001. We select these years for the actuarial reserve error analysis in that they are the turning points of the underwriting cycle in most of the lines of business. The medians of squared errors from the Chain-Ladder estimation are exhibited in tables 9.1-9.3 for year 1996, 1999, and 2001 respectively. The positive error means that the chain-ladder model underestimate the incurred loss while the negative error implies that the model overestimate the incurred loss. However, the estimation error depend upon both direction of loss pattern and the growth rate of loss, we do not restrict ourselves to expect to see only underestimation in the year that loss changes from decreasing to increasing. Therefore, we will focus on the magnitude of the errors and the difference of the errors by size of insurers

In general, the results suggest that the insurers tend to actuarially overestimate the losses in the year that the loss pattern changes from moving upward to downward. On the other hand, the estimates of loss from the Chain-Ladder technique are likely to be undervalued when the loss that was diminishing in the prior years begins to rise in the current year. We will discuss the actuarial loss reserve errors created by the Chain-Ladder method together with the loss ratio pattern by line of business. Note that not only does the actuarial estimate depend on the direction of the movement of the losses in prior years, it also depends on the rate of losses development. As a result, both loss overestimation and underestimation can be observed in the soft and hard markets. In addition, we also explore the actuarial reserve errors by premium size of the companies. As there is not a significant variation of the loss ratio in homeowner insurance market, we only include this line as a sample of the property line of business.

Considering the Chain-Ladder estimation errors in the commercial multiple peril market, the loss ratio is quite stable from 1991-2000. There is a small jump of loss ratio in 2001 and a huge drop in 2002. We focus on the loss estimation error occurred in 2001 when a major change of the pattern of the price movement is presented. According to table 9.3, the medians of the errors indicate that the Chain-Ladder method underestimates the losses of the policies that were written in 2001. Nevertheless, small, large and giant insurers exaggerate the incurred loss and the overestimation is considerable in giant insurers. An explanation for the underestimation could be that the increase rate of losses in these classes of insurers is small relative to the overall decrease rate of losses in the recent years. In addition, for these insurers, the company loss ratios may not track with the industry loss ratios. Nevertheless, the considerable errors in large and giant insurers agree with Wang and Faber (2006) who suggested that this method do not work well with large insurers.

Next, we examine the Chain-Ladder reserve error in the commercial auto liability industry. The industry plot of loss ratio states that the insurance price had a reversal direction and began to increase in 1999. The Chain-Ladder method underestimates the losses in this year, and the magnitude of the error is material for large and giant insurers as shown in table 9.2.

In the other liability market, the results confirm our hypothesis that the Chain-Ladder method is a source of loss reserve estimation errors. In 1996 is the year just before the arrival of softening market. Nevertheless, while for the small and midsize insurers the Chain-Ladder method tends to over-estimate loss reserves in this period, for the large and giant insurers the Chain-Ladder method tends to underestimate the loss reserves. When the market went deep into the soft market in 1999, the Chain-Ladder method appears to have underestimated the loss reserve for every size of insurers. The magnitude of the error is considerable in the large and giant insurers.

The results in medical malpractice industry also suggest the existence of the actuarial estimation errors. In year 1996, insurers have a tendency to underestimate the loss reserve if they utilize the Chain-Ladder method as a tool for loss predictions. As expected, large and giant insurers show the greater magnitude of the errors in comparison to the small insurers. In contrary, the incurred loss appears to be underestimated, especially for the large and giant companies, in 2001 when the price continues to decrease. The reason for the actuarial underestimation in 2001 could be that the rate of decrease in losses is greater than that in the recent years.

In product liability market, there are two turning points of the price trend in the studied period. In 1999 when the market has a sudden jump of the loss ratio, the Chain-Ladder technique seems to provide the underestimation of the loss in every size of insurers. The result, therefore, is consistent with the hypothesis that the actuarial method can create the loss reserve understatement when loss is adversely developed.

The similar analysis is performed in workers' compensation industry. The price of workers' compensation insurance was growing during 1991-1994. It began to fall in 1995 and continued to decrease until 1999. The price began to go up again from year 1999 onward. With exception of the giant insurers, the other sizes of insurers overestimate the loss reserve in 1996 as expected. When the market is in the mature soft market in 1999, the Chain-Ladder method appears to underestimate the loss reserve except for the giant insurers. In particular, the figure shows that, though it is small in magnitude, the Chain-Ladder technique exaggerates the loss reserves in the group of giant insurers.

Finally, we explore the loss reserve errors that are generated by the Chain-Ladder estimation in private passenger auto liability. The industry loss ratios indicate that the market price does not vary to a great extent during 1991-1998. The price, however, has gradually declined since 1999. By projecting the incurred losses, the empirical analysis shows that the Chain-Ladder technique underestimates the loss reserve in 1999. The loss reserve is underestimated when the incurred loss pattern changes in the adverse manner, the actuarial reserve error in large and giant insurers is greater than the smaller insurers. This finding substantiates the idea that small insurers set the loss reserves more conservatively than the large insurers.

7.4. Analysis of Benefit from Product Diversification

7.4.1. Diversification Benefit on the Incurred Losses

To visualize that our definition for diversification benefit can reflect the degree diversification benefit, we plot the diversification benefit on the incurred losses by each individual company. The company is sorted by the number of lines written, i.e., the company which is further to the right of the x-axis indicates the larger number of lines in their portfolio. As shown in figure 3, the diversification benefit appears to increase with the number of business lines. The correlation between the number of lines and the diversification benefit under this definition is equal to 73.62% when all companies are included in the calculation and is equal to 56% if only multiple-line insurers are considered.

Furthermore, we compute the average and median of the diversification benefit by the number of product lines. According to table 10, the diversification benefit is increasing with the more number of lines in the insurers' portfolio. However, the decrement of diversification benefit is observed if the insurers write the business in more than six lines. The result imply that the diversification effect from risk pooling seems to be beneficial if the insurers have less than six lines of product, but the diminishing knowledge can take an effect and reduce the diversification benefit if the insurers do the business in too many lines.

Tables 10.1-10.3 exhibit mean and median of the diversification benefit on the incurred losses for midsize, large and giant insurers respectively. The results support the hypothesis that large companies gain more benefit from product diversification. The averages of diversification benefit are 0.078, 0.2, and 0.214 for class of midsize insurer, large insurer, and giant insurer respectively. Note that almost every small insurer has single line in their portfolio and thus have zero diversification benefit under our approach.

We include the diversification credit under BCAR definition to represent the current model used by regulators. The BCAR formula applies the net premium written in determining the diversification factor. If an insurer has the net premium written less than a specified amount, the BCAR assigns zero diversification credit to that company. Otherwise, the calculation is based on the line of business with the highest percentage of the net premium written. Unlike the diversification benefit under our definition, the BCAR approach fails to consider the risk in every line in the portfolio. The diversification factor and diversification benefit have explicit formulas as follows.

$$Diversification\,Factor = \begin{cases} 1 \quad , \; if \; NPW = 0 \; or \; NPW < \dfrac{50000}{1.6} \\ 0.7 + 0.3 \max_i (\% \, of \; NPW \; in\, line\, i) \quad , \; Otherwise \end{cases}$$

and

$$\textit{Diversification Benefit} = 1 - \textit{Diversification factor}.$$

However, we use the diversification benefit derived from BCAR model as a benchmark. Instead of the net premium written, the net premium earned in a given accident-year is applied in the BCAR formula for the comparison purpose.

Table 10 illustrates that the diversification credit under BCAR increases as more lines of product are written. This suggests that the BCAR tends to give more credit to the companies that write the business in more of product lines. The correlation between the number of lines and the diversification benefit under this definition is 70.39% when all companies are included in the calculation and is equal to 12.50% if only multiple-line insurers are included.

According to tables 10.1-10.3, large companies reap more product diversification benefit than the small sizes. The averages of diversification benefit are 0.022, 0.118, and 0.161 for class of midsize insurer, large insurer, and giant insurer respectively.

Comparing our definition and BCAR formula, our definition shows the higher correlation between the diversification benefit and number of product lines, especially when only multiple-line insurers are included in the correlation computation (56% vs. 12.5%). The greater correlation under our definition implies that our approach can reflect the product diversification benefit, which tends to tie to the number of lines, better than the BCAR definition. Another advantage of our approach is that it is a predictive model that includes the historical years of data in the calculation, while BCAR employs the present year data for the calculation.

According to table 10, mean and median of the correlation in each group of the number of lines suggest that the diversification credit is higher under our definition relative to those derived from the BCAR formula. For example, the average of diversification benefit for the five-line insurers is 0.309 under our approach, while it is 0.124 under BCAR definition. Moreover, 62.09% of the insurers have the higher diversification factor if our definition is used rather than the BCAR formula. Therefore, the BCAR formula tends to undervalue the benefit from product diversification for some companies if our proposed measure were more effective.

7.4.2. Diversification Benefit on the Reserving Risk

Figure 5 exhibits insurers' diversification benefit on the loss development. The result suggests that diversification benefit generally increases with the number of business lines. The correlation between the number of lines and the diversification benefit on the loss development is equal to 64.22% when all companies are included in the calculation and is equal to 34.76% if only multiple-line insurers are included.

Next, we look into the diversification benefit when the insurers are grouped by their number of lines of business. The average and median of the diversification benefit are shown in table 11. With exception of the group of insurers who have four lines of product in their portfolio, the diversification benefit on the loss development is increasing as the insurers have more lines of business in their portfolio. Nonetheless, the diversification benefit in the four-line group of insurers is greater than groups of insurers who write the business in less than seven lines. The result implies that the product diversification, under our definition, does not show clear beneficial effect to the reserving risk. However, when we consider the diversification benefit in different size of insurers, we find that large companies benefit from product diversification compared with small insurers, according to table 12.

CHAPTER 8

8. Conclusion

This dissertation analyzes the relationship between pricing and reserving risks for property-casualty insurance companies. We hypothesize that pricing and reserving risks are, knowingly or unknowingly, correlated. We also expect that the degree of the interactions varies by insurers' risk characteristics for which we categorize in terms of firm size, firm structure, product diversification, and geographic diversification.

We find that, in a given accident year, underestimation of ultimate losses will lead to under-pricing, and vice versa, in casualty lines, especially in the long-tailed lines such as workers' compensation, other liability, and medical malpractice. For long-tailed lines, insurers use the estimated loss ratios, which are calculated from the immature data, to set reserves. Hence, the under-pricing is the root cause for under-reserving. The results also imply that pricing and reserving process are subject to the same pressures, e.g., pressures from management; therefore prices and reserves tend to be "miscalculated" in the same direction.

Even though we do not find that the loss reserve adjustment decisions are associated with the price level in a given period, we find that change in premium rate from the prior year and the loss reserve adjustments are correlated. We learn that price increment (decrement) and adverse (favorable) loss adjustment are simultaneous in casualty lines of business, implying that loss reserve errors can be a result of manipulation of the timing of loss recognition. Basically, this supports the co-coupling of the underwriting cycle and reserve cycle. In a hard market, companies bump up their reserves while increasing insurance prices. In a soft market, companies take down reserves to support their price cutting in competing for market shares.

Furthermore, we find that the link of pricing and reserving risks is associated with the size of companies. The empirical analysis indicates that price-reserve correlations are more pronounced in large insurers. This supports our intuition that large insurers, who tend to lack of information about the losses and resort more to experience rating, are likely to wrongly estimate the loss ratios and thus the loss reserves. We find the similar result in the analysis of correlations between change in prices and loss reserves. The insurers, especially large insurers, tend to increase their loss reserves in the year that prices rise since the increase in prices can provide funds for the loss reserve revision.

Disregarding the alien insurers, the publicly traded insurers and/or stock insurers exhibit higher correlations between pricing and reserving errors. As discussed before, the strong correlations can be a consequence of the earning pressures and revenue-based compensation in stock insurers. However, the results do not show clear evidence that the timings of loss reserve adjustment and the shift of underwriting policy vary according to the firm structure.

According to the empirical results, product diversification generally does not play a significant role in the interaction between price and reserve errors. Whether the benefits from product diversification or the expertise from writing in few lines of business have more influence on the interaction between pricing and reserving are ambiguous.

In contrast, the empirical results suggest muti-state insurers exhibit higher correlations between accident-year prices and ultimate loss development. Our findings have implications for multiple-state insurers. The geographic diversification tends to diminish the geographical expertise and aggravate pricing and reserving errors.

In general, the empirical analysis indicates that the interactions between pricing and reserving errors are stronger in large insurers, stock insurers, and multiple-state insurers. On the other hand, the interaction between change in premium rate and loss reserve adjustment are more related to size of insurers rather than types, number of lines, and number of states characteristics.

Additionally, the credibility theory is applied as a tool for measuring the uniqueness of underwriting risks in market segments. We find that pricing risk is marginally more homogenous within a market segment when size, type, and number of states are employed as criteria for market segmentation. Pricing risk and reserving risk generally are size-specific and type-specific, especially for large insurers and stock insurers. The results have implication that introducing the refined-segment by firm size, firm structure, and geographic diversification in risk assessment would improve the accuracy of the pricing and reserving risk prediction.

Our results suggest that loss reserve errors can be a consequence of actuarial reserving models, especially for large insurers. The Chain-Ladder reserving method tends to exaggerate losses in the year that shows favorable loss development comparing to the prior years and is likely to underestimate the losses in the year that has adverse loss development relative to the prior years.

Finally, our proposed measurement method for product diversification benefit provides support for the notion that the product diversification benefit on the incurred losses and loss development, regardless of the firm size, increases with the number of lines in the portfolio. However, the diminishing knowledge tends to decrease the product diversification benefit on the incurred losses when an insurer writes the business in excessively many lines. This implication of this finding develops a better understanding of product diversification benefit against the lack of expertise, and can be useful for the firm risk management.

In conclusion, our findings provide an understanding of the pricing and reserving risk and their interaction in both actuarial practice and behavioral aspects. The insight provides a guide for pricing and reserving decisions, and encourages the firm risk management to consider the firm's expertise and agency/incentive problems. The over-reliance on experience rating in large companies can lead to under-pricing; companies need to establish benchmarks for the true risk exposure so they can track the changes in risks more accurately than using the loss experience (Wang and Faber, 2006).

Since our findings affirm the link between pricing and reserving in long-tailed business, tracking the pricing data in the loss reserving process and using the reserving process as a part of information for pricing would enable better pricing and reserving risk assessment.

Our research also may have implication for the financial regulation whose activities are affected by reserve errors and their consequences for pricing errors. The market regulation, including risk-based capital but not limited to, should truly reflects the link between pricing and reserving and firm risk characteristics. Additionally, the variation of results in insurers even in the same line of business encourage the incorporation of company own data in conjunction with industry/segment data in the risk-based capital requirement. We envision that our findings, more or less, can offer a guide for developing the more effective risk-based capital regulation.

REFERENCES

Anderson, D.R., 1973, "Effects of Loss Reserve Evaluation upon Policyholders' Surplus," WI: Bureau of Business Research and Service, University of Wisconsin, Monograph 6.

Baker, T., 2004, "Medical Malpractice and the Insurance Underwriting Cycle," *Depaul Law Review*, 54.

Beaver, W., McNichols, M., 1998, "The Characteristics and Valuation of Loss Reserves of Property-Casualty Insurers," *Working paper, Stanford University*.

Beaver, W.H., McNichols, M.F., Nelson, K., 2003, "Management of the Loss Reserve Accrual and the Distribution of Earnings in the Property-Casualty Insurance Industry," *Journal of Accounting and Economics*, 35(3), 347-376.

Biger, N., Kahane, Y., 1978, "Risk Considerations in Insurance Rate Making," *Journal of Risk and Insurance*, 45, 121-131.

Bloom, T.S., 1987, "Cycles and Solutions," *Best's Review: Property/Casualty Insurance*, 88, 20-24.

Browne, M.J., Hoyt, R.E, 1995, "Economic and Market Predictors of Insolvency in the Property-Liability Insurance Industry," *Journal of Risk and Insurance*, 62(2), 309-327.

Bühlmann, H., 1970, "Risk Theory," Springer, Berlin.

Bühlmann, H., 1980, "An economic premium principle," *ASTIN Bulletin* 11, 52-60.

Bulow, J., Klemperer, P., 2002, "Prices and the Winner's Curse," *RAND Journal of Economics*, 33(1), 1-21.

Cagle, J.A.B., Harrington, S.E., 1995, "Insurance Supply with Capacity Constraints and Endogenous Insolvency Risk," *Journal of Risk and Uncertainty*, 11, 219-232.

Choi, S., Hardigree, D., Thistle, P., 2002, "The Property/Liability Insurance Cycle: A Comparison of Alternative Models," *Southern Economic Journal*, 68 (3), 530-48.

Conger, R.F., Wolstein, C.R., 2004, "Managing Overconfidence in Pricing," *Emphasis*, Towers Perrin.

Cooper, R.W., 1974, "Investment Return and Property-Liability insurance Ratemaking," *Journal of Risk and Insurance*, 45, 121-132.

Cummins, J. D., S. E. Harrington, Klein, R. W., 1991, "Cycles and Crises in Property-Casualty Insurance: Causes and Implications for Public Policy," *Journal of Insurance Regulation*, Fall, 50-93.

Cummins, J.D., Danzon, P.M., 1992, "Price Shocks and Capital Flows in Liability Insurance," *Working Paper, University of Pennsylvania*.

Cummins, D., Danzon, P. M., 1997, "Price, Financial Quality and Capital Flows in Insurance Markets," *Journal of Financial Intermediation*, 6, 3-38.

Cummins, J. D., Grace, E., 1994, "Tax Management and Investment Strategies of Property-Liability Insurers," *Journal of Banking and Finance*, 18, 43-72.

Cummins, J. D., Grace, M. F., Phillips, R. D., 1997, "Regulatory Solvency Prediction in Property-Liability Insurance: Risk-Based Capital, Audit Ratios, and Cash Flow Simulation." *Center for Risk Management and Insurance Research Working Paper 97-4*, Georgia State University.

Cummins, J.D., Harrington, S. , Niehaus, G., 1993a, "An Economic Analysis of Risk-Based Capital Requirements in the Property-Liability Insurance Industry," *Journal of InsuranceRegulation,*11, 427-447.

Cummins, J.D., Outreville, J.F., 1987, "An International Analysis of Underwriting Cycles," *Journal of Risk and Insurance*, 54, 246-262.
Daniel, K., Hirshleifer, D., Subrahmanyam, A., 1998, "Investor Psychology and Security Market Under- and Overreactions," *The Journal of Finance*, 53(6), 1839-1885.
D'Arcy, S.P., Garven, J.R., 1990, "Property-Liability Insurance Pricing Models: An Empirical Evaluation," *The Journal of Risk and Insurance*, 57(3), 391-430.
Diacon, S.R., Fenn, P.T., O'Brien, C., 2003, "How Accurate are the Disclosed Provisions of UK General Insurers?" presented at the 30th Meeting of the European Group of Risk and Insurance Economists, Zurich.
Doherty, N.A., Garven, J., 1992, "Insurance Cycles: Interest Rates and the Capacity Constraint Model," *Journal of Business*, vol. 68, p. 383-404.
Doherty, N.A, Posey, L., 1993. "Asymmetric Information and Availability Crises in Insurance Markets: Theory and Evidence," *Working paper, University of Pennsylvania*.
Embrechts, P., 2000, "Actuarial versus Financial Pricing of Insurance," *Risk Finance,* 1(4), 17-26.
Fairley,W.B., 1979, "Investment Income and Profit Margins In Property-Liability Insurance: Theory and Empirical Results," *Bell Journal*, 10(1), 192-210.
Feldblum, S., 1996, "NAIC Property/Casualty Company Risk-Based Capital Requirements," Proceedings of the Casualty Actuarial Society, 83.
Feldblum, S., Hodes, D. M., Neghaiwi, T., 1999, "The Financial Modeling of Property Casualty Insurance Companies," *North American Actuarial Journal Society of Actuaries,* 3(3), 41-69.
Fitzpatrick, S. M., 2004, "Fear is the Key: A Behavioral Guide to Underwriting Cycles," *Connecticut Insurance Law Journal*, 10(2), 255-275.
Froot, K.A, Stein, J.C, 1998, "Risk Management, Capital Budgeting, and Capital Structure Policy for financial Institutions: an Integrated Approach," *Journal of Financial Economics*, 47, 55-82
Gaver, J. J., Paterson, J. S., 1999, "Managing Insurance Company Financial Statements to Meet Regulatory and Tax Reporting Goals," *Contemporary Accounting Research*, 16 (Summer), 207-241.
Gaver, J. J., Paterson, J. S., 2004, "Do Insurers Manipulate Loss Reserves to mask Solvency Problems?" *Journal of Accounting and Economics*, 37(September), 393-416.
Gerber, H.U., 1979, "An Introduction to Mathematical Risk Theory," Huebner Foundation, Wharton School, University of Pennsylvania.
Grace, E.V., 1990, "Property-Liability Insurer Reserve Error: A Theoretical and Empirical Analysis, *The Journal of Risk and Insurance*, 57(1), 28-46.
Grace, M. F., Harrington, S. E., Klein, R. W., 1995, "An Analysis of the FAST Monitoring System," National Association of Insurance Commissioners, Kansas City, Mo.
Grace, M. F., Harrington, S. E., Klein, R. W., 1998, "Risk-Based Capital and Solvency Screening in Property-Liability Insurance," *Journal of Risk and Insurance*, 65, 213-243.
Grace, M., Leverty, T., 2005, "Reserve Error Motive, Manipulation or Mistake," *Working paper, World Risk Insurance Economic Congress.*
Gron, A., 1989, "Price and Profit Cycles in the Property-Casualty Insurance Industry," Mimeo, Department of Economics, Massachusetts Institute of Technology.

Gron, A., 1990, "Property-Casualty Insurance Cycles, Capacity Constraints, and Empirical Results," Ph.D. dissertation, Department of Economics, Massachusetts Institutes of Technology.

Gron, A., 1994, "Capacity Constraints in Property-Casualty Insurance Markets," *Rand Journal of Economics*, 25, 110-127.

Harrington, S.E., Danzon, P.M., 1994, "Price Cutting in Liability Insurance Markets," *Journal of Business*, 67, 511-538.

Harrington, S. E., Danzon , P.M., 2000, "The Economics of Liability Insurance," in G.Dionne (Ed.): Handbook of Insurance, Kluwer Academic Publishers, 277-313.

Hill, R., 1979, "Profit Regulation in Property-Liability Insurance," *Bell Journal*, 10, 172-191.

Ho, T.S.Y, 1999, "Corporate Performance Measures: An Integrated Approach," *ASTIN Colloquium International Actuarial Association - Brussels, Belgium* 1999: Toyko.

Hodes, D. M., Neghaiwi, T., Cummins, J. D., Phillips, R., Feldblum, S., 1996, "The Financial Modeling of Property/Casualty Insurance Companies," *Casualty Actuarial Society Forum*, Spring, 3-88.

Klein, R.W., 2005, A Regulator's Introduction to the Insurance Industry, Prepared for the National Association of Insurance Commissioners.

Madsen, C. K., 2002, "Does the NAIC Risk-Based Capital Suffice? And Are Property & Casualty Insurance Company Asset Allocations Rational?" *Casualty Actuarial Society Forum Casualty Actuarial Society - Arlington,* Virginia, Summer, 175-196.

Mayers, D., Smith, C. W. Jr., 2000, "Organizational Forms Within the Insurance Industry," Handbook of Insurance, 689.

Miller, E.M., 1977, "Risk, Uncertainty, and Divergence of Opinion," *Journal of Finance*, American Finance Association, 32(4), 1151-1168.

Myers, S.C., Cohn, R.A., 1987, "Insurance Rate Regulation and the Capital Asset Pricing Model," *In Fair Rate of Return in Property-Liability Insurance*, edited by Cummins, J.D., and Harrington, S., Norwell, MA:Kluwer Academic Publishers.

Nelson, K. K., 2000, "Rate Regulation, Competition, and Loss Reserve Discounting by Property-Casualty Insurers," *The Accounting Review,* 75, 115-138.

Penalva, F., 1998, "Loss reserves and accounting discretion in the property-casualty insurance industry," *Working paper, University of California at Berkeley*.

Petroni, K. R., 1992, "Optimistic reporting in the property casualty insurance industry," *Journal of Accounting and Economics*, 15, 485-508.

Phillips, R. D., Cummins, J. D., Allen, F., 1998, "Financial Pricing of Insurance in the Multiple-Line Insurance Company," *Journal of Risk and Insurance*, 65(4).

Rabin, M., 1998, "Psychology and Economics," *Journal of Economic Literature*, 36(1), 11-46.

Reinmuth, D. F., 1964, "What is a Reciprocal?: Comment," *The Journal of Risk and Insurance*, 31(4), 641-646.

Sandstrőm, A., 2006, Solvency Models, Assessment and Regulation, Chapman and Hall/CRC, FL.

Schiegl, M., 2002, "On the Safety Loading for Chain Ladder Estimates: a Monte Carlo Simulation Study," *ASTIN Bulletin*, 32(1), 107-128.

Shefrin, H., Statman, M., "Behavioral Portfolio Theory," *The Journal of Financial and Quantitative Analysis*, 35(2), 127-151.

Smith, B.D., 1980, "An Analysis of Auto Liability Loss Reserves and Underwriting Results," *Journal of Risk and Insurance*, 47, 305-320
Sommer, D.W., 1996, "The Impact of Firm Risk on Property-Liability Insurance Prices," *The Journal of Risk and Insurance*, 63(3), 501-514.
Stanard, J.N., 1985, "A Simulation Test of Prediction Errors of Loss Reserve Estimation Techniques," *PCAS*, 72, 124-148.
Stewart, B.D., 1984, "Profit Cycles in Property-Liability Insurance," in J.D. Long, Ed., Issues in Insurance, Malvern, PA: American Institute for P/L Underwriters.
Tennyson, S., 1993, "Regulatory Lag in Automobile Insurance," *Journal of Risk and Insurance*, 63, 36-58.
UK Working Party, 2003, "The Cycle Survival Kit," available online from http://www.actuaries.org.uk/files/pdf/proceedings/giro2003/Line.pdf.
Van, E. J., 1981, "Loss Reserving Methods," *Surveys of Actuarial Studies No.1*, Nationale Nederlanden N.V.
Venezian, E., 1985, "Ratemaking Methods and Profit Cycles in Property and liability Insurance," *Journal of Risk and Insurance*, 52, 477-500.
Verral, R. J., 1989, "A State Space Representation of the Chain Ladder Linear Model," *Journal of the Institute of Actuaries,* 116, Part. III, 589-610.
Verrall, R. J.,1990, "Bayes and Empirical Bayes Estimation for the Chain-Ladder Model," *ASTIN Bulletin*, 20(2), 217-243.
Wang, S., Faber, R., 2006, "Enterprise Risk Management for Insurance Companies," *Project report, Casualty Actuarial Society, ERM Institute International, Ltd, and CAS/SOA Risk Management Section.*
Weiss, M., 1985, "A Multivariate Analysis of Loss Reserving Estimates in Property-Liability Insurers," *Journal of Risk and Insurance*, 52 (2), 199-221.
Winter, R.A., 1988, "The Liability Crisis and the Dynamics of Competitive Insurance Markets," *Yale Journal of Regulation*, 5(2), 455-499.
Winter, R.A., 1991, "Solvency Regulation and the Property-Liability Insurance Cycle," *Economic Inquiry*," 29, 458-471.
Winter, R.A., 1994, "The Dynamics of Competitive Insurance Markets," *Journal of Financial Intermediation*, 3, 379-415.

APPENDIX

Incurred Bornhuetter-Ferguson Method

The Incurred Bornhuetter-Ferguson (BF) method assigns partial weight to the initial expected losses (calculated from the initial expected loss ratio), and partial weight to the observed incurred losses. The weights assigned to the initial expected losses decrease as the accident year matures. This method can be viewed as using Bayesian approach.

The basic idea behind this method is that the developed loss is equal to what is actually paid plus what we would expect to develop if the *Expected Loss Ratio (ER)* was correct. According to the loss development triangle, the expected loss ratio is typically defined as

$$ER = \frac{S_{0,n}}{P_0},$$

where P_0 is the earned premium of the first year accident that appears in the loss development triangle table. The *ER* is assumed to be constant for accident years thereafter.

The final estimate of the ultimate loss is based on the expected loss (typically the product of the expected loss ratio and the earned premium) and the Chain-Ladder estimate. The estimate of ultimate loss can be expressed in a formal form as:

$$S_{i,n}^{BF} = S_{i,n-i} + (1 - \frac{1}{f}) \times EL_i \quad ,$$

where

$$f = \frac{S_{i,n}^{CL}}{S_{i,n-i}} \quad ,$$

and $S_{i,n}^{BF}$ is the Bornheutter-Ferguson ultimate loss of accident year *i* and development year *n*; $S_{i,n-i}$ is the actual losses developed to date figure (see loss development triangle); and *EL* is expected losses which is equal to the expected loss ratio times the earned premium of accident year *i*.

Using credibility factor (*Z*), the BF ultimate loss can be re-written as:

$$S_{i,n}^{BF} = z \times S_{i,n}^{CL} + (1 - z) \times EL_i \quad ,$$

where $z = \dfrac{1}{f}$.

TABLES

Table 1: Loss Development Triangle

Accident Year	**Development Year**								
	0	1	…	k	…	n-i	…	n-1	N
0	$S_{0,0}$	$S_{0,1}$	…	$S_{0,k}$	…	$S_{0,n-i}$	…	$S_{0,n-1}$	$S_{0,n}$
1	$S_{1,0}$	$S_{1,1}$	…	$S_{1,k}$	…	$S_{1,n-i}$	…	$S_{1,n-1}$	
⋮	⋮	⋮		⋮		⋮			
I	$S_{i,0}$	$S_{i,1}$	…	$S_{i,k}$	…	$S_{i,n-i}$			
⋮	⋮	⋮		⋮					
n-k	$S_{n-k,0}$	$S_{n-k,1}$	…	$S_{n-k,k}$					
⋮	⋮	⋮							
n-1	$S_{n-1,0}$	$S_{n-1,1}$							
N	$S_{n,0}$								

Table 2: Descriptive Statistics of the loss ratios during 1991-2004

Accident Year	Commercial Multiple Peril			Commercial Auto Liability			Other Liability			Medical Malpractice		
	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.
1991	425	63.62%	24.60%	376	73.16%	17.95%	468	59.05%	31.89%	74	77.64%	30.99%
1992	461	88.56%	87.66%	414	73.87%	21.08%	503	58.12%	31.49%	78	74.69%	29.59%
1993	479	69.84%	38.02%	426	77.54%	20.45%	520	60.82%	30.77%	98	82.84%	35.28%
1994	491	75.25%	28.73%	442	80.66%	22.19%	554	65.17%	40.74%	104	84.58%	33.44%
1995	490	67.83%	24.23%	446	80.86%	32.97%	555	62.49%	32.93%	104	93.33%	40.38%
1996	489	75.92%	22.68%	445	80.86%	18.91%	555	65.52%	31.25%	103	105.62%	43.56%
1997	492	67.42%	21.69%	445	85.73%	25.39%	554	67.94%	30.10%	104	120.82%	76.59%
1998	493	84.23%	48.53%	443	89.81%	34.15%	553	78.05%	42.31%	105	135.05%	77.27%
1999	492	82.73%	28.45%	442	94.70%	26.68%	551	89.18%	51.21%	105	146.38%	89.03%
2000	492	81.25%	33.55%	440	94.49%	30.39%	550	89.59%	48.43%	104	136.27%	58.21%
2001	489	86.55%	60.64%	441	83.79%	25.44%	554	82.72%	42.79%	101	119.39%	40.74%
2002	479	59.77%	18.12%	439	71.20%	19.41%	549	70.13%	37.14%	101	104.09%	34.84%
2003	473	57.08%	21.58%	426	66.74%	16.49%	537	60.66%	22.30%	96	87.76%	35.01%
2004	460	59.91%	30.00%	414	66.53%	15.98%	532	63.36%	27.43%	95	81.26%	25.54%

Table 2 (Continue)

Accident Year	Private Passenger Auto Liability			Workers Compensation			Product Liability			Homeowners		
	N	Mean	S.D.	N	Mean	S.D.	N*	Mean	S.D.	N	Mean	S.D.
1991	474	81.06%	16.76%	311	81.05%	15.66%				474	79.85%	24.17%
1992	526	77.89%	14.96%	339	72.57%	15.57%				511	97.24%	113.70%
1993	547	77.40%	13.65%	360	63.94%	12.99%				530	75.68%	25.10%
1994	560	78.51%	13.97%	373	62.02%	13.09%	146	91.19%	61.72%	547	82.50%	22.89%
1995	565	78.43%	14.89%	376	62.34%	14.79%	150	85.62%	51.63%	551	74.20%	18.94%
1996	565	77.73%	12.82%	377	67.39%	15.87%	148	87.26%	64.53%	552	86.66%	27.41%
1997	566	76.49%	12.96%	377	76.17%	18.85%	148	105.49%	69.79%	549	64.97%	18.33%
1998	564	78.64%	19.49%	377	86.87%	23.19%	143	109.96%	114.82%	550	78.60%	30.89%
1999	563	82.51%	15.22%	378	99.36%	27.72%	135	141.26%	185.30%	548	71.28%	19.82%
2000	566	87.81%	17.49%	376	99.84%	24.14%	140	129.53%	115.73%	549	78.68%	22.20%
2001	561	85.82%	15.03%	377	92.42%	20.93%	133	109.11%	102.21%	548	82.34%	27.15%
2002	557	83.81%	16.25%	372	80.90%	15.77%	137	82.94%	52.51%	541	70.42%	19.07%
2003	544	78.66%	14.31%	366	75.42%	15.08%	132	78.04%	61.57%	534	68.89%	19.95%
2004	534	78.50%	14.61%	357	77.17%	14.70%	153	73.91%	42.61%	525	69.21%	45.16%

* The data file for product liability in year 1993 is damaged. We thus report the data since 1994.

Table 3: Industry aggregate level -- correlations between accident-year direct loss ratio and loss development

	CMP	CAL	OL	MM	PPA	WC	PL	HO
All	0.615	0.891	0.953	0.870	0.638	0.915	0.908	0.233
Small	0.557	0.860	0.676	0.694	0.446	0.951	0.369	0.586
Midsize	0.752	0.759	0.931	0.787	0.764	0.969	0.764	0.328
Large	0.522	0.913	0.953	0.885	0.618	0.918	0.618	0.197
Giant	0.507	0.507	0.942	0.913	0.567	0.898	0.901	0.190

CMP = Commercial Multiple Peril ; CAL = Commercial Auto Liability; HO = Homeowners; OL = Other Liability; MM = Medical Malpractice; PPA = Private Passenger Auto Liability; WC = Workers' Compensation; PL = Product Liability

Table 3.1: Company level -- descriptive statistics of correlations between accident-year direct loss ratio and loss development in commercial multiple peril

	N	Mean	S.D.	Median	% of positive correlation
All	502	0.388*	0.311	0.452	86.06%
Small	125	0.357*	0.323	0.442	84.80%
Midsize	251	0.390*	0.316	0.448	86.85%
Large	126	0.414*	0.289	0.466	85.71%
Giant	26	0.345*	0.337	0.438	76.92%
Public Stock	39	0.519*	0.300	0.628	92.31%
Stock	351	0.426*	0.305	0.502	87.18%
Mutual	150	0.295*	0.315	0.358	82.67%
Risk Retention Group	0				
Reciprocal	8	0.317*	0.285	0.183	100.00%
Alien	8	0.430	0.179	0.386	100.00%
Mono-line	19	0.254	0.360	0.292	78.95%
Multiple-line	487	0.382*	0.311	0.446	85.63%
Few-line	59	0.425*	0.308	0.518	89.83%
Mono-state	117	0.348*	0.339	0.411	83.76%
Multiple-state	416	0.396*	0.309	0.467	85.82%
Few-state	187	0.342*	0.340	0.415	82.35%

Table 3.2: Company level -- descriptive statistics of correlations between accident-year direct loss ratio and loss development in commercial auto liability

	N	Mean	S.D.	Median	% of positive correlation
All	451	0.494*	0.361	0.629	91.35%
Small	112	0.488*	0.380	0.614	88.39%
Midsize	226	0.483*	0.354	0.583	91.59%
Large	113	0.521*	0.359	0.681	93.81%
Giant	23	0.609*	0.359	0.752	95.65%
Public Stock	27	0.576*	0.341	0.688	92.59%
Stock	424	0.488*	0.362	0.620	91.27%
Mutual	346	0.524*	0.363	0.665	92.20%
Risk Retention Group	103	0.411*	0.319	0.458	90.29%
Reciprocal	2	0.044	0.069	0.044	50.00%
Alien	9	0.337	0.511	0.558	77.78%
Mono-line	5	0.577*	0.254	0.574	100.00%
Multiple-line	13	0.650*	0.253	0.690	92.31%
Few-line	436	0.494*	0.360	0.631	91.51%
Mono-state	57	0.558*	0.374	0.687	91.23%
Multiple-state	78	0.461*	0.390	0.625	87.18%
Few-state	391	0.502*	0.360	0.644	92.07%

Table 3.3: Company level -- descriptive statistics of correlations between accident-year direct loss ratio and loss development in other liability

	N	Mean	S.D.	Median	% of positive correlation
All	567	0.508*	0.328	0.592	90.65%
Small	141	0.464*	0.286	0.478	92.91%
Midsize	284	0.488*	0.345	0.576	88.73%
Large	142	0.593*	0.320	0.704	92.25%
Giant	29	0.633*	0.425	0.835	86.21%
Public Stock	53	0.572*	0.254	0.661	96.23%
Stock	421	0.547*	0.329	0.626	91.69%
Mutual	135	0.405*	0.290	0.422	88.89%
Risk Retention Group	19	0.425*	0.372	0.521	78.95%
Reciprocal	15	0.453*	0.368	0.559	86.67%
Alien	7	0.588*	0.257	0.599	100.00%
Mono-line	69	0.468*	0.350	0.603	82.61%
Multiple-line	517	0.505*	0.329	0.589	90.91%
Few-line	133	0.518*	0.343	0.615	87.22%
Mono-state	102	0.447*	0.314	0.503	91.18%
Multiple-state	491	0.514*	0.332	0.603	90.22%
Few-state	166	0.498*	0.302	0.550	93.98%

Table 3.4: Company level -- descriptive statistics of correlations between accident-year direct loss ratio and loss development in medical malpractice

	N	Mean	S.D.	Median	% of positive correlation
All	107	0.631*	0.268	0.743	95.33%
Small	26	0.574	0.286	0.650	92.31%
Midsize	54	0.617*	0.283	0.751	94.44%
Large	27	0.715*	0.197	0.781	100.00%
Giant	6	0.605*	0.251	0.626	100.00%
Public Stock	16	0.704*	0.147	0.763	100.00%
Stock	77	0.638*	0.264	0.743	96.10%
Mutual	25	0.699*	0.223	0.784	96.00%
Risk Retention Group	9	0.646*	0.181	0.624	100.00%
Reciprocal	12	0.522*	0.305	0.572	91.67%
Alien	1	0.763		0.763	100.00%
Mono-line	36	0.591*	0.318	0.745	91.67%
Multiple-line	94	0.635*	0.270	0.746	94.68%
Few-line	67	0.631*	0.299	0.765	92.54%
Mono-state	34	0.655	0.286	0.773	94.12%
Multiple-state	88	0.625*	0.267	0.718	94.32%
Few-state	51	0.646*	0.300	0.774	92.16%

Table 3.5: Company level -- descriptive statistics of correlations between accident-year direct loss ratio and loss development in private passenger auto liability

	N	Mean	S.D.	Median	% of positive correlation
All	577	0.417*	0.362	0.469	86.66%
Small	144	0.415*	0.350	0.446	87.50%
Midsize	288	0.401*	0.357	0.466	86.81%
Large	145	0.451*	0.382	0.552	85.52%
Giant	29	0.459*	0.398	0.523	79.31%
Public Stock	27	0.452*	0.298	0.593	88.89%
Stock	429	0.426*	0.376	0.494	86.01%
Mutual	139	0.409*	0.310	0.430	89.93%
Risk Retention Group	0				
Reciprocal	14	0.253*	0.397	0.338	71.43%
Alien	3	-0.030*	0.112	-0.094	33.33%
Mono-line	12	0.439*	0.260	0.412	91.67%
Multiple-line	565	0.414*	0.362	0.465	86.55%
Few-line	127	0.428*	0.379	0.517	85.04%
Mono-state	186	0.390*	0.384	0.446	83.87%
Multiple-state	449	0.432*	0.351	0.482	87.97%
Few-state	279	0.394*	0.384	0.463	84.23%

Table 3.6: Company level -- descriptive statistics of correlations between accident-year direct loss ratio and loss development in workers' compensation

	N	Mean	S.D.	Median	% of positive correlation
All	398	0.677*	0.245	0.748	98.24%
Small	99	0.645*	0.238	0.693	98.99%
Midsize	199	0.678*	0.268	0.761	96.98%
Large	100	0.707*	0.196	0.776	100.00%
Giant	20	0.723*	0.211	0.776	100.00%
Public Stock	30	0.684*	0.202	0.663	100.00%
Stock	292	0.697*	0.221	0.761	98.63%
Mutual	99	0.616*	0.298	0.689	96.97%
Risk Retention Group	0				
Reciprocal	12	0.662*	0.240	0.710	100.00%
Alien	5	0.759*	0.239	0.890	100.00%
Mono-line	65	0.590*	0.341	0.676	95.38%
Multiple-line	359	0.682*	0.246	0.757	98.05%
Few-line	99	0.632*	0.307	0.719	95.96%
Mono-state	100	0.648*	0.276	0.733	98.00%
Multiple-state	341	0.681*	0.237	0.746	98.24%
Few-state	144	0.663*	0.261	0.738	98.61%

* Significant at α=0.05

Table 3.7: Company level -- descriptive statistics of correlations between accident-year direct loss ratio and loss development in product liability

	N	Mean	S.D.	Median	% of positive correlation
All	170	0.475*	0.298	0.534	91.18%
Small	42	0.534*	0.213	0.567	100.00%
Midsize	85	0.471	0.292	0.509	89.41%
Large	43	0.426*	0.369	0.474	86.05%
Giant	9	0.683*	0.122	0.704	100.00%
Public Stock	14	0.509*	0.265	0.554	92.86%
Stock	141	0.475*	0.292	0.537	90.78%
Mutual	26	0.497*	0.305	0.503	96.15%
Risk Retention Group	2	0.170	0.675	0.170	0.00%
Reciprocal	1	0.537		0.537	100.00%
Alien	9	0.447*	0.240	0.389	100.00%
Mono-line	7	0.345*	0.399	0.489	85.71%
Multiple-line	162	0.480*	0.295	0.537	91.36%
Few-line	22	0.384	0.349	0.469	90.91%
Mono-state	6	0.312	0.207	0.332	100.00%
Multiple-state	160	0.479*	0.302	0.544	90.63%
Few-state	17	0.344	0.379	0.451	88.24%

Table 3.8: Company level -- descriptive statistics of correlations between accident-year direct loss ratio and loss development in homeowners

	N	Mean	S.D.	Median	% of positive correlation
All	568	0.233*	0.296	0.240	80.81%
Small	142	0.239*	0.293	0.199	83.80%
Midsize	284	0.236*	0.312	0.263	78.87%
Large	142	0.221*	0.266	0.226	81.69%
Giant	29	0.211	0.280	0.248	75.86%
Public Stock	29	0.219*	0.243	0.205	86.21%
Stock	331	0.241*	0.274	0.238	84.89%
Mutual	229	0.208*	0.326	0.239	74.67%
Risk Retention Group	0				
Reciprocal	12	0.309*	0.310	0.326	75.00%
Alien	3	-0.214	0.415	-0.109	33.33%
Mono-line	14	0.262*	0.238	0.253	92.86%
Multiple-line	551	0.228*	0.296	0.234	80.40%
Few-line	62	0.278*	0.261	0.269	87.10%
Mono-state	183	0.244*	0.293	0.253	81.42%
Multiple-state	423	0.222*	0.291	0.229	80.38%
Few-state	268	0.245*	0.295	0.258	80.97%

Table 4: Industry aggregate level -- correlations between accident-year net loss ratio and one-calendar-year loss development

	CMP	CAL	OL	MM	PPA	WC	PL	HO
All	-0.715	0.085	-0.666	0.247	0.448	-0.071	-0.186	0.148
Small	-0.755	0.008	-0.850	0.084	0.520	0.402	0.945	-0.102
Midsize	-0.300	0.012	-0.664	0.087	0.322	0.125	0.322	0.067
Large	-0.705	0.090	-0.678	0.205	0.481	-0.096	0.481	0.158
Giant	-0.779	0.128	-0.632	0.490	0.533	-0.249	-0.555	0.144

Note: 1 CY loss development = One calendar year loss development ÷ Earned Premium

Table 4.1: Company level -- descriptive statistics of correlations between accident-year net loss ratio and one-calendar-year loss development in commercial multiple peril

	N	Mean	S.D.	Median	% of positive correlation
All	492	-0.076*	0.329	-0.069	42.28%
Small	120	-0.079	0.288	-0.069	41.67%
Midsize	248	-0.063*	0.327	-0.062	42.74%
Large	124	-0.097*	0.371	-0.097	41.94%
Giant	26	-0.137	0.329	-0.173	38.46%
Public Stock	39	0.035	0.261	0.101	53.85%
Stock	345	-0.096*	0.337	-0.094	39.71%
Mutual	146	-0.025	0.305	-0.010	48.63%
Risk Retention Group	0				
Reciprocal	8	-0.095	0.365	-0.324	37.50%
Alien	8	0.073	0.288	0.016	62.50%
Mono-line	18	-0.072*	0.381	-0.114	27.78%
Multiple-line	477	-0.080*	0.328	-0.070	42.14%
Few-line	56	-0.090*	0.343	-0.122	33.93%
Mono-state	114	-0.063*	0.321	-0.089	42.11%
Multiple-state	408	-0.084*	0.327	-0.069	41.67%
Few-state	180	-0.053*	0.323	-0.068	43.89%

Table 4.2: Company level -- descriptive statistics of correlations between accident-year net loss ratio and one-calendar-year loss development in commercial auto liability

	N	Mean	S.D.	Median	% of positive correlation
All	366	0.029*	0.375	0.058	55.19%
Small	74	-0.073	0.377	-0.097	45.95%
Midsize	188	0.033	0.366	0.047	55.32%
Large	104	0.092*	0.380	0.112	61.54%
Giant	22	0.118*	0.384	0.177	68.18%
Public Stock	21	0.067*	0.463	0.090	61.90%
Stock	281	0.030*	0.383	0.066	56.23%
Mutual	88	0.021	0.339	0.020	51.14%
Risk Retention Group	1	-0.724		-0.724	0.00%
Reciprocal	5	-0.127	0.494	-0.299	40.00%
Alien	4	0.081	0.270	0.138	75.00%
Mono-line	9	0.039	0.436	0.043	66.67%
Multiple-line	358	0.033*	0.375	0.065	55.59%
Few-line	38	-0.001*	0.351	0.009	52.63%
Mono-state	55	-0.056	0.378	-0.069	40.00%
Multiple-state	328	0.039*	0.374	0.085	57.93%
Few-state	96	-0.050*	0.393	-0.073	41.67%

Table 4.3: Company level -- descriptive statistics of correlations between accident-year net loss ratio and one-calendar-year loss development in other liability

	N	Mean	S.D.	Median	% of positive correlation
All	553	-0.088*	0.381	-0.056	44.12%
Small	136	-0.085*	0.358	-0.029	47.06%
Midsize	276	-0.070*	0.395	-0.051	45.29%
Large	141	-0.124*	0.374	-0.089	39.01%
Giant	28	-0.298*	0.383	-0.417	25.00%
Public Stock	53	0.066*	0.316	0.050	60.38%
Stock	411	-0.114*	0.383	-0.094	39.42%
Mutual	132	-0.032	0.371	0.049	54.55%
Risk Retention Group	16	-0.005*	0.490	0.068	50.00%
Reciprocal	15	0.122*	0.238	0.088	80.00%
Alien	7	-0.083*	0.570	-0.117	28.57%
Mono-line	61	-0.041*	0.363	0.022	55.74%
Multiple-line	505	-0.090*	0.377	-0.062	42.97%
Few-line	123	-0.084*	0.401	-0.001	49.59%
Mono-state	97	-0.001	0.326	0.035	56.70%
Multiple-state	479	-0.101*	0.382	-0.067	42.80%
Few-state	158	-0.039*	0.351	0.015	51.90%

Table 4.4: Company level -- descriptive statistics of correlations between accident-year net loss ratio and one-calendar-year loss development in medical malpractice

	N	Mean	S.D.	Median	% of positive correlation
All	105	-0.005*	0.378	0.050	53.33%
Small	26	0.070	0.345	0.084	57.69%
Midsize	52	-0.064*	0.396	-0.058	44.23%
Large	27	0.036*	0.369	0.093	66.67%
Giant	6	-0.167*	0.608	-0.164	50.00%
Public Stock	16	0.044	0.384	0.071	56.25%
Stock	76	0.016*	0.372	0.055	55.26%
Mutual	23	0.066	0.401	0.161	65.22%
Risk Retention Group	9	-0.228	0.272	-0.320	11.11%
Reciprocal	12	-0.288*	0.278	-0.359	16.67%
Alien	1	0.248		0.248	100.00%
Mono-line	34	-0.142*	0.402	-0.114	35.29%
Multiple-line	94	0.023*	0.376	0.061	56.38%
Few-line	65	-0.069*	0.379	-0.047	46.15%
Mono-state	32	-0.004	0.387	0.024	50.00%
Multiple-state	87	0.021*	0.376	0.062	57.47%
Few-state	49	-0.046	0.375	-0.002	48.98%

Table 4.5: Company level -- descriptive statistics of correlations between accident-year net loss ratio and one-calendar-year loss development in private passenger auto liability

	N	Mean	S.D.	Median	% of positive correlation
All	567	0.130*	0.396	0.158	62.79%
Small	137	0.157*	0.375	0.214	64.23%
Midsize	286	0.105*	0.395	0.115	60.49%
Large	144	0.155*	0.418	0.223	65.97%
Giant	28	0.196*	0.395	0.274	71.43%
Public Stock	26	0.329*	0.379	0.313	84.62%
Stock	422	0.132*	0.409	0.163	62.56%
Mutual	138	0.154	0.335	0.184	64.49%
Risk Retention Group	0				
Reciprocal	14	-0.114*	0.498	-0.078	50.00%
Alien	3	-0.313*	0.621	-0.381	33.33%
Mono-line	11	0.212	0.279	0.230	72.73%
Multiple-line	556	0.130*	0.398	0.158	62.41%
Few-line	122	0.077*	0.391	0.094	58.20%
Mono-state	182	0.070	0.392	0.094	57.14%
Multiple-state	443	0.155*	0.396	0.188	65.24%
Few-state	269	0.079*	0.386	0.098	57.62%

Table 4.6: Company level -- descriptive statistics of correlations between accident-year net loss ratio and one-calendar-year loss development in workers' compensation

	N	Mean	S.D.	Median	% of positive correlation
All	379	0.034*	0.355	0.047	56.46%
Small	90	0.075*	0.340	0.107	61.11%
Midsize	191	0.038*	0.347	0.078	56.54%
Large	98	-0.010*	0.381	0.012	52.04%
Giant	19	-0.229*	0.340	-0.375	26.32%
Public Stock	29	0.254*	0.233	0.272	86.21%
Stock	285	0.034*	0.335	0.030	56.49%
Mutual	90	0.045	0.399	0.133	58.89%
Risk Retention Group	0				
Reciprocal	12	-0.019	0.468	-0.011	50.00%
Alien	5	-0.027	0.261	-0.070	40.00%
Mono-line	52	-0.099*	0.352	-0.129	36.54%
Multiple-line	349	0.055*	0.348	0.082	59.60%
Few-line	82	-0.084*	0.339	-0.103	34.15%
Mono-state	86	-0.034	0.358	-0.093	45.35%
Multiple-state	332	0.044*	0.350	0.055	57.83%
Few-state	125	-0.057	0.358	-0.073	43.20%

Table 4.7: Company level -- descriptive statistics of correlations between accident-year net loss ratio and one-calendar-year loss development in product liability

	N	Mean	S.D.	Median	% of positive correlation
All	105	-0.110*	0.408	-0.124	39.05%
Small	20	-0.083*	0.359	-0.124	40.00%
Midsize	53	-0.108*	0.379	-0.124	39.62%
Large	32	-0.129*	0.487	-0.145	37.50%
Giant	6	-0.335	0.375	-0.471	16.67%
Public Stock	7	-0.139	0.283	-0.152	14.29%
Stock	85	-0.117*	0.427	-0.133	36.47%
Mutual	20	-0.041	0.299	0.018	55.00%
Risk Retention Group	2	0.003	0.610	0.003	50.00%
Reciprocal	1	-0.603		-0.603	0.00%
Alien	7	-0.219	0.374	-0.196	14.29%
Mono-line	3	-0.220	0.023	-0.223	0.00%
Multiple-line	103	-0.117*	0.409	-0.133	37.86%
Few-line	11	-0.176	0.319	-0.196	27.27%
Mono-state	2	0.052	0.415	0.052	50.00%
Multiple-state	101	-0.120*	0.409	-0.133	37.62%
Few-state	7	-0.024	0.346	-0.039	42.86%

Table 4.8: Company level -- descriptive statistics of correlations between accident-year net loss ratio and one-calendar-year loss development in homeowners

	N	Mean	S.D.	Median	% of positive correlation
All	552	0.036*	0.331	0.041	53.80%
Small	131	0.011	0.313	0.028	51.91%
Midsize	280	0.035*	0.340	0.043	53.57%
Large	141	0.062	0.328	0.044	56.03%
Giant	28	0.108*	0.315	0.135	75.00%
Public Stock	29	-0.045	0.348	-0.002	48.28%
Stock	326	0.071*	0.339	0.089	58.59%
Mutual	220	-0.027*	0.322	-0.033	46.36%
Risk Retention Group	0				
Reciprocal	12	0.086	0.250	0.059	50.00%
Alien	3	-0.268	0.268	-0.299	33.33%
Mono-line	13	-0.070	0.425	-0.199	30.77%
Multiple-line	536	0.037*	0.329	0.045	54.48%
Few-line	59	0.043*	0.367	-0.013	49.15%
Mono-state	172	0.027*	0.324	0.058	54.65%
Multiple-state	418	0.043*	0.333	0.045	54.55%
Few-state	253	0.019*	0.317	0.008	50.99%

Table 5: Industry aggregate level -- correlations between change in accident-year net loss ratio and one-calendar-year loss development

	CMP	CAL	OL	MM	PPA	WC	PL	HO
All	-0.435	-0.783	-0.641	-0.725	-0.112	-0.799	-0.082	-0.110
Small	-0.735	-0.269	-0.708	-0.386	-0.083	-0.635	0.728	-0.473
Midsize	-0.485	-0.582	-0.619	-0.703	-0.504	-0.787	-0.504	-0.090
Large	-0.360	-0.796	-0.634	-0.621	-0.080	-0.769	-0.080	-0.096
Giant	-0.224	-0.224	-0.423	-0.335	0.017	-0.730	-0.135	-0.109

Table 5.1: Company level -- descriptive statistics of correlations between change in accident-year net loss ratio and one-calendar-year loss development in commercial multiple peril

	N	Mean	S.D.	Median	% of positive correlation
All	492	-0.148*	0.299	-0.144	28.05%
Small	120	-0.143*	0.290	-0.133	30.00%
Midsize	248	-0.170*	0.294	-0.171	25.40%
Large	124	-0.110	0.313	-0.131	31.45%
Giant	26	-0.099*	0.313	-0.131	30.77%
Public Stock	39	-0.193	0.287	-0.210	23.08%
Stock	345	-0.161*	0.296	-0.166	24.64%
Mutual	146	-0.127*	0.312	-0.126	33.56%
Risk Retention Group	0				
Reciprocal	8	-0.045	0.220	0.075	62.50%
Alien	8	0.008	0.358	0.027	50.00%
Mono-line	18	-0.164	0.427	-0.201	33.33%
Multiple-line	477	-0.147*	0.296	-0.145	27.88%
Few-line	56	-0.212	0.360	-0.221	23.21%
Mono-state	114	-0.112	0.310	-0.109	33.33%
Multiple-state	408	-0.155*	0.288	-0.152	26.72%
Few-state	180	-0.119	0.321	-0.122	31.67%

Table 5.2: Company level -- descriptive statistics of correlations between change in accident-year net loss ratio and one-calendar-year loss development in commercial auto liability

	N	Mean	S.D.	Median	% of positive correlation
All	366	-0.182*	0.345	-0.207	25.96%
Small	74	-0.186*	0.343	-0.182	27.03%
Midsize	188	-0.161*	0.344	-0.191	25.53%
Large	104	-0.215	0.350	-0.292	25.96%
Giant	22	-0.212*	0.386	-0.357	22.73%
Public Stock	21	-0.016	0.418	-0.126	42.86%
Stock	281	-0.181*	0.355	-0.214	25.27%
Mutual	88	-0.191*	0.314	-0.192	25.00%
Risk Retention Group	1	-0.309		-0.309	
Reciprocal	5	-0.170	0.268	0.004	60.00%
Alien	4	-0.115	0.326	-0.179	25.00%
Mono-line	9	0.009	0.459	-0.147	33.33%
Multiple-line	358	-0.185*	0.344	-0.207	26.26%
Few-line	38	-0.101	0.361	-0.149	31.58%
Mono-state	55	-0.176	0.302	-0.187	21.82%
Multiple-state	328	-0.181*	0.354	-0.211	26.52%
Few-state	96	-0.158	0.340	-0.172	25.00%

Table 5.3: Company level -- descriptive statistics of correlations between change in accident-year net loss ratio and one-calendar-year loss development in other liability

	N	Mean	S.D.	Median	% of positive correlation
All	553	-0.171*	0.335	-0.190	31.28%
Small	136	-0.151*	0.353	-0.159	36.76%
Midsize	276	-0.163*	0.336	-0.179	31.16%
Large	141	-0.206	0.314	-0.219	26.24%
Giant	28	-0.291*	0.279	-0.326	17.86%
Public Stock	53	-0.064	0.276	-0.089	35.85%
Stock	411	-0.195*	0.340	-0.215	29.44%
Mutual	132	-0.105*	0.312	-0.108	36.36%
Risk Retention Group	16	-0.064*	0.320	0.015	56.25%
Reciprocal	15	-0.126	0.317	-0.100	33.33%
Alien	7	0.098*	0.388	0.108	57.14%
Mono-line	61	-0.183*	0.288	-0.173	27.87%
Multiple-line	505	-0.171*	0.335	-0.189	31.29%
Few-line	123	-0.161*	0.345	-0.156	34.96%
Mono-state	97	-0.164*	0.335	-0.167	32.99%
Multiple-state	479	-0.184*	0.333	-0.200	29.44%
Few-state	158	-0.162*	0.329	-0.164	34.81%

Table 5.4: Company level -- descriptive statistics of correlations between change in accident-year net loss ratio and one-calendar-year loss development in medical malpractice

	N	Mean	S.D.	Median	% of positive correlation
All	105	-0.256*	0.310	-0.280	18.10%
Small	26	-0.141	0.297	-0.194	30.77%
Midsize	52	-0.281*	0.323	-0.305	13.46%
Large	27	-0.317*	0.276	-0.316	14.81%
Giant	6	-0.219*	0.450	-0.242	33.33%
Public Stock	16	-0.205*	0.398	-0.256	31.25%
Stock	76	-0.234*	0.326	-0.273	21.05%
Mutual	23	-0.280*	0.276	-0.334	17.39%
Risk Retention Group	9	-0.289*	0.289	-0.397	22.22%
Reciprocal	12	-0.367*	0.204	-0.340	0.00%
Alien	1	-0.397		-0.397	0.00%
Mono-line	34	-0.295*	0.270	-0.341	17.65%
Multiple-line	94	-0.252*	0.316	-0.279	19.15%
Few-line	65	-0.313*	0.271	-0.328	12.31%
Mono-state	32	-0.314*	0.241	-0.331	9.38%
Multiple-state	87	-0.232*	0.322	-0.272	21.84%
Few-state	49	-0.326*	0.250	-0.334	8.16%

Table 5.5: Company level -- descriptive statistics of correlations between change in accident-year net loss ratio and one-calendar-year loss development in private passenger auto liability

	N	Mean	S.D.	Median	% of positive correlation
All	567	-0.122*	0.314	-0.149	32.80%
Small	137	-0.114	0.299	-0.139	29.93%
Midsize	286	-0.136*	0.316	-0.175	31.12%
Large	144	-0.101*	0.324	-0.101	38.89%
Giant	28	-0.162	0.383	-0.170	28.57%
Public Stock	26	-0.011	0.269	0.008	57.69%
Stock	422	-0.114*	0.322	-0.153	34.60%
Mutual	138	-0.138*	0.289	-0.137	27.54%
Risk Retention Group	0				
Reciprocal	14	-0.197*	0.293	-0.188	28.57%
Alien	3	-0.486*	0.279	-0.448	0.00%
Mono-line	11	-0.149	0.242	-0.169	18.18%
Multiple-line	556	-0.122*	0.313	-0.149	32.91%
Few-line	122	-0.152*	0.307	-0.224	24.59%
Mono-state	182	-0.130*	0.324	-0.193	30.77%
Multiple-state	443	-0.117*	0.311	-0.140	33.86%
Few-state	269	-0.139*	0.319	-0.208	29.00%

Table 5.6: Company level -- descriptive statistics of correlations between change in accident-year net loss ratio and one-calendar-year loss development in workers' compensation

	N	Mean	S.D.	Median	% of positive correlation
All	401	-0.257*	0.336	-0.306	19.70%
Small	90	-0.202*	0.326	-0.181	27.78%
Midsize	191	-0.267*	0.325	-0.316	17.80%
Large	98	-0.270*	0.367	-0.309	16.33%
Giant	19	-0.358*	0.398	-0.306	5.26%
Public Stock	29	-0.196*	0.324	-0.314	27.59%
Stock	285	-0.221*	0.350	-0.260	23.16%
Mutual	90	-0.346*	0.282	-0.372	12.22%
Risk Retention Group	0				
Reciprocal	12	-0.290*	0.225	-0.265	0.00%
Alien	5	-0.254	0.399	-0.233	40.00%
Mono-line	52	-0.259*	0.381	-0.332	23.08%
Multiple-line	349	-0.243*	0.336	-0.286	20.63%
Few-line	82	-0.237*	0.368	-0.282	24.39%
Mono-state	86	-0.233*	0.331	-0.255	24.42%
Multiple-state	332	-0.250*	0.337	-0.301	19.58%
Few-state	125	-0.281*	0.332	-0.318	19.20%

Table 5.7: Company level -- descriptive statistics of correlations between change in accident-year net loss ratio and one-calendar-year loss development in product liability

	N	Mean	S.D.	Median	% of positive correlation
All	170	-0.064*	0.442	-0.090	38.82%
Small	42	-0.123	0.434	-0.103	38.10%
Midsize	85	-0.037*	0.430	-0.078	40.00%
Large	43	-0.058*	0.477	-0.090	37.21%
Giant	9	0.101	0.426	-0.069	44.44%
Public Stock	14	0.008*	0.598	-0.052	50.00%
Stock	141	-0.061*	0.446	-0.090	39.72%
Mutual	26	-0.083	0.366	-0.092	34.62%
Risk Retention Group	2	0.450	0.763	0.450	50.00%
Reciprocal	1	-0.764		-0.764	
Alien	9	0.080	0.573	-0.055	44.44%
Mono-line	7	0.244	0.487	0.045	57.14%
Multiple-line	162	-0.073*	0.444	-0.096	38.27%
Few-line	22	0.023	0.407	-0.067	40.91%
Mono-state	6	-0.128	0.594	-0.176	33.33%
Multiple-state	160	-0.057*	0.448	-0.089	39.38%
Few-state	17	-0.094	0.378	-0.090	29.41%

Table 5.8: Company level -- descriptive statistics of correlations between change in accident-year net loss ratio and one-calendar-year loss development in homeowners

	N	Mean	S.D.	Median	% of positive correlation
All	552	-0.098*	0.323	-0.082	41.30%
Small	131	-0.118*	0.301	-0.110	40.46%
Midsize	280	-0.089*	0.336	-0.048	43.57%
Large	141	-0.098	0.317	-0.117	37.59%
Giant	28	-0.102*	0.257	-0.039	39.29%
Public Stock	29	-0.114*	0.285	-0.134	37.93%
Stock	326	-0.082	0.334	-0.055	44.79%
Mutual	220	-0.118*	0.299	-0.107	35.91%
Risk Retention Group	0				
Reciprocal	12	-0.100*	0.409	-0.007	50.00%
Alien	3	-0.195	0.084	-0.148	0.00%
Mono-line	13	-0.255	0.409	-0.195	30.77%
Multiple-line	536	-0.096*	0.320	-0.076	41.42%
Few-line	59	-0.118	0.365	-0.082	47.46%
Mono-state	172	-0.121*	0.321	-0.110	37.79%
Multiple-state	418	-0.090*	0.323	-0.058	42.34%
Few-state	253	-0.115*	0.326	-0.110	39.13%

Table 6: Correlations of residual from vector autoregression analysis

	Model 1: L = Direct loss ratio R = Loss dvlp	Model 2: L = Net loss ratio R = CY loss dvlp	Model 3: L = Δ net loss ratio R = CY loss dvlp
CMP	0.025	-0.109*	-0.145*
CAL	0.171*	-0.099*	-0.087*
OL	0.095*	-0.189*	-0.183*
MM	0.320*	0.398*	0.389*
PPA	0.071*	-0.073*	-0.094*
WC	0.258*	-0.459*	0.193*
PL	0.032*	0.412*	0.341*
HO	0.061	0.060*	0.030*
Null Hypothesis	> 0	< 0	< 0

Table 7.1: Credibility estimation errors of pricing risk in commercial multiple peril

Choice of Credibility Complement	N	MSE	Median of Squared Error
All	467	0.096	0.007
Small	118	0.036	0.007
Midsize	233	0.162	0.007
Large	116	0.023	0.007
Giant	24	0.049	0.020
Public Stock	35	0.037	0.001
Stock	321	0.093	0.007
Mutual	144	0.104	0.007
Risk Retention Group	0		
Reciprocal	8	0.010	0.011
Alien	6	0.093	0.008
Mono-line	17	0.107	0.010
Multiple-line	455	0.096	0.007
Few-line	50	0.065	0.009
Mono-state	110	0.261	0.009
Multiple-state	388	0.072	0.007
Few-state	176	0.196	0.008

Table 7.2: Credibility estimation errors of pricing risk in commercial auto liability

Choice of Credibility Complement	N	MSE	Median of Squared Error
All	419	0.023	0.005
Small	102	0.037	0.007
Midsize	210	0.022	0.006
Large	107	0.010	0.002
Giant	22	0.008	0.002
Public Stock	24	0.006	0.002
Stock	321	0.019	0.005
Mutual	97	0.033	0.008
Risk Retention Group	2	0.320	0.320
Reciprocal	8	0.018	0.015
Alien	4	0.013	0.014
Mono-line	12	0.060	0.003
Multiple-line	405	0.021	0.004
Few-line	54	0.028	0.005
Mono-state	73	0.051	0.011
Multiple-state	363	0.017	0.004
Few-state	131	0.038	0.010

Table 7.3: Credibility estimation errors of pricing risk in other liability

Choice of Credibility Complement	N	MSE	Median of Squared Error
All	542	0.074	0.012
Small	134	0.073	0.014
Midsize	272	0.072	0.010
Large	136	0.078	0.012
Giant	29	0.124	0.013
Public Stock	51	0.090	0.017
Stock	402	0.075	0.010
Mutual	129	0.065	0.014
Risk Retention Group	19	0.064	0.016
Reciprocal	15	0.091	0.016
Alien	6	0.062	0.045
Mono-line	68	0.171	0.016
Multiple-line	494	0.070	0.011
Few-line	128	0.138	0.016
Mono-state	102	0.093	0.018
Multiple-state	468	0.070	0.010
Few-state	162	0.088	0.015

Table 7.4: Credibility estimation errors of pricing risk in medical malpractice

Choice of Credibility Complement	N	MSE	Median of Squared Error
All	96	0.070	0.020
Small	17	0.038	0.026
Midsize	52	0.046	0.020
Large	27	0.135	0.016
Giant	6	0.349	0.112
Public Stock	12	0.035	0.023
Stock	66	0.082	0.015
Mutual	24	0.039	0.017
Risk Retention Group	9	0.040	0.037
Reciprocal	12	0.043	0.019
Alien	0		
Mono-line	35	0.055	0.024
Multiple-line	85	0.074	0.022
Few-line	65	0.054	0.024
Mono-state	32	0.068	0.026
Multiple-state	78	0.069	0.017
Few-state	48	0.059	0.023

Table 7.5: Credibility estimation errors of pricing risk in private passenger auto liability

Choice of Credibility Complement	N	MSE	Median of Squared Error
All	542	0.016	0.002
Small	132	0.027	0.002
Midsize	271	0.015	0.002
Large	139	0.009	0.001
Giant	29	0.006	0.001
Public Stock	26	0.005	0.000
Stock	398	0.016	0.002
Mutual	135	0.019	0.002
Risk Retention Group	0		
Reciprocal	14	0.006	0.002
Alien	2	0.016	0.016
Mono-line	10	0.002	0.001
Multiple-line	532	0.016	0.002
Few-line	113	0.012	0.001
Mono-state	177	0.022	0.001
Multiple-state	420	0.013	0.002
Few-state	264	0.019	0.002

Table 7.6: Credibility estimation errors of pricing risk in workers' compensation

Choice of Credibility Complement	N	MSE	Median of Squared Error
All	374	0.025	0.010
Small	87	0.040	0.013
Midsize	192	0.024	0.012
Large	95	0.012	0.006
Giant	18	0.006	0.003
Public Stock	30	0.016	0.005
Stock	274	0.021	0.011
Mutual	93	0.034	0.012
Risk Retention Group	0		
Reciprocal	12	0.032	0.035
Alien	5	0.003	0.000
Mono-line	62	0.025	0.008
Multiple-line	337	0.025	0.010
Few-line	93	0.028	0.011
Mono-state	96	0.040	0.011
Multiple-state	321	0.022	0.010
Few-state	138	0.033	0.010

Table 7.7: Credibility estimation errors of pricing risk in product liability

Choice of Credibility Complement	N	MSE	Median of Squared Error
All	129	0.094	0.029
Small	25	0.074	0.023
Midsize	68	0.116	0.032
Large	36	0.066	0.039
Giant	6	0.034	0.016
Public Stock	10	0.031	0.012
Stock	106	0.091	0.035
Mutual	22	0.082	0.025
Risk Retention Group	0		
Reciprocal	0		
Alien	7	0.029	0.014
Mono-line	4	0.197	0.123
Multiple-line	124	0.086	0.029
Few-line	15	0.138	0.039
Mono-state	3	0.039	0.039
Multiple-state	122	0.091	0.029
Few-state	11	0.161	0.039

Table 7.8: Credibility estimation errors of pricing risk in homeowners

Choice of Credibility Complement	N	MSE	Median of Squared Error
All	540	0.225	0.033
Small	131	0.114	0.020
Midsize	270	0.263	0.031
Large	139	0.256	0.038
Giant	29	0.046	0.038
Public Stock	27	0.212	0.033
Stock	304	0.299	0.032
Mutual	224	0.128	0.028
Risk Retention Group	0		
Reciprocal	12	0.101	0.115
Alien	3	0.411	0.187
Mono-line	12	0.049	0.037
Multiple-line	525	0.230	0.033
Few-line	55	0.719	0.038
Mono-state	175	0.251	0.034
Multiple-state	398	0.224	0.033
Few-state	256	0.202	0.033

Table 8.1: Credibility estimation errors of reserving risk in commercial multiple peril

Choice of Credibility Complement	N	MSE	Median of Squared Error
All	479	15.169	0.024
Small	119	58.824	0.037
Midsize	240	1.056	0.024
Large	120	0.104	0.015
Giant	26	0.153	0.014
Public Stock	35	0.021	0.013
Stock	330	21.976	0.019
Mutual	147	0.085	0.026
Risk Retention Group	0		
Reciprocal	8	0.076	0.004
Alien	6	1163.852	0.150
Mono-line	17	0.110	0.043
Multiple-line	466	15.588	0.023
Few-line	54	0.224	0.029
Mono-state	111	0.132	0.033
Multiple-state	398	18.229	0.020
Few-state	178	0.148	0.037

Table 8.2: Credibility estimation errors of reserving risk in commercial auto liability

Choice of Credibility Complement	N	MSE	Median of Squared Error
All	430	1.173	0.192
Small	103	1.710	0.201
Midsize	218	1.137	0.158
Large	109	0.739	0.165
Giant	23	0.270	0.060
Public Stock	24	0.958	0.357
Stock	331	1.153	0.196
Mutual	97	0.848	0.169
Risk Retention Group	2	9.274	9.274
Reciprocal	9	3.403	1.513
Alien	4	12.084	0.382
Mono-line	13	1.434	0.196
Multiple-line	416	1.136	0.170
Few-line	55	1.708	0.353
Mono-state	77	1.299	0.197
Multiple-state	371	1.114	0.165
Few-state	139	1.420	0.224

Table 8.3: Credibility estimation errors of reserving risk in other liability

Choice of Credibility Complement	N	MSE	Median of Squared Error
All	546	252.584	1.283
Small	135	915.886	2.668
Midsize	272	19.957	1.540
Large	139	63.594	0.551
Giant	29	144.227	0.262
Public Stock	51	4.645	1.089
Stock	406	329.437	1.027
Mutual	130	30.492	2.779
Risk Retention Group	18	52.373	9.834
Reciprocal	15	15.500	3.299
Alien	6	20.902	3.406
Mono-line	69	34.979	3.808
Multiple-line	498	273.872	1.072
Few-line	129	33.905	2.296
Mono-state	102	91.963	5.510
Multiple-state	472	274.994	1.067
Few-state	163	760.989	4.031

Table 8.4: Credibility estimation errors of reserving risk in medical malpractice

Choice of Credibility Complement	N	MSE	Median of Squared Error
All	98	0.117	0.010
Small	18	0.200	0.010
Midsize	53	0.126	0.010
Large	27	0.044	0.005
Giant	6	0.024	0.003
Public Stock	12	0.012	0.002
Stock	68	0.155	0.010
Mutual	24	0.011	0.007
Risk Retention Group	9	0.013	0.011
Reciprocal	12	0.066	0.010
Alien	0		
Mono-line	36	0.046	0.008
Multiple-line	85	0.110	0.009
Few-line	67	0.066	0.006
Mono-state	33	0.085	0.005
Multiple-state	79	0.124	0.010
Few-state	50	0.082	0.006

Table 8.5: Credibility estimation errors of reserving risk in private passenger auto liability

Choice of Credibility Complement	N	MSE	Median of Squared Error
All	547	0.192	0.008
Small	133	0.660	0.015
Midsize	275	0.044	0.009
Large	139	0.036	0.005
Giant	29	0.018	0.004
Public Stock	25	0.045	0.001
Stock	403	0.246	0.007
Mutual	135	0.036	0.009
Risk Retention Group	0		
Reciprocal	14	0.066	0.003
Alien	3	0.594	0.177
Mono-line	11	0.069	0.010
Multiple-line	535	0.194	0.008
Few-line	116	0.160	0.011
Mono-state	178	0.122	0.011
Multiple-state	422	0.200	0.006
Few-state	268	0.354	0.010

Table 8.6: Credibility estimation errors of reserving risk in workers' compensation

Choice of Credibility Complement	N	MSE	Median of Squared Error
All	383	0.067	0.006
Small	92	0.086	0.012
Midsize	193	0.054	0.005
Large	98	0.072	0.005
Giant	20	0.036	0.004
Public Stock	30	0.026	0.004
Stock	281	0.077	0.005
Mutual	95	0.035	0.008
Risk Retention Group	0		
Reciprocal	12	0.039	0.008
Alien	5	0.010	0.010
Mono-line	63	0.046	0.007
Multiple-line	345	0.067	0.005
Few-line	95	0.107	0.006
Mono-state	96	0.052	0.010
Multiple-state	329	0.066	0.005
Few-state	140	0.085	0.007

Table 8.7: Credibility estimation errors of reserving risk in product liability

Choice of Credibility Complement	N	MSE	Median of Squared Error
All	120	254.036	0.851
Small	23	33.607	0.835
Midsize	64	30.007	1.006
Large	33	842.151	0.688
Giant	6	0.569	0.355
Public Stock	10	3.676	0.840
Stock	99	307.525	0.956
Mutual	21	1.865	0.351
Risk Retention Group	0		
Reciprocal	0		
Alien	7	4.476	2.450
Mono-line	3	2.107	2.451
Multiple-line	118	23.850	0.850
Few-line	12	2307.505	1.459
Mono-state	3	1.647	1.513
Multiple-state	115	24.429	0.841
Few-state	8	3464.146	1.245

Table 8.8: Credibility estimation errors of reserving risk in homeowners

Choice of Credibility Complement	N	MSE	Median of Squared Error
All	547	0.074	0.003
Small	135	0.107	0.004
Midsize	273	0.052	0.003
Large	139	0.086	0.002
Giant	29	0.019	0.002
Public Stock	27	0.108	0.001
Stock	311	0.118	0.003
Mutual	225	0.015	0.002
Risk Retention Group	0		
Reciprocal	12	0.006	0.002
Alien	3	1.161	0.031
Mono-line	13	0.712	0.021
Multiple-line	530	0.058	0.003
Few-line	59	0.183	0.014
Mono-state	176	0.075	0.003
Multiple-state	403	0.094	0.003
Few-state	261	0.060	0.002

Table 9.1: Mean and Median of Chain-ladder loss estimation errors of accident-year 1996

Commercial Multiple Peril					
AY 1996	All	Small	Midsize	Large	Giant
Mean	-0.279	-0.095	-0.037	-0.853	-4.169
Median	0.007	0.006	0.006	0.018	0.067

Commercial Auto Liability					
AY 1996	All	Small	Midsize	Large	Giant
Mean	-0.012	-0.085	-0.035	0.084	0.184
Median	0.019	-0.031	0.015	0.097	0.131

Other Liability					
AY 1996	All	Small	Midsize	Large	Giant
Mean	-0.130	-0.377	-0.112	0.043	0.100
Median	0.039	0.039	0.019	0.073	0.038

Medical Malpractice					
AY 1996	All	Small	Midsize	Large	Giant
Mean	0.320	0.323	0.257	0.423	0.535
Median	0.271	0.808	0.176	0.339	0.475

Private Passenger Auto Liability					
AY 1996	All	Small	Midsize	Large	Giant
Mean	-0.058	-0.134	-0.083	0.045	0.026
Median	-0.012	-0.018	-0.027	0.020	0.012

Workers' Compensation					
AY 1996	All	Small	Midsize	Large	Giant
Mean	-0.089	-0.145	-0.114	-0.009	0.048
Median	-0.076	-0.101	-0.095	-0.031	0.007

Product Liability					
AY 1996	All	Small	Midsize	Large	Giant
Mean	-0.288	-1.397	0.082	0.050	0.253
Median	-0.029	-0.190	0.007	0.071	0.224

Homeowners					
AY 1996	All	Small	Midsize	Large	Giant
Mean	-0.035	-0.195	-0.059	0.019	0.070
Median	0.011	-0.002	0.012	0.019	0.013

Table 9.2: Mean and Median of Chain-ladder loss estimation errors of accident-year 1999

Commercial Multiple Peril					
AY 1999	All	Small	Midsize	Large	Giant
Mean	-0.004	-0.142	0.006	0.104	0.132
Median	0.051	0.012	0.048	0.101	0.120
Commercial Auto Liability					
AY 1999	All	Small	Midsize	Large	Giant
Mean	0.086	0.029	0.051	0.201	0.222
Median	0.104	0.090	0.079	0.135	0.176
Other Liability					
AY 1999	All	Small	Midsize	Large	Giant
Mean	0.237	0.136	0.023	0.760	0.424
Median	0.143	0.140	0.105	0.248	0.501
Medical Malpractice					
AY 1999	All	Small	Midsize	Large	Giant
Mean	0.647	1.040	0.449	0.674	0.651
Median	0.297	0.227	0.263	0.400	0.561
Private Passenger Auto Liability					
AY 1999	All	Small	Midsize	Large	Giant
Mean	0.007	-0.035	-0.032	0.115	0.090
Median	0.047	0.034	0.038	0.081	0.081
Workers' Compensation					
AY 1999	All	Small	Midsize	Large	Giant
Mean	0.137	0.110	0.155	0.123	-0.009
Median	0.190	0.135	0.190	0.215	0.295
Product Liability					
AY 1999	All	Small	Midsize	Large	Giant
Mean	0.384	0.147	0.578	0.216	0.602
Median	0.144	0.145	0.122	0.202	0.583
Homeowners					
AY 1999	All	Small	Midsize	Large	Giant
Mean	-0.098	-0.080	-0.026	-0.299	-0.055
Median	0.011	-0.009	0.011	0.017	0.020

Table 9.3: Mean and Median of Chain-ladder loss estimation errors of accident-year 2001

Commercial Multiple Peril					
AY 2001	All	Small	Midsize	Large	Giant
Mean	0.037	-0.040	0.099	-0.853	-4.169
Median	0.023	0.012	0.023	0.039	0.040

Commercial Auto Liability					
AY 2001	All	Small	Midsize	Large	Giant
Mean	0.044	-0.002	0.082	0.012	0.046
Median	0.038	0.042	0.038	0.021	0.059

Other Liability					
AY 2001	All	Small	Midsize	Large	Giant
Mean	-0.172	-0.100	0.203	-0.953	0.252
Median	0.126	0.092	0.122	0.154	0.259

Medical Malpractice					
AY 2001	All	Small	Midsize	Large	Giant
Mean	0.420	0.210	0.532	0.378	0.461
Median	0.316	0.175	0.291	0.423	0.566

Private Passenger Auto Liability					
AY 2001	All	Small	Midsize	Large	Giant
Mean	0.002	0.029	-0.045	0.068	0.059
Median	0.053	0.041	0.054	0.064	0.061

Workers' Compensation					
AY 2001	All	Small	Midsize	Large	Giant
Mean	0.091	0.072	0.120	0.052	-0.119
Median	0.111	0.118	0.111	0.108	0.066

Product Liability					
AY 2001	All	Small	Midsize	Large	Giant
Mean	0.193	-0.555	-0.034	1.245	0.234
Median	0.051	-0.031	0.069	0.179	0.133

Homeowners					
AY 2001	All	Small	Midsize	Large	Giant
Mean	0.012	0.004	0.019	0.005	0.030
Median	0.028	0.017	0.033	0.037	0.060

Table 10: Mean and Median of the diversification Benefit on Incurred Losses under our definition and BCAR definition

Number of line	Diversification Benefit		BCAR definition	
	Mean	Median	Mean	Median
2	0.077	0.013	0.026	0.000
3	0.191	0.172	0.069	0.018
4	0.267	0.265	0.089	0.081
5	0.309	0.277	0.124	0.157
6	0.343	0.320	0.173	0.202
7	0.318	0.283	0.202	0.222
8	0.288	0.230	0.216	0.220

Table 10.1: Mean and Median of the diversification Benefit on Incurred Losses under our definition and BCAR definition of midsize insurers

Number of line	Average of Diversification Benefit		Median of Diversification Benefit	
	Our Definition	BCAR	Our Definition	BCAR
2	0.066	0.013	0.000	0.000
3	0.207	0.034	0.184	0.000
4	0.318	0.041	0.318	0.000
5	0.325	0.069	0.288	0.000
6	0.313	0.069	0.288	0.000
7	0.231	0.000	0.231	0.000
Overall	0.078	0.022	0.000	0.000

Table 10.2: Mean and Median of the diversification Benefit on Incurred Losses under our definition and BCAR definition of large insurers

Number of line	Average of Diversification Benefit		Median of Diversification Benefit	
	Our Definition	BCAR	Our Definition	BCAR
2	0.068	0.050	0.017	0.010
3	0.175	0.104	0.152	0.119
4	0.237	0.121	0.197	0.151
5	0.302	0.224	0.277	0.171
6	0.354	0.180	0.337	0.202
7	0.300	0.204	0.283	0.222
8	0.288	0.216	0.230	0.220
Overall	0.200	0.118	0.173	0.140

Table 10.3: Mean and Median of the diversification Benefit on Incurred Losses under our definition and BCAR definition of giant insurers

Number of line	Average of Diversification Benefit		Median of Diversification Benefit	
	Our Definition	BCAR	Our Definition	BCAR
2	0.070	0.077	0.011	0.033
3	0.170	0.070	0.136	0.048
4	0.155	0.117	0.072	0.112
5	0.217	0.130	0.168	0.149
6	0.275	0.201	0.267	0.202
7	0.230	0.210	0.236	0.223
8	0.299	0.216	0.240	0.217
Overall	0.214	0.161	0.195	0.199

Table 11: Mean and Median of the diversification Benefit on the loss reserve adequacy

Number of line	Average	Median
2	0.129	0.100
3	0.197	0.166
4	0.260	0.212
5	0.225	0.190
6	0.243	0.220
7	0.300	0.268
8	0.336	0.343

Table 12: Mean and Median of the diversification Benefit on the loss reserve adequacy by size of insurers

Number of line	Midsize		Large		Giant	
	Average	Median	Average	Median	Average	Median
2	0.143	0.113	0.103	0.060	0.129	0.033
3	0.228	0.195	0.170	0.140	0.153	0.103
4	0.303	0.251	0.236	0.195	0.103	0.064
5	0.241	0.239	0.217	0.184	0.225	0.176
6	0.243	0.215	0.242	0.229	0.246	0.220
7	0.545	0.545	0.297	0.268	0.307	0.275
8			0.336	0.343	0.332	0.334
Overall	0.092	0.000	0.178	0.138	0.236	0.211

Figure 1.1a: Industry Aggregate -- plots of accident-year loss ratio and accident-year loss development in workers' compensation

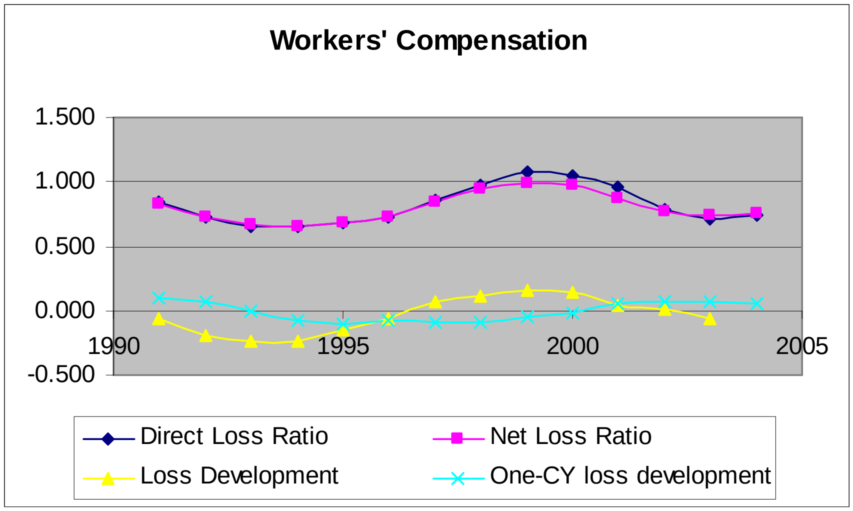

Figure 1.1b: Industry Aggregate -- plots of change in accident-year loss ratio and one-calendar year loss development in workers' compensation

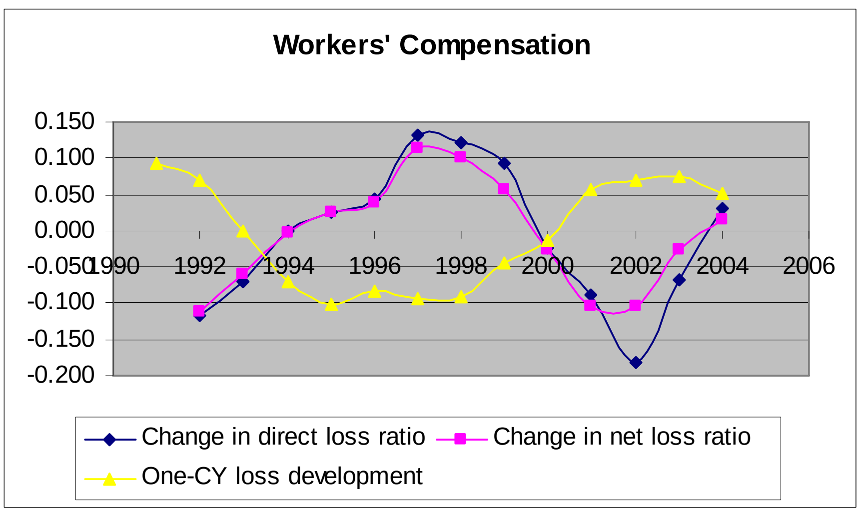

Figure 1.2a: Industry Aggregate -- plots of accident-year loss ratio and accident-year loss development in other liability

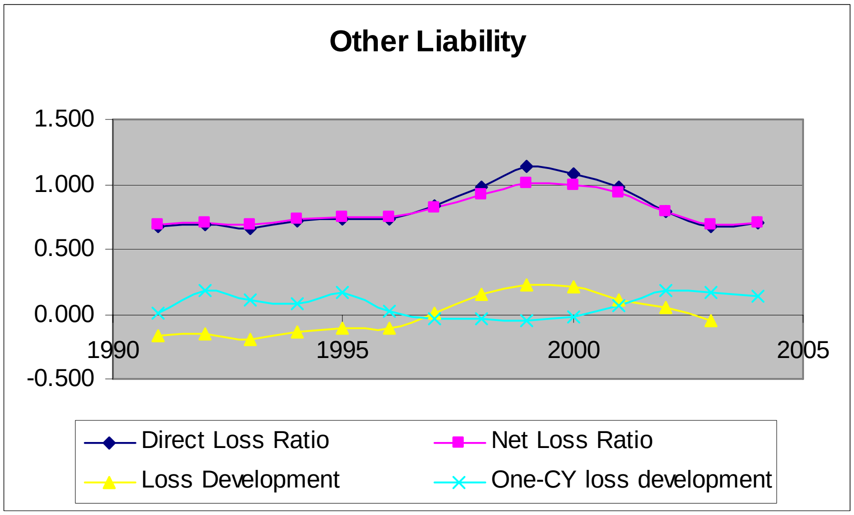

Figure 1.2b: Industry Aggregate -- plots of change in accident-year loss ratio and one-calendar year loss development in other liability

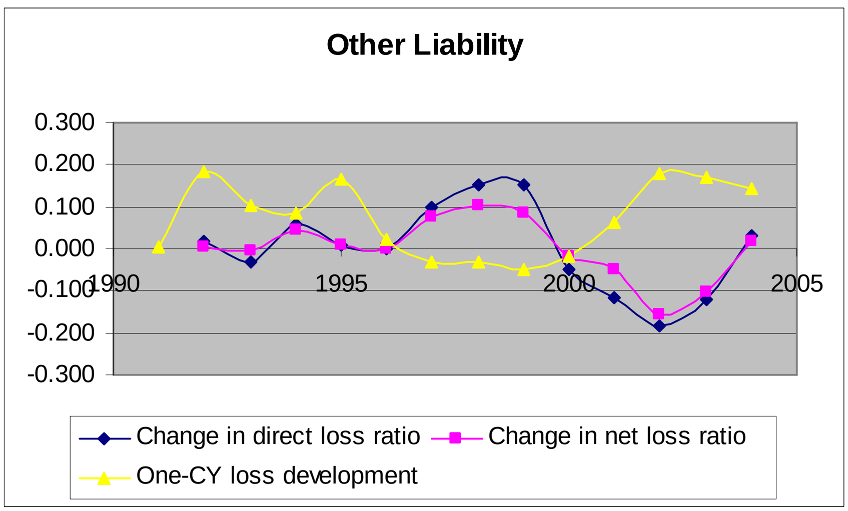

Figure 1.3a: Industry Aggregate -- plots of accident-year loss ratio and accident-year loss development in private passenger auto liability

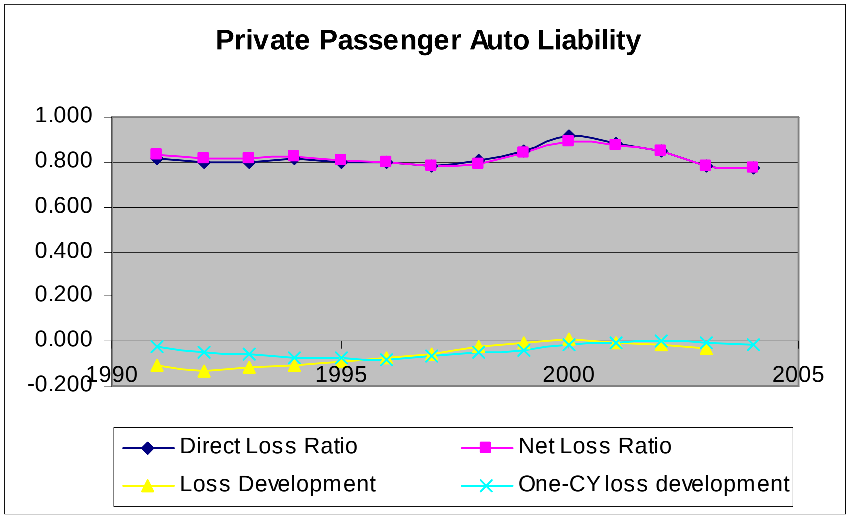

Figure 1.3b: Industry Aggregate -- plots of change in accident-year loss ratio and one-calendar year loss development in private passenger auto liability

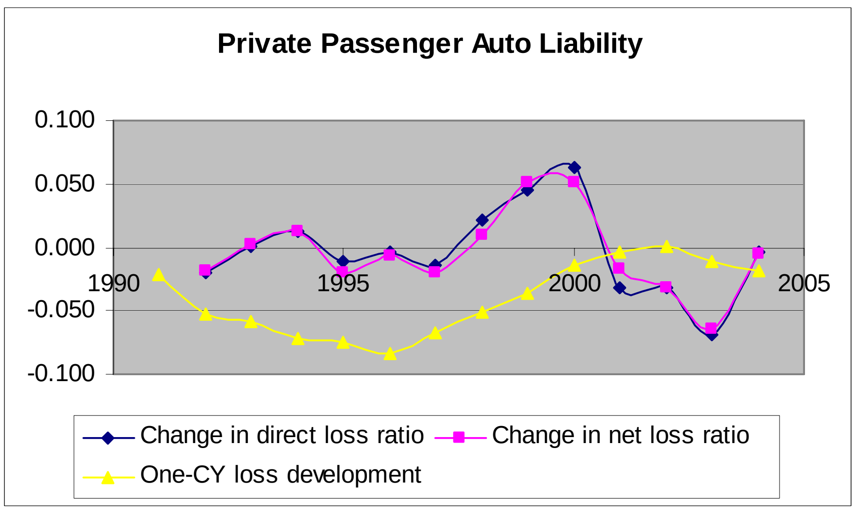

Figure 1.4a: Industry Aggregate -- plots of accident-year loss ratio and accident-year loss development in commercial auto liability

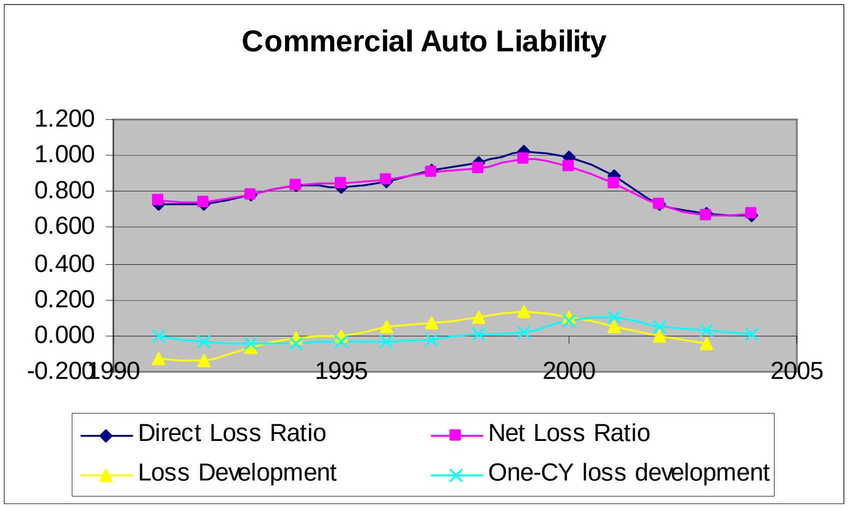

Figure 1.4b: Industry Aggregate -- plots of change in accident-year loss ratio and one-calendar year loss development in commercial auto liability

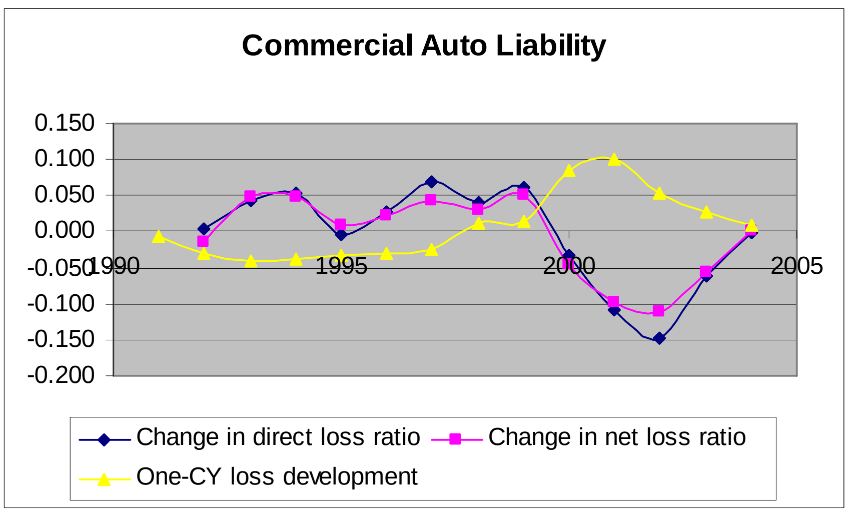

Figure 1.5a: Industry Aggregate -- plots of accident-year loss ratio and accident-year loss development in commercial multiple peril

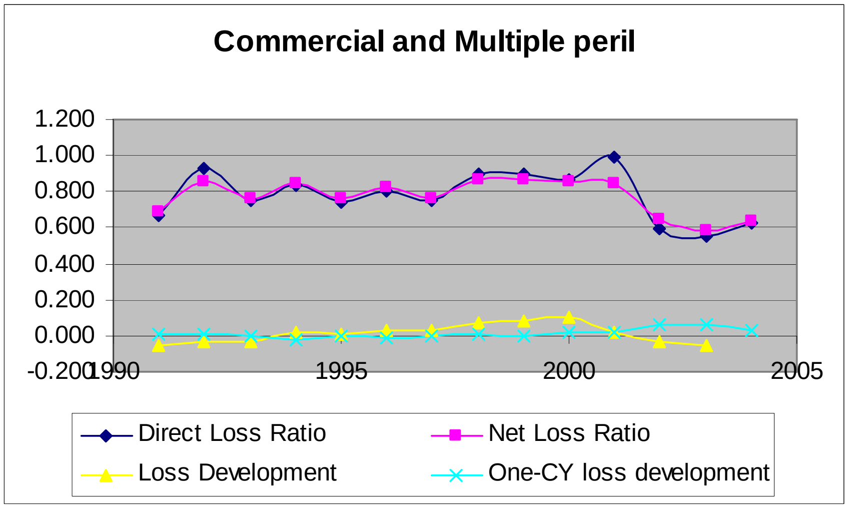

Figure 1.5b: Industry Aggregate -- plots of change in accident-year loss ratio and one-calendar year loss development in commercial multiple peril

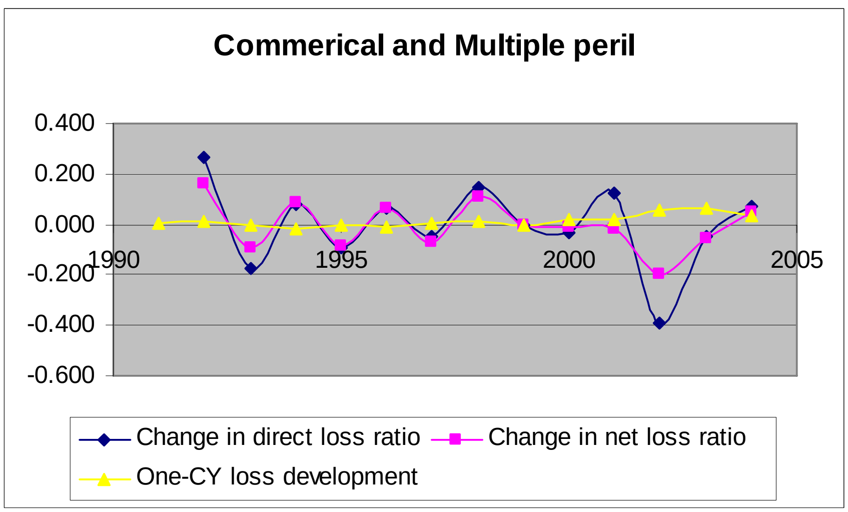

Figure 1.6a: Industry Aggregate -- plots of accident-year loss ratio and accident-year loss development in medical malpractice

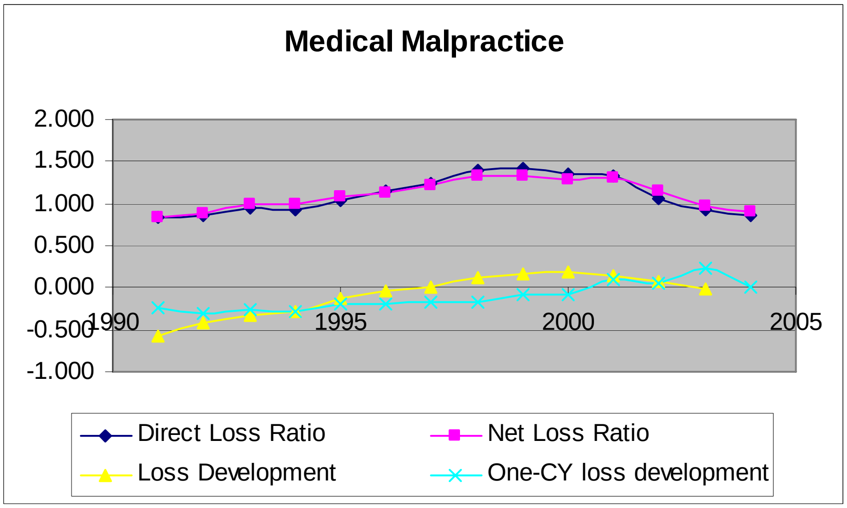

Figure 1.6b: Industry Aggregate -- plots of change in accident-year loss ratio and one-calendar year loss development in medical malpractice

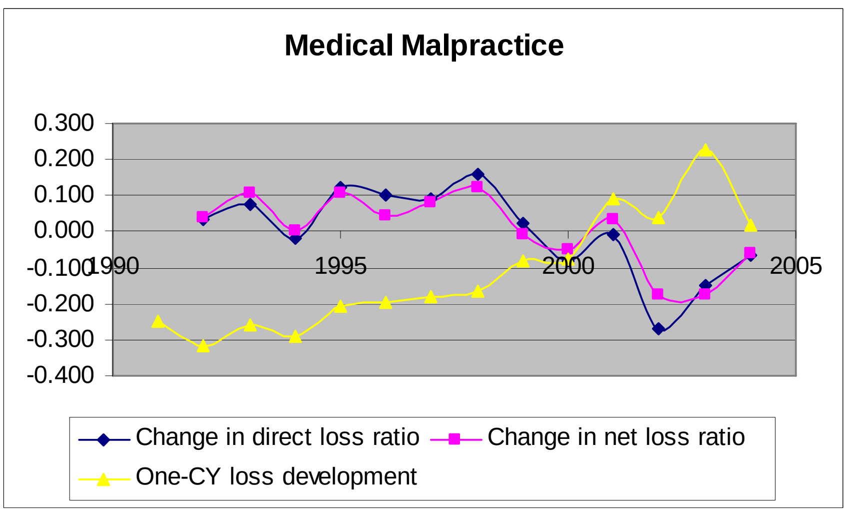

Figure 1.7a: Industry Aggregate -- plots of accident-year loss ratio and accident-year loss development in product liability

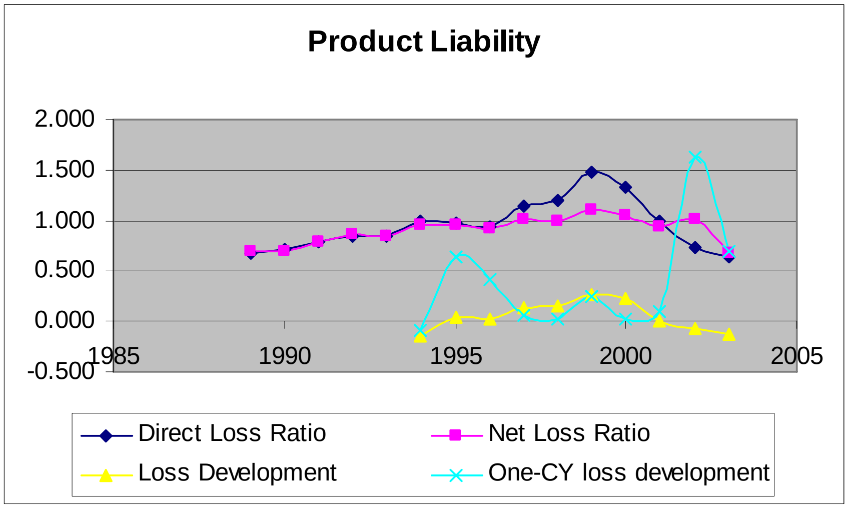

Figure 1.7b: Industry Aggregate -- plots of change in accident-year loss ratio and one-calendar year loss development in product liability

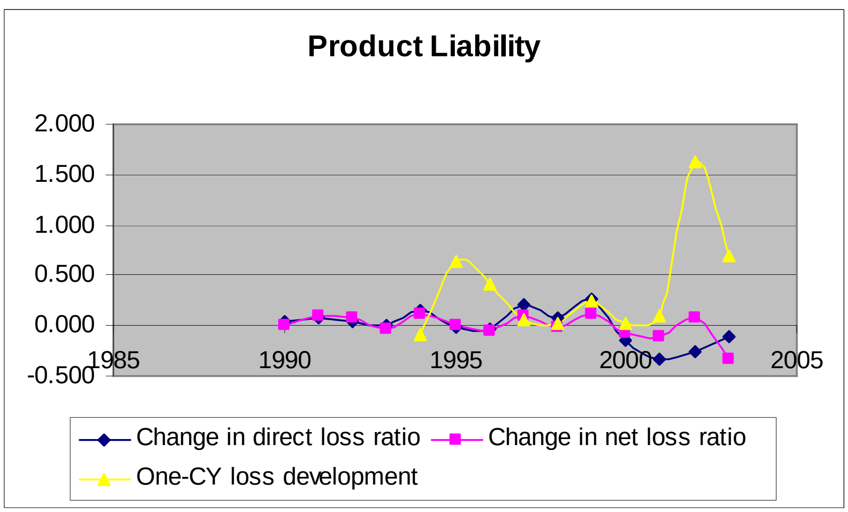

Figure 1.8a: Industry Aggregate -- plots of accident-year loss ratio and accident-year loss development in homeowners

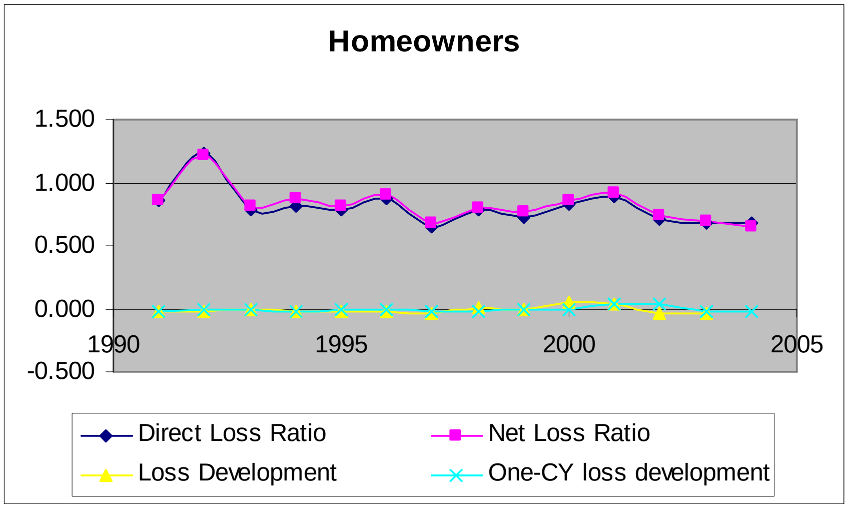

Figure 1.8b: Industry Aggregate -- plots of change in accident-year loss ratio and one-calendar year loss development in homeowners

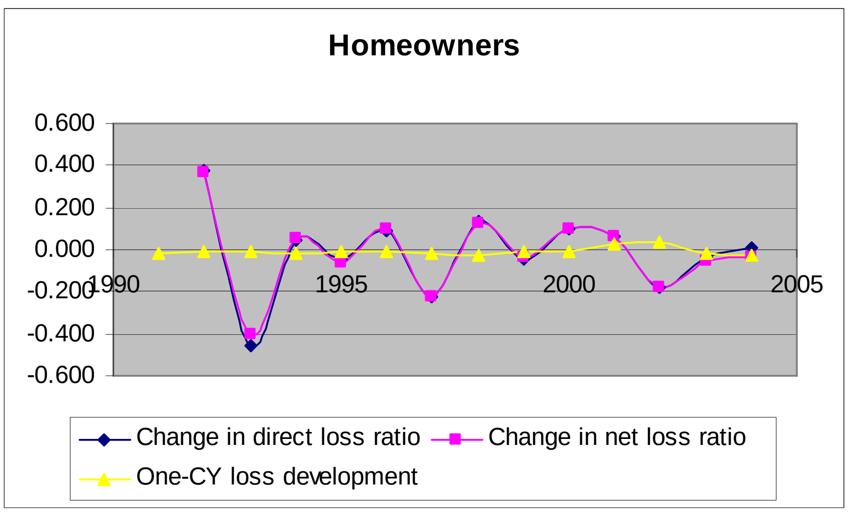

Figure 2.1: Industry Aggregate -- comparison between actuarial reserve estimates and actual incurred losses for accident year 1996

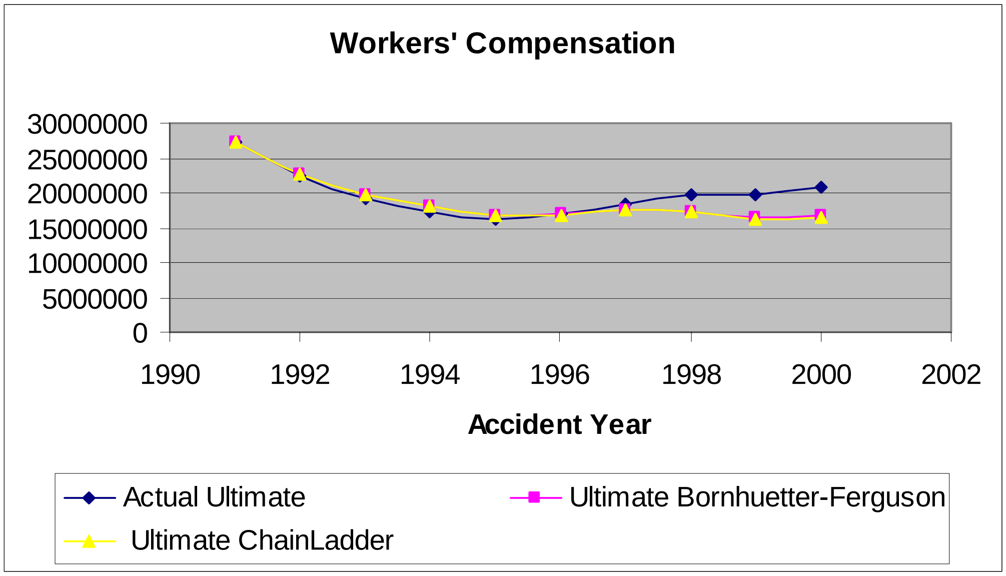

Figure 2.2: Industry Aggregate -- comparison between actuarial reserve estimates and actual incurred losses for accident year 1999

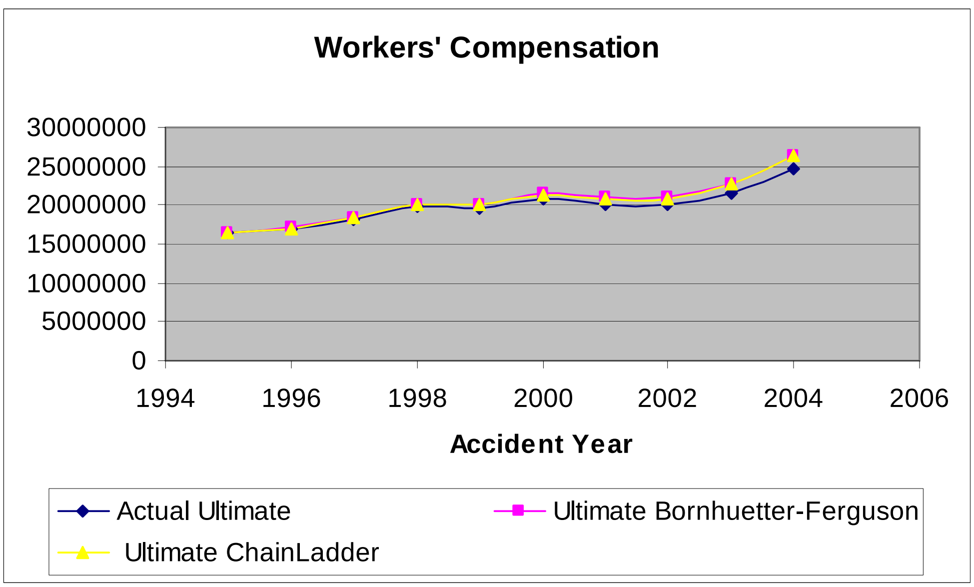

Figure 3: Diversification Benefit on the insured losses (sorted by number of lines)

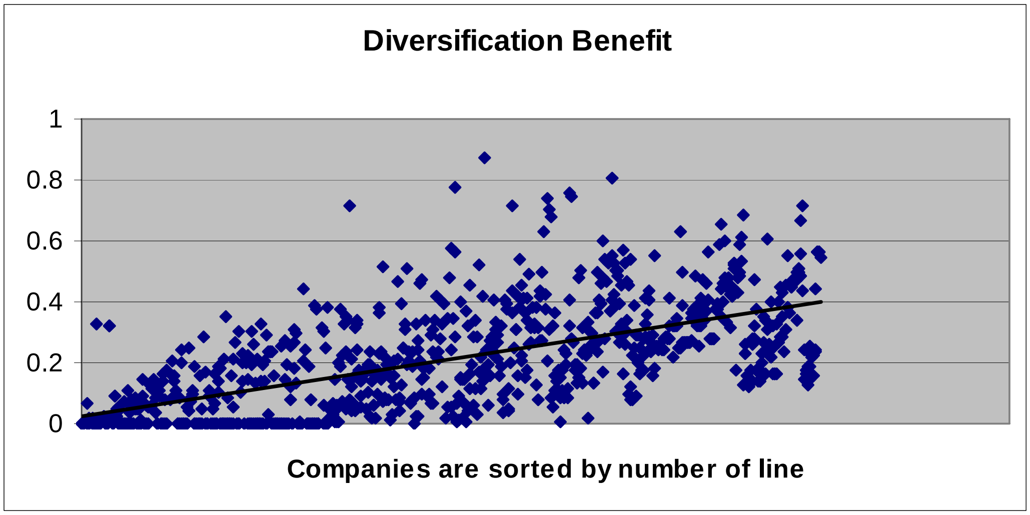

Figure 4: Diversification Benefit on the insured losses under BCAR definition (sorted by number of lines)

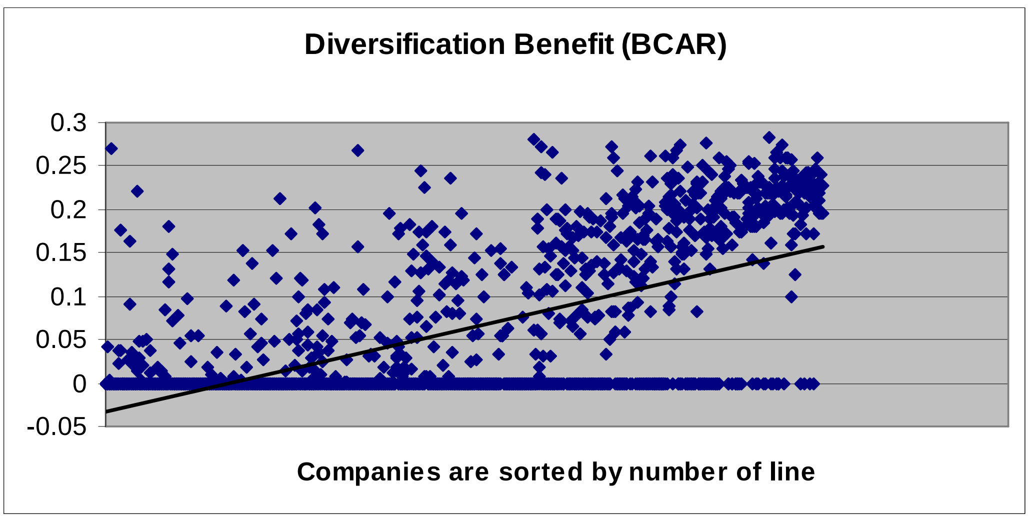

Figure 5: Diversification Benefit on the losses development (sorted by number of lines)