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A re-examination of the U.S. insurance market's capacity to pay catastrophe losses[1]

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Abstract

Cummins, Doherty, and Lo (2002) present a theoretical and empirical analysis of the capacity of the property liability insurance industry in the U.S. to finance catastrophic losses. In their theoretical analysis, they show that a sufficient condition for capacity maximization is for all insurers to hold a net of reinsurance underwriting portfolio that is perfectly correlated with aggregate industry losses. Estimating capacity from insurers' financial statement data, they find that the U.S. insurance industry could adequately fund a $100 billion event in 1997. As a matter of comparison, Hurricane Katrina in 2005 cost the insurance industry $40 to $65 billion (2005 dollars). Our main objective is to update the study of Cummins et al. (2002) with new data available up to the end of 2020. We verify how the insurance market's capacity has evolved over recent years. We show that the U.S. insurance industry's capacity to pay catastrophe losses is higher in 2020 than it was in 1997. Insurers could pay 98% of a $200 billion loss in 2020, compared to 81% in 1997.

Keywords: Catastrophe loss, U.S. insurance industry, industry capacity, reinsurance, climate finance, climate risk, weather risk.

JEL numbers: G22, G52, Q54, Q57, D81, D53.

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Introduction

Cummins, Doherty, and Lo (2002) present a theoretical and empirical analysis of the capacity of the property and liability insurance industry in the U.S. to finance catastrophic losses. In their theoretical analysis, they show that a sufficient condition for capacity maximization is for all insurers to hold a net of reinsurance underwriting portfolio that is perfectly correlated with aggregate industry losses. Estimating capacity from insurers' financial statement data, they find that the U.S. insurance industry could adequately fund a $100 billion event in 1997. As a matter of comparison, Hurricane Katrina in 2005 cost the insurance industry $40 to $65 billion (2005 dollars), representing about 10% of total insurers' capital (Swiss Re, 2020).[1] The hurricane's total cost was about $125 billion, indicating how low insurance coverage is for these losses. Moreover, at least 1,800 fatalities were reported with Katrina. Such events may also cause numerous insolvencies and severely destabilize the insurance markets. According to the authors, the prospect of a mega-catastrophe also brings with it a real threat of insurer failures and unpaid claims. Surviving insurers may have to reduce future sales of property liability insurance, causing price increases and availability problems. Some insurers may even leave the market (Born and Klimaszewski-Blettner, 2013).

Our main objective is to update this important study published in 2002 with new data that is available up to the end of 2020. We want to verify how the insurance market's capacity has changed over recent years. The article of Cummins et al. (2002) covers all catastrophe losses managed by insurers. In recent years, new risks have become important, including cybersecurity, terrorism, liability (social inflation), pandemic, and climate risks. Although our data includes all these new risks, our discussion will focus on the emergence of climate risk, because of its relative importance, at least in the United States, where the data come from.

The rest of the paper is organized as follows. The next section presents recent developments on climate finance in the finance literature, while Section 2 discusses the importance of climate risk for the property and liability insurance industry. Section 3 reviews the main contributions in the insurance literature on catastrophic risk, including the contribution of Cummins et al. (2002).

[1].The $40 billion estimate does not include the flood cost to the National Flood Insurance Program while the $65 billion does.

Section 4 presents the theoretical model proposed for estimating the insurance industry's capacity to compensate catastrophic losses, and Section 5 presents our empirical estimates. We show that the U.S. insurance industry's capacity to pay catastrophe losses is higher in 2020 than it was in 1997. Insurers could pay 98% of a $200 billion loss in 2020, compared to 81% in 1997. We also document in detail the data and methodology used to carry out our research. Section 6 analyzes different causes of the relative capital increases over the study period. Section 7 concludes and proposes different avenues for future research. The online appendix contains additional data used for the robustness of the estimations.

1. Climate finance

Climate finance is defined by the United Nations Framework Convention on Climate Change (UNFCCC) as "local, national, or transnational financing—drawn from public, private, and alternative sources of financing—that seeks to support mitigation and adaptation actions that will address climate change" (reported in Hong et al., 2020). Such financing is intended to change the world economy and build resilience to climate change.

Many financial sectors, ranging from banking and insurance to real estate, are directly impacted by the risks from tornadoes, wildfires, and floods. This raises difficult questions, which were recently discussed in a special issue of the *Review of Financial Studies,* edited by Hong et al. (2020): How can financial market prices mitigate risks from global warming? How can capital markets raise sufficient financing? How should the distribution of damages from catastrophic events be managed? Despite this type of reflection, however, no studies in finance or insurance have looked at the causal effects of climate change on the insurance industry, though various correlations have been documented.

Here is a typical question in the recent financial literature: Given the potential impact of climate change, are asset prices or firm values sensitive to exposure to climate risks? Three recent contributions address this important question on market efficiency in pricing these risks. Murfin and Spiegel (2020) use information on recent residential real estate transactions to determine whether house prices reflect the differential risks of sea levels rising. They obtain limited house pricing effects with their methodology. By contrast, Baldauf et al. (2020) use transaction data to

measure the effect on house prices of flooding projections for individual homes and local measures of *beliefs* about climate change. They demonstrate that houses projected to be underwater are sold at a discount. Issler et al. (2020) study wildfires in California between 2000 and 2018 with a comprehensive data set that merges information on fires, mortgages, property characteristics, and weather zones. Using the difference-in-differences approach, the authors find a significant causal increase in mortgage delinquency and foreclosure after fire events.

A crucial input in the analysis of climate change risks is the causal impact of climate events on economic activity, which is known as the distribution of damages. It raises an important question about the modeling and sharing of extreme weather risks.[2] Do extreme weather risks, such as the impact of Hurricane Sandy in 2012 or of the 2018 California wildfires, have long-run causal effects on insurance markets? These distributions of damages depend on location-based decisions by households and firms, and technological (self-protection and self-insurance) decisions on preventing and mitigating disaster damages. They also depend on market insurance coverage (including moral-hazard and adverse-selection effects). By modeling these loss distributions suitably, the insurance industry should be able to play a critical role in facilitating risk-sharing and extending insurance coverage for extreme weather events. These research results should also improve public authorities' role in improving social resilience against climate risk (GAO, 2007; Postal, 2008; Hallegate, 2012, 2014).

2. Climate risk and the insurance industry

The potential causal impacts of new climate patterns on damages from catastrophe risks must be better estimated by the insurance industry and public authorities. These potential impacts may have been underestimated in risk management for many years. Here are some worldwide statistics obtained from the Munich Re reports of 2014, 2019, and 2021:[3]

[2] Many references consider weather and climate risks to be synonymous. In this study, we use the NASA (2005) definitions of climate and weather. The main difference between the two definitions is time. Weather is atmospheric conditions over a short period of time, while climate covers a long period of time. Climate change is related to changes in average daily weather. We thank a referee for pointing out this importance of the difference.

[3] See also the Sigma (Swiss Re) reports (2009, 2015, 2022) and the AON reports.

- Climate change was rated number one among the top-ten risks facing the insurance sector (Ernst and Young, 2008).

- 88% of all natural catastrophic events worldwide were weather-related between 1980 and 2014 (83% in 2019); and 40% of the overall losses from 1980 to 2014 occurred in Asia (43% in 2019).

- 64% of insured losses were incurred in North America (incl. Central America and the Caribbean) during this period (35% in 2019), which represents about 30% of overall losses in this region, which is similar to the proportion of overall losses in the rest of the world. Insurance penetration is low, even in developed countries.

- Natural disasters accounted for $280 billion in economic losses around the world in 2021 ($120 billion insured). The record year was 2011, with losses of $355 billion. About 10,000 deaths were attributed to natural disasters in 2021. In the U.S., $145 billion in losses were observed in 2021, with $85 billion insured.

The average economic losses related to natural catastrophes over the last 10 years are $187 billion ($340 billion in 2017 only). The year 2019 was below the last 10-year average, with a total loss of $150 billion, while, in 2020, the total loss was $210 billion (Munich Re). However, event frequency has increased. In 2019, there were 33 events of over $1 billion in total losses each. Nine events cost the insurance industry over $1 billion that year, and all of them were weather risk events (cyclones, storms with flooding, and tornadoes). Moreover, in April 2020, severe weather events in the U.S. cost insurers billions of dollars, with 14 tornadoes occurring that month— the fifth-highest monthly number on record since 1950, according to the Aon *Global Catastrophe Recap* (2021).

In 2021, 22 weather disasters of $1 billion or more were observed in the United States, for a total of $145 billion in damages. Since 1980, 310 events of $1 billion or more have accounted for $2.5 trillion, with an average of $148 billion per year over 2016–2021 (www.climate.gov/disasters2020).

Modeling firm AIR Worldwide now estimates that the losses to insured industry from Hurricane Ida in 2021 will be between $20 billion and $30 billion (possibly 35 billion with 67 billion

economic losses, according to Munich Re). The estimate includes wind and storm surge losses of $17 to $25 billion, and private-market insured losses from inland flooding of $2.5 billion to $5 billion. These estimates include insured physical damage to residential and commercial property and autos, but do not include National Flood Insurance Program losses. Most insured losses are in the homeowner and commercial property lines of business in Louisiana and in the Northeast, including New York and New Jersey. With an estimated $30 billion in insurance losses, Ida is in the range of Hurricanes Andrew, Maria, Irma, and Harvey. State officials have reported more than 80 deaths due to Ida.[4] Irma caused economic losses of 67 billion in 2007, with 30 billion to the insurance industry, according to Swiss Re.

The escalating frequency and severity of extreme weather-related events highlights a dangerous link between insurance risk and climate change, even though less than 40% of the total losses are covered. According to a Price Waterhouse Coopers survey conducted in 2017, natural catastrophes are now the second-highest risk that insurance companies face, while global warming is ranked fourth. A more recent survey by Deloitte (2020) found that most U.S. state insurance regulators expect all types of climate change risks to insurance companies to increase over the medium to long term. More than half the state regulators surveyed also indicated that climate change is likely to have a high impact on coverage availability and underwriting assumptions. U.S. state regulators and lawmakers are concerned about the insurance industry's response to climate change. Two traditional mechanisms are usually used to reduce financial fragility: insurers can increase premiums in the states or counties most affected, or increase reinsurance coverage (Grenier, 2019). However, these two alternatives may not be sufficient to ensure the long-run stability of the industry.

We can summarize the major issues related to climate risks as follows (Dionne, 2015):

- For many years the population has concentrated in high-risk areas. This increases insurers' exposure to major catastrophes related to natural hazards (low frequency and high severity) (Grislain-Letrémy and Villeneuve, 2019; Goussebaïle, 2016).
- The demand for insurance coverage for weather risk among individuals is low (Arrow, 1982; Dixon et al., 2006; Robinson and Botzen, 2022) because the potential insured underestimate

[4] According the recent estimates, Hurricane Ian could cost insurers more than 25 billion.

the risk and are biased in estimating their potential net loss due to anticipated government intervention. For example, although flood insurance has been subsidized by the U.S. federal government since 1968, demand remains low (Kousky, 2018; Landry and Jahan-Parvar, 2011; Wagner, 2022).

- On the supply side, a survey funded by the National Association of Insurance Commissioners (NAIC) mentions that insurers reported increased engagement in climate-related activities over recent years, while they were not really prepared to cover weather risk in 2014 (NAIC, 2020). See also the study of Gatzert and Reichel (2022).
- Natural hazard losses fluctuate radically. This is a long-run issue. Insurers cannot restrict themselves to recent loss history to calculate premiums and capital. They must compute, for example, the estimated maximum loss (EML) or the expected shortfall (or CVaR), obtained from data over many years, and perform appropriate dynamic stress testing.
- Prevention is a long-run investment activity, yet insurance coverage is annual. This creates a problem of the insurance industry having a long-run commitment to potential investors, leading to underinvestment in prevention.
- Insurers can spread their liabilities through reinsurance. In principle, the effects of catastrophes can be diversified through the worldwide reinsurance market. Historically, the capacity available to reinsurers was limited, but it has increased significantly since Hurricane Andrew (Cummins and Weiss, 2000, 2004).[5] Even though insurers and investors around the world are now more convinced that lack of action to combat climate change is becoming costly in the long run, no real structural changes have been made. The current actions intended to reduce the social costs of climate risk may not be the most efficient. In fact, some reinsurers have limited their exposure to such losses, and rating agencies seem to encourage such a move to maintain the current ratings of (re)insurance companies. Some reinsurers are more positive but argue that this new environment is very complex and that the reinsurance industry is learning how to improve its participation in these new environmental and economic realities (Kessler, 2015; Drexler and Rosen, 2022).

[5] On reinsurance, see Bernard (2013), Cummins et al. (1997, 2001, 2021), Chen et al. (2020), Desjardins et al. (2022), and Powell and Sommer (2017).

- Insurance-linked securities (ILS) are becoming important in the reinsurance market for catastrophe losses related to climate risk and earthquakes (Lakdawalla and Zanjani, 2012; Götze and Gürtler, 2022; Carayannopoulos et al., 2022). They are not very prevalent in the insurance market. ILSs can lower the cost of risk transfer in harsh (re)insurance market conditions. They help maintain (re)insurance capacity and offer multi-year protection. They limit credit risk by collateralizing losses. For investors, ILSs are noncorrelated with other market, liquidity, and credit risks, so they represent an important diversification asset. Moreover, the capitalization of financial markets is much higher than that of (re)insurance markets. ILS penetration can reduce the price of insurance in the long run and increase the demand for insurance. However, the participation of financial markets in weather risk after a major disaster is a long-run commitment issue: will they stay in such a risky market after suffering a very big loss?
- Securitization and market consolidation are other market mechanisms that can improve market capacity (Cummins and Weiss, 2009; Cummins and Trainar, 2009; Boubakri et al., 2008; Berger et al., 2000; Akhigbe and Madura, 2001; Cummins et al., 1999b; Cummins and Xie, 2006; Weiss and Chung, 2004; Weston et al., 2004).

Although estimates vary, it seems clear that a substantial gap exists between the existing reinsurance coverage and a catastrophic loss exceeding the $15–20 billion range. For example, Swiss Re (1998) estimated that reinsurers would pay 39% of a once-in-a-century catastrophe loss in the U.S., such as a $56 billion hurricane or a $65 billion earthquake in California. The Swiss Re study estimated there was a worldwide total of $53 billion in catastrophe excess-of-loss reinsurance in place in 1997. Cummins and Weiss (2000) showed that the reinsurance industry could have funded $60 billion of a $100 billion above-expected loss.

According to 2014 data, the total reinsurance capital is about $575 billion ($660 billion, 2021), including $62 billion in ILS capacity other than traditional reinsurance. Alternative capacity (ILS) includes collateral reinsurance, sidecar, industry loss warranty (ILW), and CAT bonds. As complements to reinsurance, they represented about 10% of the global catastrophe reinsurance capital in 2014 (250-year occurrence). We may think there is sufficient capacity because annual

average long-run catastrophe losses are around $150 billion, but there have been significant recent exceptions: in 2011 ($375 billion), 2017 ($340 billion), and 2021 ($343 billion) (AON, 2022)[6].

3. Academic research on catastrophic risk and the insurance market[7]

The early academic contributions agree that natural catastrophes affect the insurance market and that this effect was increasing over time because of population migration to coastal areas and the increased valuation of properties in these high-risk areas. Shelor et al. (1992) and Lamb (1995) obtain contradictory results, however, on what effect natural disasters have on the insurance industry's profitability. Berz (1997) was one of the first to hypothesize the impact of the greenhouse effect on the insurance industry, concluding that the future of the insurance industry could be jeopardized if insurers do not adapt to the new climate conditions. He did not document the effect with data, however. Cummins et al. (2002) show that unanticipated natural events may create liquidity problems for insurance companies in the short run, and solvency problems in the long run.

In their theoretical analysis, Cummins et al. (2002) propose a sufficient condition for capacity maximization: all insurers must hold a net of reinsurance underwriting portfolio that is perfectly correlated with aggregate industry losses. Estimating capacity using insurers' financial statement data for 1983 to 1997, they find that the industry could adequately fund a $100 billion insured loss event, whereas U.S. insurers' equity capital was approximately equal to $370 billion (see Table 2). To provide an idea of the potential losses at that time, Hurricane Andrew (1992) represented a loss of $19 billion, while the Northridge earthquake (1994) cost more than $13 billion. Moreover, scenarios constructed in 1997 by catastrophe modeling firms suggest the feasibility of a $76 billion hurricane in Florida, a $21 billion hurricane in the Northeast, a $72 billion California earthquake, and a $101 billion New Madrid earthquake.

Cummins et al. (2002) also show that the industry would be able to pay very high percentages of industry losses. For example, for a $20 billion catastrophe, they estimate that the industry could

[6] Exact statistics vary from one source to another, but the ranges are comparable.

[7] See the special issue on climate risk and insurance published in 2022 by *The Geneva Papers on Risk and Insurance – Issues and Practice* for additional topics not discussed here, including applications in France (Charpentier et al., 2022) and in Japan (Shao, 2022).

have paid at least 98.6% of the insured loss in 1997. The estimated percentages paid for larger losses declines, however. For example, according to their parameter estimates, the industry would have been able to pay, in 1997, about 96.4% of a $100 billion loss based on the group sample, and 92.8% based on the company sample. For a $200 billion loss, the industry could have paid 84.0% based on the group sample, and 78.6% based on the company sample.

Moreover, such events may cause numerous insolvencies and severely destabilize insurance markets. For instance, a $100 billion catastrophe is projected to cause 30 insolvencies for the group sample and 136 insolvencies for the company sample. The number of insolvencies at 1991 capitalization levels would have been 108 groups and 216 companies. This means that many insurers were not ready for such potential catastrophes and may have become good targets for acquisition. Their data are taken from the regulatory annual statements filed by insurers with the NAIC.

They are able to estimate insurers' responses for different scenarios, such as a Category-5 hurricane hitting Miami or a magnitude-8.2 earthquake in San Francisco. Their measure of capacity is based on how much equity or surplus is available, and how effectively the riskiness of insurance losses is spread though the insurance market. The traditional instrument for spreading risk among insurers is reinsurance. By buying and selling options on their portfolios with each other or with specialized reinsurers, insurers can change the risk characteristics of their portfolios.

However, there is a very large number of potential catastrophe scenarios, and the data requirements to conduct such an analysis for the entire insurance industry are enormous. Moreover, while such scenarios are valuable for planning at the firm level, they do not provide enough detail to assess the risk-spreading efficiency of the total insurance market. Rather, they seek a more general response function. Cummins et al. (2002) estimate the distributional characteristics of catastrophic losses and allocate such losses to individual insurers, using correlations between losses and financial data. The result is an option-like function that defines the estimated deliverable insurance payments conditional on any given size of aggregate catastrophic loss and that projects the number of insurer insolvencies that would result.

When capital and surplus levels are high, most insurers plan to use capital to make deals. According to a recent survey by KPMG (2018), about three-quarters of insurers expect to conduct

an acquisition, and two-thirds plan to seek partnership opportunities over the next three years. Eighty-one percent say they will conclude up to three acquisitions or partnerships in the same period. As a top priority, 37% hope to transform their business model, 24% want to transform their operating model, and 10% are looking to acquire new innovative capabilities and emerging technologies through their acquisitions. The key goal is to obtain a deal that generates a contribution over the next 10 to 15 years.

A.M. Best manages a database of more than 1,000 property- and casualty-insurance companies that have failed in the United States since 1969 (Kelly, 2015). The most common reasons for insolvency are deficient loss reserves, inadequate pricing, and rapid growth. Natural disasters are the seventh-most common reason, accounting for 7% of insolvencies. The Financial Services Authority (FSA) in the United Kingdom has assessed 270 property and casualty insurance companies that failed in the European Union since 1969. Many factors are identified as primary or contributing factors, with natural hazards found to have made a small contribution. Yet, in both these studies, the data cover a very long period, and it is not clear that they are representative of the last 20 years.

Regarding other pertinent contributions, Anderson and Gardiner (2008) provide a guideline to help insurance companies manage climate risk. Availability and affordability are the major problems. Insurers alone cannot effectively reduce the social cost of climate risk. More coordination with governments is necessary for prevention. Another failure is the lack of a link between sustainability and disaster resilience. Insurers must be more active in unifying green and disaster-resilience efforts in sectors such as construction, agriculture, and land use (see also Hallegate, 2014).

Mills (2009) analyzes different mechanisms that aim to improve the insurance industry's capacity to cover insurable losses: new coverage products; a better understanding of climate change; and the financing of activities intended to reduce climate risk, including government participation when necessary. Gollier (2005) discusses in detail the necessary role played by government to reduce the fragility of the insurance industry when extreme events occur. He argues that the government should act as a reinsurer to reduce the number of bankruptcies. The government should be the reinsurer of last resort, as in the Terrorism Risk Insurance Act (TRIA) or the Price-Anderson

Act. Others favor stronger private risk-management activities for natural disasters[8] (see Mills, 2009; Michel-Kerjan, 2012, 2015; Kunreuther, 2018; Aerts et al., 2014; Collier et al., 2021; and Klein and Wang, 2009). Jametti and Ungern-Sternberg (2010) do not consider the observed risk selection between the private and public sectors as optimal in cases where the private sector keeps acceptable or lower losses, and the public sector is limited to extreme losses. Louass and Picard (2021) propose a new characterization of optimal insurance coverage for low-probability catastrophic risks. They derive determinants of insurability and socially optimal risk sharing for events that have a low probability and high severity and that affect many individuals.

Born and Viscusi (2006) take a different approach to analyzing the effect of natural catastrophes on the insurance industry. Using data from the Swiss Re Sigma Reports for the 1984–2004 period, they show that small insurers are more likely to be affected, because they are less diversified. Finally, Born and Klimaszewski-Blettner (2013) affirm that some insurers tend to reduce their activities when they are subject to severe regulations or when they receive unanticipated large claims. Such reduction-of-activities behavior is less frequent for large insurers that are better diversified.

4. Theory

4.1 Borch theorem

Borch (1962) shows, in an expected utility (EU) framework, that value-maximizing risk-sharing transactions would leave all risk-averse insurers holding losses net of reinsurance portfolios defined solely on the market's aggregate loss, and, under certain conditions, that insurance would be priced solely on the first two moments of the aggregate portfolio. Each insurer holds a proportion of the aggregate loss, and all insurers' portfolios become perfectly correlated. This result is obtained assuming that transactions between insurers are costless.

Let L_i be the random loss or claim payment of insurer *i,* and Q_i its capital. $F_i(L_i)$ is the distribution of L_i. The utility function of insurer *i* can be written as

[8] On risk management in the insurance industry, see Cummins et al. (2009), Bauer et al. (2013), and Hoyt and Liebenberg (2011).

$$U_i(L_i) = U(Q_i, F_i(L_i)) = \int_0^{\infty} U_i(Q_i - L_i)\, dF_i(L_i). \quad (1)$$

Risk-averse insurers can increase their welfare by writing a treaty or collective agreement (L^P) with the *N* insurers in the industry:

$$L^P = (L_1^P(L_1 \ldots L_N) \ldots L_N^P(L_1 \ldots L_N)) \quad (2)$$

where $L_i^P(L_1 \ldots L_N) = L_i^P(\bar{L})$ is the sum of the payments insurer *i* must pay according to the treaty. The treaty must satisfy the resource allocation condition under full liability:

$$\sum_{i=1}^{N} L_i^P(\bar{L}) = \sum_{i=1}^{N} L_i.$$

A treaty is Pareto optimal (Borch, 1962) if there exist *N* nonnegative constants $k_1 \ldots k_N$, such that

$$k_i U_i'(Q_i - L_i^P(\bar{L})) = k_1 U_1'(Q_1 - L_1^P(\bar{L})) \text{ for all } i = 1 \ldots N, \quad (3)$$

where U_i' is marginal utility of insurer *i*. It is important to observe that (3) is independent of $F_i(L_i)$ meaning that the optimal treaty does not depend on the loss distributions. Moreover, if $L_i^P(\bar{L})$ is differentiable, the Pareto-optimal treaty is only a function of the total claims amount $\sum_{i=1}^{N} L_i$ and not of the individual results.

Lemaire (1977, 1991) shows that, for a set *K* of constants $(k_1 \ldots k_N)$, there exists only one Pareto-optimal treaty. Finally, one can verify that, for exponential utility functions, each risk-averse insurer will pay a share of each claim that is inversely proportional to its constant risk-aversion parameter. The optimal treaty contains monetary side payments to compensate the least risk-averse companies that will have to pay higher shares. This condition is necessary to have all insurers participate in the treaty. See the Appendix for more details on the maximization problem.

4.2 The Cummins et al. (2002) proposition

Extending Borch's result to a world with risk neutrality and limited liability, Cummins et al. (2002) show that the distribution of insurance liabilities, which minimizes insolvencies and therefore maximizes payments to policyholders, is similar to the Borch equilibrium. Their market structure provides a framework for measuring the insurance industry's available capacity to respond to major catastrophes.

Their objective is to develop an optimal sharing rule that maximize payouts to policyholders for a given loss scenario. Their starting point is the result of Borch (1962), namely, that a Pareto optimal risk-sharing arrangement is one of mutualization between insurers, where each insurer hold a proportional claim of total insured claims. The riskiness of the aggregate portfolio depends on the total number of individual policies and their correlations. In the presence of a high correlation between insured losses, for catastrophe risk, *L* is riskier. Let us define T_i as the terminal value of equity for insurer *i*. In the presence of limited liability,

$$T_i = \text{Max}\left(\left(P_i + Q_i^0\right)(1+r) - \alpha_i L;\, 0\right) \tag{4}$$

where Q_i^0 is the starting surplus of insurer *i*, P_i is premium income, *r* is the rate of return on investments, and α_i is the quota share of insurer's *i* total loss. $\alpha_i L = L_i$ from Borch's result. Without transaction costs, $P_i = E(L_i)/(1+r)$. Writing $Q_i = Q_i^0(1+r)$, (4) becomes

$$T_i = \text{Max}\left(E(L_i) + Q_i - L_i;\, 0\right). \tag{5}$$

By aggregation, under limited liability, the total terminal equity of insurers is equal to

$$\sum_{i=1}^{N} T_i = \text{Max}\left(E(L) + \sum_{i=1}^{N} Q_i - L;\, 0\right), \tag{6}$$

while the aggregate losses paid to policyholders L^P is equal to

$$\sum_{i=1}^{N} L_i^P = \text{Min}\left(L; E(L) + \sum_{i=1}^{N} Q_i\right). \tag{7}$$

Insurers are exposed to two types of losses: idiosyncratic or diversifiable loss, d_i, and catastrophe losses, L_U. It is assumed that $\text{cov}(d_i, d_j) = 0$ and that catastrophe losses, such as

hurricanes losses, are correlated, so $L_i = c_i L_U + d_i$, where c_i is the proportion of the total catastrophe loss L_U belonging to insurer *i*.

Proposition:

A necessary condition for the average industry capacity per policyholder, $\sum_i E\left(L_i^P/n\right)$, *where* n *is the number of policyholders, to be maximized is that all firms hold a net of reinsurance portfolio that is proportional to* L_U *and D, where* $D = \sum_{i=1}^{N} d_i$.

The proof is in Cummins et al. (2002). From this proposition, the authors derive the following corollary.

Corollary:

When the necessary condition for the maximization of capacity per policyholder $\sum_i E\left(L_i^P/n\right)$ *is satisfied, all insurers will hold net of reinsurance portfolios* L_i *that are perfectly correlated with the aggregate industry losses L.*

Proof of the corollary is obtained when L_i is proportional to L_U, and d_i is diversifiable.

4.3 Application to catastrophe losses

Under limited liability and risk neutrality, the ability of the insurer *i* to pay the total insured loss $L_i^p = \text{Min}\left(L_i; E\left(L_i\right) + Q_i\right)$ depends on its equity capital Q_i and the collected premiums without transaction costs $E\left(L_i\right)$, where L_i is the total insured loss of insurer *i,* and $E\left(L_i\right)$ its expected value. The insurer has a put option on L_i with a corresponding strike value equal to the available resources $E\left(L_i\right) + Q_i$, as illustrated in Figure 1.

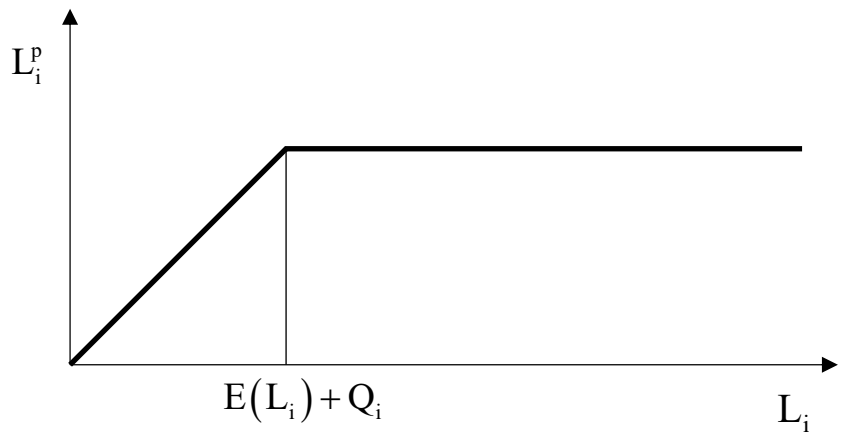

FIGURE 1 Limited liability of insurer *i*

Aggregating these values under limited liability, they show that the aggregate loss that will be paid by the insurance industry to policyholders will be the minimum of the value of aggregate losses L and the industry's total resources, as shown in (8):

$$\sum_{i=1}^{N} L_i^P = \text{Min}\left\{L; E(L) + \sum_{i=1}^{N} Q_i\right\}, \tag{8}$$

where N is the total number of insurers in the market, and $E(L)+\sum Q_i$ measures the total resources in the industry for expected and unexpected losses. Consequently, they obtain the following definition for maximizing payouts to policyholders.

Definition of the insurance industry's payment capacity:
For any configuration of losses for which insurers are liable, the payment capacity of the insurance industry is the proportion of those liabilities that is deliverable, given the financial resources of the firms and given all arrangements (such as reinsurance, guarantee funds, etc.) for reallocating those losses among insurers.

This provides a reference for measuring industry capacity. Let us define the proportional payment of aggregate loss *L* by insurer *i* as

$$\alpha_i L = c_i L_U + k_i D = L_i, \tag{9}$$

where

α_i is the proportion of *L* paid by insurer *i*;

c_i is the proportion of the aggregate catastrophe risk L_U paid by insurer *i*;

k_i is insurer *i*'s proportion of the aggregate industry diversifiable losses *D*.

They show that (9) maximizes industry capacity for a given industry surplus *Q*. This implies perfect correlation between L_i and *L*.

To estimate the industry's observed response function, we must make distributional assumptions about *L*. Using the normal distribution, the expected terminal equity value is equal to

$$E\left(T_i \middle| Q_i, L\right) = \left(E\left(L_i\right) + Q_i - \mu_{L_i|L}\right) N\left[\frac{E\left(L_i\right) + Q_i - \mu_{L_i|L}}{\sigma_{L_i|L}}\right] + \sigma_{L_i|L} \frac{1}{\sqrt{2\pi}} e^{-(1/2)\left(\left(E(L_i)+Q_i-\mu_{L_i|L}\right)/\sigma_{L_i|L}\right)^2}$$

where

$$\mu_{L_i|L} = \mu_i + \frac{\rho_i \sigma_i}{\sigma_L}\left(L - \mu_L\right) \text{ and } \sigma^2_{L_i|L} = \sigma_i^2\left(1-\rho_i^2\right), \tag{10}$$

and where T_i is the terminal equity of insurer *i,* $\mu_i = E\left(L_i\right)$, $\mu_L = E\left(L\right)$, and ρ_i is the correlation coefficient between L_i and *L*. The corresponding response function can be written as

$$R_i \middle| L = E\left(L_i\right) + Q_i - E\left(T_i \middle| Q_i, L\right) = \left(E\left(L_i\right) + Q_i\right) N\left(-C_i\right) + \mu_{L_i|L} N\left(C_i\right) - \sigma_{L_i|L} n\left(C_i\right), \tag{11}$$

where

$$C_i = \frac{E\left(L_i\right) + Q_i - \mu_{L_i|L}}{\sigma_{L_i|L}} \tag{12}$$

is the standardized capacity, $N\left(C_i\right)$ is the standard normal distribution function, and $n\left(C_i\right)$ is the standard normal density function. Using (11), we can measure the capacity of the industry for any industry loss L, as a function of two industry variables, $\left\{E\left(L\right), \sigma\left(L\right)\right\}$, and three firm variables, $\left\{\sigma_i, \rho_i, Q_i\right\}$. One can show that the expected response value is decreasing in σ_i and positively related to ρ_i. This occurs because the value of the insurer's nonpayment option is increasing in σ_i and because the industry gets closer to optimal compensation as ρ_i gets higher.

In summary, since (9) maximizes the industry's payment capacity for a given initial industry surplus Q, the estimated empirical correlations will provide an empirical measure of the insurance industry's capacity utilization for a given Q.

However, many frictions in the market can reduce the conditions described in the corollary on capacity maximization, including small insurer size, geographical distribution of insurers, loading in insurance pricing, reinsurance costs, and other insurer diversification costs. For example, Cummins et al. (2002) estimate the average transaction costs for reinsurance $\left(\text{price} - \text{expected loss}\right)/\text{expected loss}$ to be equal to 65% for the ten years preceding their study.

Figure 2 represents such a measure of empirical average capacity E(L)Z that has to be estimated, where X is the estimated capacity utilization for an aggregate loss of $\mathrm{E}(\mathrm{L})$ plus \$30 billion, and W would be the estimated capacity value for a less diversified industry while Y would be for a more diversified industry.

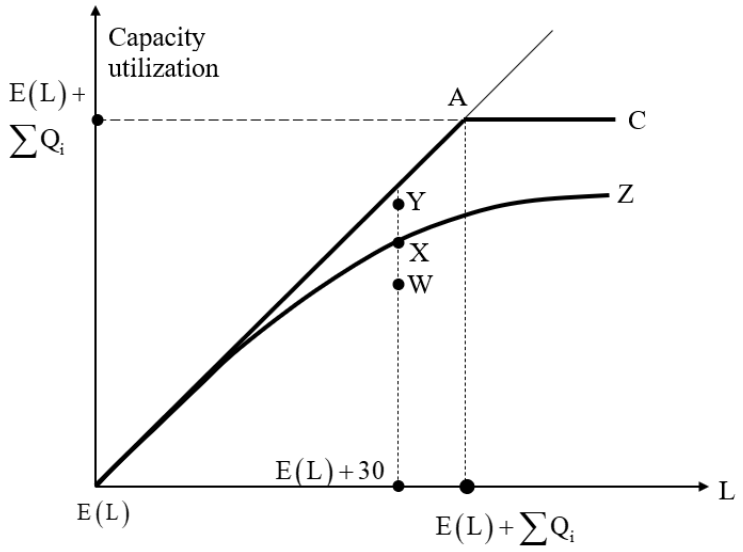

FIGURE 2 Empirical capacity utilization of the industry

5. Extension of the Cummins et al. (2002) empirical analysis

5.1 Introduction

In their theoretical analysis, Cummins et al. (2002) show that the condition for capacity maximization, given a level of total resources in the industry, is for all insurers to hold a net of reinsurance underwriting portfolio that is perfectly correlated with aggregate industry losses. Such a measure of capacity relies on two broad components: the size of the capital and industry diversification. How much equity or surplus is available? And how effectively is the riskiness of insurance losses spread through the insurance market? The main objective of this study is to update the computation of this correlation coefficient and measure the capital capacity of the U.S. insurance industry with new data up to the end of 2020.

We develop estimates of response functions for the U.S. property liability insurance industry by selecting samples of insurers and estimating the parameters of Eq. (11). The response functions are then calculated for various values of *L*, the total industry loss that can be observed in various years. The objective of the analysis is to determine the ability of the U.S. insurance industry to respond to catastrophic losses, and to measure the industry's capacity to spread risk across the market. This section discusses the method we use to measure industry capacity, as well as sample selection, parameter estimation, and estimation results.

The fact that some insurers do not write insurance that covers catastrophes, or do not do business in catastrophe-prone areas, or happen to be lucky in suffering relatively low losses as a result of a given event is captured by the estimated correlation coefficient ρ_i between the losses of company *i* and those of the industry. To the extent that differences in loss correlations can be under- or overestimated for these features of industry loss exposure and experience, these estimates must be viewed as approximations.

The data for the study are taken from the regulatory annual statements filed by insurers with the NAIC. In Cummins et al. (2002), the capacity estimates are for 1997, the most recent report year available at the time the study began. To estimate parameters, Cummins et al. (2002) use data from the period of 1983 to 1997, providing 15 annual observations for the companies in the sample.

The losses used in estimating capacity are the net losses incurred, which are defined as direct losses incurred, plus losses due to reinsurance assumed, minus losses due to reinsurance ceded. Direct losses incurred are losses paid or owed directly to policyholders, while net losses incurred reflect the netting out of reinsurance transactions. Our analysis thus does not take into account the direct effects of the reinsurance industry on capacity. There may be some indirect effects, as discussed in the conclusion. We use the values from line 2 to line 11 of column 28 in "Schedule P – Part 1 – Summary" of the NAIC annual statements as our main source of data. These are the net losses and loss expenses incurred during one year. In what follows, "net losses" (for short) and "net losses plus loss expenses" should be considered synonymous.

5.2 Sample selection and modeling approach

Cummins et al. (2002) used a 15-year period to estimate their parameters for the year 1997. Our objective, in this section, is to replicate their 1997 results and to add estimations for the years 2005, 2014 and 2020. It was not possible to create a 15-year database for the same time period as in Cummins et al. (2002) to make a direct comparison with the year 1997. Our data period is from 1990 to 2020, while their data period is from 1983 to 1997. One way to compare our results to theirs is to employ the observations from line 2 to line 11 in column 28 of "Schedule P – Part 1 – Summary" of the NAIC reports, that contain historical data on previous years and can provide 10 annual observations on the companies for the four years of our study. We label this sample "Sample 1." Note that Cummins et al (2002) used 15 annual observations from line 11 only of the NAIC reports.

One question that then arises is how the results might differ from using 10 annual observations, rather than the 15 in their study, and from a different period. To answer this question, we first estimate our parameters over 10 years. We concentrate the comparison on three 10-year periods, respectively, from 1996 to 2005, from 2005 to 2014, and from 2011 to 2020, using this time the data at line 11 only, in column 28 of "Schedule P – Part 1 – Summary" of the NAIC reports, providing 10 annual observations on the companies. We label this sample "Sample 2." The details are presented in Online Appendix OA2. We compare these results from Sample 2 with those from Sample 1, to verify how parameter estimates can be affected by the type of data used in the estimations (lines 2 to 11 in Sample 1, versus line 11 only in Sample 2).

Second, again for the years 2005, 2014, and 2020, we estimate the parameters for three 15-year periods, from 1991 to 2005, from 2001 to 2014, and from 2006 to 2020, with the values from line 11 only of column 28 in "Schedule P – Part 1 – Summary" of the NAIC reports, providing 15 annual observations on the companies. We call this sample "Sample 3." The details are presented in Online Appendix OA3. We then compare these results with those estimated from Sample 2, to verify how parameters can be affected by the length of the estimation period.

Two data series are available. Full-time series (FTS) are companies that are present in the samples for the entire period and have net losses and equity capital strictly greater than 0 each year. Regression models are then estimated from FTS data to provide parameter estimates for firms that are not in the full-time series (NFTS). Parameters for these companies are computed by inserting their 1997, 2005, 2014, and 2020 financial data into the regression models. Observations for net admitted assets and total liability had to be strictly greater than zero, while those for cash and short-term investments and for liquid assets had to be greater than or equal to zero.

All main estimates presented in the following discussion are derived from Sample 1. Sample 2 and Sample 3 are for robustness analysis. They show that results in Sample 1 are not dependent on the type of data (lines 2 to 11, instead of line 11 only) nor on the estimation methodology (10 years instead of 15 years).

5.3 Raw data from Sample 1

Tables OA1.1 to OA1.4 in Online Appendix OA1 report net losses and capital for Sample 1 during the 1990–2020 period. We can see from tables OA1.1 and OA1.3 that the number of companies significantly decreases after 2015. Also, the mean of the net losses increases yearly with few exceptions. Summary statistics on equity capital, the other determinant used to compute industry capacity, are presented in tables OA1.2 and OA1.4 for the same period. Equity capital increased significantly during the period of analysis.

Table 1 and Table 2 report net losses and equity capital for FTS and NFTS data in different years for all companies and for groups and unaffiliated companies. For the moment, only the number of firms differs between the two types of companies, but it will be interesting to observe their respective diversification behavior. Table 2 also compares our data with those of Cummins et al.

(2002) for the year 1997. We observe that our estimates are quite similar. The net losses in 1997 are equal to $202 billion for 2,256 insurance companies in their study, while it is equal to $210 billion for 2,286 insurance companies in our database during the same period. Net losses increased to $461 billion for 1,787 insurers in 2020, while capital increased more rapidly during the same period. The ratio of net losses over capital decreased over the years. For example, in Table 1 (Table 2), the ratio of net losses incurred over equity capital was 57% (56%) in 1997 and 42% (41.5%) in 2020.

Table 1: FTS Sample 1
Summary statistics: Net losses and equity capital
($000 omitted)

Sample	Net losses incurred	Equity capital	Number of firms
1997			
Groups & unaffiliated companies	201,252,911	355,097,195	877
All companies	201,252,911	355,097,195	1,667
2005			
Groups & unaffiliated companies	301,274,767	496,797,400	853
All companies	301,274,767	496,797,400	1,578
2014			
Groups & unaffiliated companies	343,463,626	780,443,239	844
All companies	343,463,626	780,443,239	1,574
2020			
Groups & unaffiliated companies	455,137,413	1,085,524,198	841
All companies	455,137,413	1,085,524,198	1,509

Table 2: NFTS Sample 1
Summary statistics: Net losses and equity capital
($000 omitted)

Insurance industry	Net losses incurred	Equity capital	Number of firms
1997			
Cummins et al. 2002 study			
Groups & unaffiliated companies	201,905,979	370,993,421	1,248
All companies	201,905,979	370,993,421	2,256
Our database			
Groups & unaffiliated companies	209,800,900	373,035,693	1,179
All companies	209,800,900	373,035,693	2,286

Insurance industry	Net losses incurred	Equity capital	Number of firms
2005			
Groups & unaffiliated companies	311,568,085	520,451,387	1,200
All companies	311,568,085	520,451,387	2,152
2014			
Groups & unaffiliated companies	349,123,503	803,479,225	1,064
All companies	349,123,503	803,479,225	1,923
2020			
Groups & unaffiliated companies	461,350,387	1,109,446,600	992
All companies	461,350,387	1,109,446,600	1,787

5.4 Capacity estimation

Let $L_t = \sum_{i=1}^{N} L_{it}$ be the total industry net losses in year *t,* and L_{it} the net loss of insurer *i* in period *t*. The estimator of the mean of net losses for the industry is equal to $\bar{L} = 1/T \sum_{t=1}^{T} L_t$ and the estimator of the variance of net losses for the industry is equal to $\hat{\sigma}^2 = \frac{1}{T-1} \sum_{t=1}^{T} \left(L_t - \bar{L} \right)^2$. We write $\hat{\sigma}$ for the standard deviation of the net losses for the industry. Table OA1.5 presents the total net losses, their means, and their standard deviations over the 1990–2020 period for the FTS population.

Detailed values for $\hat{\sigma}_i$ are presented in Table OA1.6. The correlation coefficient between company *i*'s losses and the industry losses is estimated using the following formula:

$$\hat{\rho}_i = \frac{\frac{1}{T-1} \sum_{t=1}^{T} \left(L_{it} - \bar{L}_i \right) \left(L_t - \bar{L} \right)}{\hat{\sigma}_i \hat{\sigma}}. \tag{19}$$

On average, the standard deviation of the net losses incurred by a company is less than $30 million from 1990 to 2001, increases to $44 million in 2008, decreases to $39 million in 2014, and increases again to about $50 million during the last three years of observation. We can see from Table OA1.7 that, on average, the correlation coefficient between company *i*'s losses and the

industry losses is 0.5996 in 1990, decreases to 0.4071 in 1999, decreases to 0.3683 in 2010, and increases beyond 0.4000 during the last four years.

5.5 Detrended parameter estimates

The detrended estimates are based on the residuals from the time trend regressions. The reason for computing the detrended estimators is that property liability insurance losses are subject to a strong positive time trend. Thus, the raw estimates of the loss standard deviation capture trend-related growth in losses across the years. Differences in losses across the years due to this trend effect are thus anticipated loss fluctuations and should not be included when measuring the effect of catastrophes and other types of random shocks on the insurance market's capacity.

By measuring capacity using both the raw and detrended parameters, we can isolate potential time-trend bias. Detrended estimates of $\hat{\sigma}_i^2$ and $\hat{\sigma}^2$ are obtained by applying formulas (21) and (22) to the estimated residuals ε_{it} and ε_i, both obtained from (20). The detrended estimate of $\hat{\rho}_i$ is obtained by applying formula (23) to the estimated residual series ε_{it}, and ε_i from (20).

To obtain the detrended parameter estimates, we first conduct the following regressions:

$$L_{it} = \alpha_{0i} + \alpha_{1i} t + \varepsilon_{it}$$
$$L_t = \alpha_0 + \alpha_1 t + \varepsilon_t . \qquad (20)$$

The detrended estimator of the variance of losses for the industry is equal to

$$\det \hat{\sigma}^2 = \frac{1}{T-1} \sum_{t=1}^{T} \left(\hat{\varepsilon}_t - 0 \right)^2 . \qquad (21)$$

We write *det* $\hat{\sigma}$ for the detrended estimator of the standard deviation of the losses for the industry. The detrended estimator of the variance of losses for company *i* is equal to

$$\det \hat{\sigma}_i^2 = \frac{1}{T-1} \sum_{t=1}^{T} \left(\hat{\varepsilon}_{it} - 0 \right)^2 . \qquad (22)$$

The detrended correlation coefficient between company *i*'s losses and the industry losses is estimated using the following formula:

$$\det \hat{\rho}_i = \frac{\frac{1}{T-1}\sum_{t=1}^{T}\left(\hat{\varepsilon}_{it}-0\right)\left(\hat{\varepsilon}_t-0\right)}{\det \hat{\sigma}_i \det \hat{\sigma}}. \tag{23}$$

On average, Table OA1.8 indicates that the mean of the detrended standard deviation of the net losses incurred for a company is less than $15 million from 1990 to 2000, increases up to $22 million in 2007, and is beyond $25 million afterward (with few exceptions), reaching $28 million in 2020—this last value being about three times the value of 1990.

We can see from Table OA1.9 that, on average, the detrended correlation coefficient between company *i*'s losses and the industry losses is 0.2020 in 1990 and decreases to 0.0891 in 2007, then it increases from 0.1760 in 2008 to 0.2419 in 2020. The estimated detrended correlation coefficients in Table OA1.9 are much lower than those observed in Table OA1.7, indicating a real time-trend bias in the raw data.

5.6 Regression models for parameter estimations

Regression models estimate the parameters of the companies that did not have data for the full time period covered by the study (NFTS companies). The procedure is to estimate regression models with the parameters of the FTS companies as dependent variables and companies' financial characteristics as regressors. The NFTS company parameters are computed by inserting the financial characteristics of these firms into the estimated equation to obtain fitted parameter values, which are used in estimating the insurance industry's capacity.

We need to estimate the parameters $\{\hat{\sigma}_i, \hat{\rho}_i\}$ for companies that do not have the FTS period covered. Since those parameters are censored at 0 for the standard deviation and censored to -1 and 1 for the correlation coefficient, we estimated the tobit model (censored normal regression) to obtain the parameters values.

For the 1997 market, we report the results of these regressions in Table OA1.10a for the standard deviation, and in Table OA1.11a for the correlation coefficient. For the 2005 market, we report the results of these regressions in Table OA1.10b for the standard deviation, and in Table OA1.11b for the correlation coefficient. Similar results are obtained for the years 2014 and 2020. They are reported in panels c and d of tables OA1.10 and OA1.11.

By inserting the financial characteristics of the NFTS firms into the estimated equations, we obtain fitted parameters $\hat{\sigma}_i$ and $\hat{\rho}_i$. Table OA1.12 presents the summary statistics for the standard deviation of the net losses incurred for a company, by year, for the NFTS sample. Table OA1.13 presents the summary statistics for the correlation coefficient between company *i*'s losses and the industry losses, by year, for the NFTS sample.

The average values of the raw and detrended parameter estimates for all companies and groups and unaffiliated companies are presented in Table 3 for the FTS and NFTS samples. As anticipated, the detrended values of sigma and correlation coefficients are much lower than the raw values. The detrended standard deviations and correlations are higher in 2020 than in previous years. Detrended sigmas are higher for groups and unaffiliated companies, while detrended correlations are lower after 2014.

Table 3: Detrended and raw parameter estimates: Property liability insurance industry with values from Sample 1

	Average				Number of firms
Case	Detrended sigma × 10^8	Detrended correlation	Raw sigma × 10^8	Raw correlation	
1997					
Insurance industry (FTS)					
Groups & unaffiliated companies	0.1766	0.1141	0.3703	0.5092	877
All companies	0.1311	0.1257	0.2536	0.4390	1,667
Insurance industry (NFTS)					
Groups & unaffiliated companies	0.2066	0.1243	0.4320	0.4899	1,179
All companies	0.0955	0.1004	0.2935	0.4376	2,286
2005					
Insurance industry (FTS)					
Groups & unaffiliated companies	0.3198	-0.0077	0.6241	0.5110	853
All companies	0.2157	0.0545	0.3969	0.4609	1,578
Insurance industry (NFTS)					
Groups & unaffiliated companies	0.3629	0.0352	0.7009	0.4765	1,200
All companies	0.1582	0.0409	0.4245	0.4399	2,152
2014					
Insurance industry (FTS)					
Groups & unaffiliated companies	0.3872	0.1162	0.6258	0.3927	844
All companies	0.2582	0.1621	0.3912	0.4039	1,574
Insurance industry (NFTS)					

Case	Average				Number of firms
	Detrended sigma × 10^8	Detrended correlation	Raw sigma × 10^8	Raw correlation	
Groups & unaffiliated companies	0.4202	0.1233	0.6817	0.3489	1,064
All companies	0.2113	0.1337	0.4156	0.3848	1,923
2020					
Insurance industry (FTS)					
Groups & unaffiliated companies	0.4135	0.1690	0.8693	0.4282	841
All companies	0.2804	0.2419	0.5348	0.4668	1,509
Insurance industry (NFTS)					
Groups & unaffiliated companies	0.4299	0.1716	0.9699	0.4138	902
All companies	0.2368	0.2093	0.5811	0.4487	1,787

Note: FTS: Full Time Sample. NFTS: Non Full Time Sample.

As expected, detrending reduces the magnitude of loss standard deviations and the correlations between companies' and industry losses. Because detrending leads to larger reductions in correlations than in the standard deviations, we expect the estimated loss payments to be lower for the detrended parameter estimates than for the raw estimates.

5.7 Response function for industry capacity

The response function is calculated for various values of L, the total industry potential net loss, as shown in Figure 2. The horizontal axis measures possible values for aggregate insurance industry net losses. The vertical axis measures the amount paid by all firms considered. The empirical response functions for the insurance industry (Sample 1) are shown in Figure 3 and Figure 4 for 1997 and 2020, respectively. Those of 2005 and 2014 are reported in Online Appendix 1 (Figure OA1.1 and Figure OA1.2). This sample is made up of firms that have full time series (FTS). The corresponding four figures for the NFTS are in Online Appendix 1 (figures OA1.3, OA1.4, OA1.5, and OA1.6).

The figures show the estimated amounts that would be paid for the industry losses, starting from the actual expected losses and adding unexpected losses for a given year: spanning from $200 billion to $500 billion in 1997; from $300 billion to $600 billion in 2005; from $340 billion to $740 billion in 2014; and from $460 billion to $1,260 billion in 2020. These limits were chosen from the total observed losses for the U.S. property liability insurance industry during the

corresponding year and the total equity capital for that year. Four response curves are shown in each figure based on raw and detrended parameters for group and company samples. Our main interpretation will be for detrended parameters for all companies.

The existing market capacity departs from the Borch theorem result that losses are perfectly correlated and that insurers are evenly capitalized under full liability. Figure 3 shows that the 1997 response curve with detrended FTS data begins to diverge from the 45° line at approximately $220 billion. In Figure 4, the 2020 response curve begins to diverge from the 45° line at approximately $620 billion, meaning that the insurance industry could easily cover an extra loss of $200 billion in 2020.

The corresponding numbers for realized capacity are presented in Table 4. Realized capacity is obtained as the ratio, at the chosen loss level, of the value of the response curve E(L)Z to the value of the maximum curve E(L)AC, in Figure 2. We observe that all companies in the FTS sample were able to pay 93% of a $100 billion loss in 1997, but only 81% for a $200 billion loss. Cummins et al. (2002) obtained 93% and 79%, respectively, with their data in 1997 (see their Figure 4). In 2020, the percentages are 99.6% and 98%. We also observe that, in 2020, the industry seems to be able to cover 92% of a $400 billion event during one year, or possibly, 2 events of $200 billion each. Tables 5 and 6 show the robustness of our results from Sample 2 and Sample 3. We observe, in Table 6, that the percentages for a $100 billion loss are 99.9% (Sample 2) and 99.7% (Sample 3). The corresponding numbers for a $200 billion loss are 98.9% and 97.8%. For a $400 billion loss, they are, respectively, 93.5% and 89.6%.

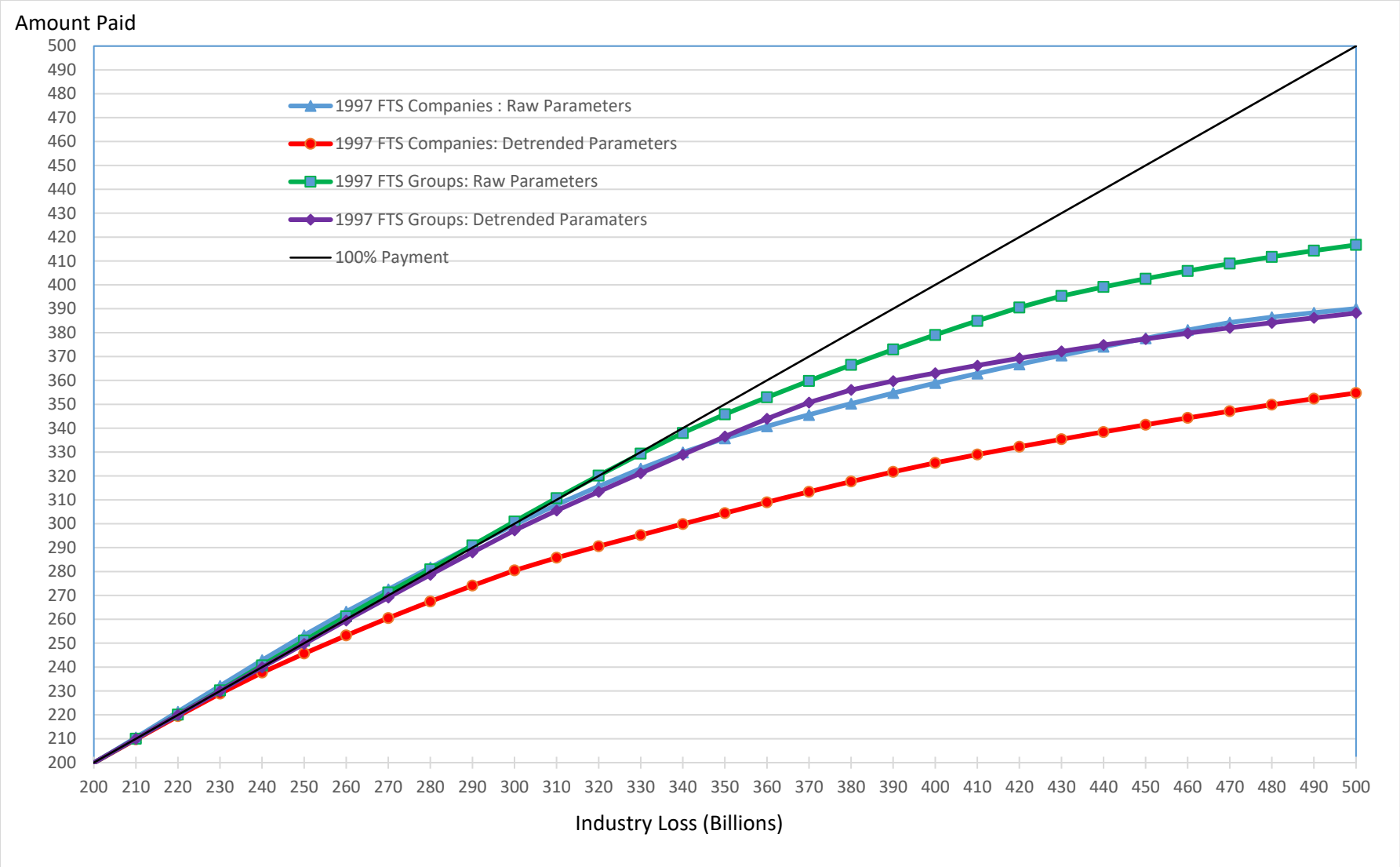

FIGURE 3 Industry capacity in 1997 (FTS sample 1)

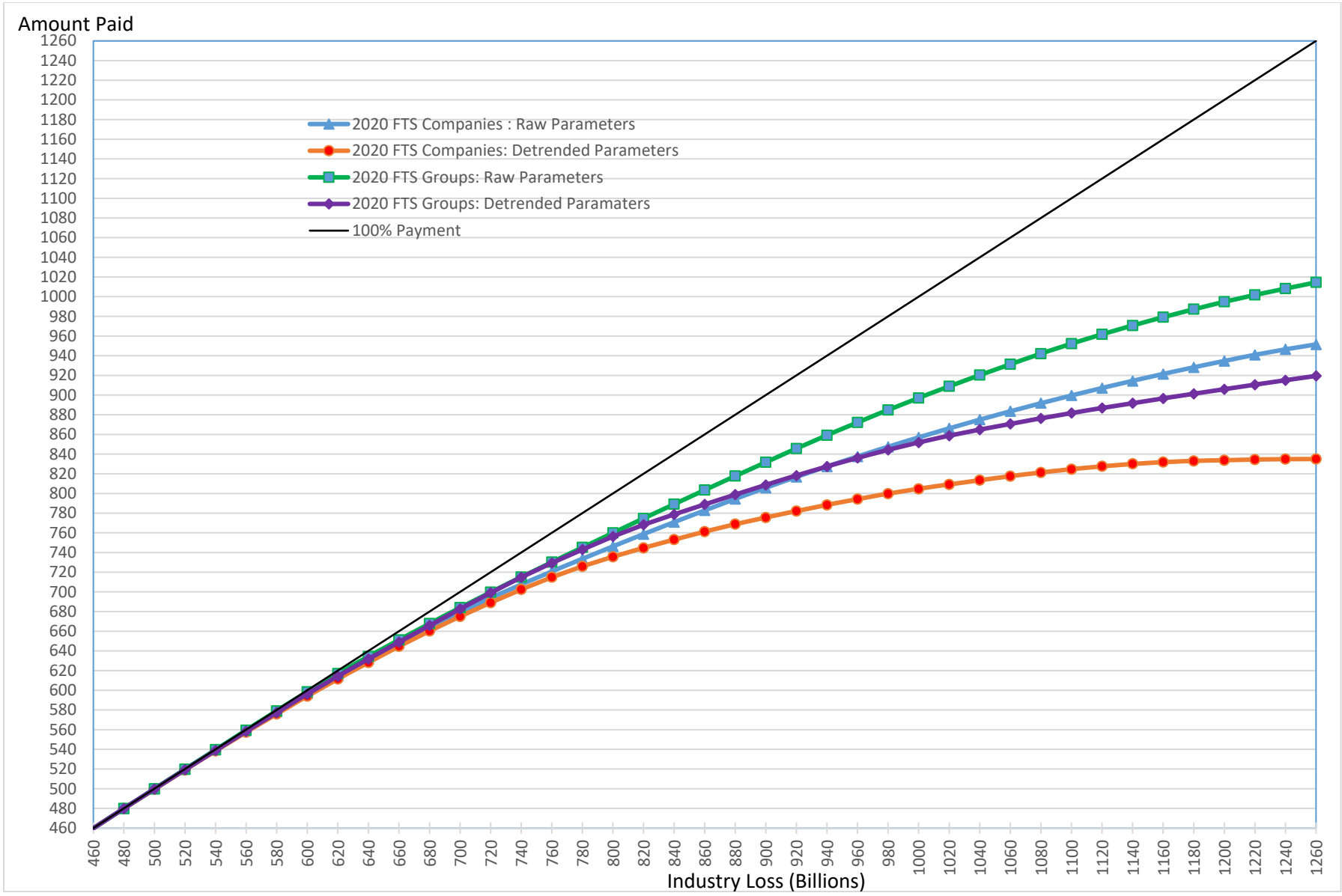

FIGURE 4 Industry capacity in 2020 (FTS sample 1)

Table 4 Capacity from Sample 1 with detrended values

	%			
1997	100 billion	200 billion	300 billion	400 billion
Insurance industry (FTS)				
Groups & unaffiliated companies	99.0	90.8	77.6	67.1
All companies	93.3	81.3	70.9	62.2
Insurance industry (NFTS)				
Groups & unaffiliated companies	94.7	87.9	77.3	67.0
All companies	94.6	82.8	72.4	63.5
	%			
2005	100 billion	200 billion	300 billion	400 billion
Insurance industry (FTS)				
Groups & unaffiliated companies	97.9	90.5	82.2	75.3
All companies	95.3	85.1	74.3	65.0
Insurance industry (NFTS)				
Groups & unaffiliated companies	95.8	90.7	83.3	77.1
All companies	97.3	89.2	80.3	72.9
	%			
2014	100 billion	200 billion	300 billion	400 billion
Insurance industry (FTS)				
Groups & unaffiliated companies	99.2	96.6	91.5	85.5
All companies	98.5	94.6	87.8	80.5
Insurance industry (NFTS)				
Groups & unaffiliated companies	97.7	94.8	90.5	85.2
All companies	99.0	95.7	89.7	83.1

	%					
2020	100 billion	200 billion	300 billion	400 billion	500 billion	600 billion
Insurance industry (FTS)						
Groups & unaffiliated companies	99.6	98.3	95.9	91.7	87.1	82.1
All companies	99.5	97.7	94.1	88.5	82.7	77.1
Insurance industry (NFTS)						
Groups & unaffiliated companies	98.9	97.3	94.9	91.2	86.6	82.1
All companies	99.9	98.8	95.9	91.0	85.8	80.8

Table 5: Summary statistics from Sample 2 and Sample 3: Losses and equity capital ($000 omitted)

Sample	Insurance industry FTS		Number of firms
	Net losses incurred	Equity capital	
2020 Sample 2 FTS			
Groups & unaffiliated companies	455,145,860	1,087,840,856	877
All companies	455,145,860	1,087,840,856	1,570
2020 Sample 2 NFTS			
Groups & unaffiliated companies	461,350,387	1,109,446,600	992
All companies	461,350,387	1,109,446,600	1,787
2020 Sample 3 FTS			
Groups & unaffiliated companies	448,309,430	1,069,230,397	784
All companies	448,309,430	1,069,230,397	1,407
2020 Sample 3 FTS			
Groups & unaffiliated companies	461,350,387	1,109,446,600	992
All companies	461,350,387	1,109,446,600	1,787

Table 6: Capacity from Sample 2 and Sample 3 with detrended values

	%					
2020 Sample 2	100 billion	200 billion	300 billion	400 billion	500 billion	600 billion
Insurance industry (FTS)						
Groups & unaffiliated companies	99.9	98.9	96.3	93.5	90.5	86.9
All companies	99.4	97.3	92.3	85.8	79.4	73.0
Insurance industry (NFTS)						
Groups & unaffiliated companies	98.8	97.4	94.8	90.9	86.2	81.4
All companies	99.4	97.5	92.8	86.3	79.9	73.5
	%					
2020 Sample 3	100 billion	200 billion	300 billion	400 billion	500 billion	600 billion
Insurance industry (FTS)						
Groups & unaffiliated companies	99.7	97.8	97.1	89.6	85.2	80.8
All companies	99.3	96.2	90.4	84.2	78.6	73.4
Insurance industry (NFTS)						
Groups & unaffiliated companies	98.3	96.4	93.1	89.6	85.3	81.6
All companies	99.5	96.9	91.4	85.2	79.6	74.4

6. Potential sources of relative capital increase

In this section we provide a preliminary discussion on possible sources of capital that may explain our results. As already mentioned, ILS products are more prevalent in the reinsurance industry than in the insurance industry. In 2021, alternative risk transfer represented 14% of the total reinsurance capital, with more than 95% being CAT bonds (American Academy of Actuaries, 2022). We start with the reinsurance demand. Figures 5 and 6 present the evolution of the reinsurance demand over our period of analysis. The two figures represent the evolution of the average demand for reinsurance over time for the U.S. property-liability insurance industry. They update those provided by Desjardins et al. (2022). The data are from NAIC's annual financial statements. The data period ranges from 1990 to 2020, which gives us coverage of the 2007–2008 financial crisis and the 2001 recession. An insurer's demand for reinsurance is defined as the ratio of (affiliated reinsurance ceded + nonaffiliated reinsurance ceded) / (direct business written plus reinsurance assumed). Figure 5 is for all insurers, while Figure 6 is for large insurers. Large insurers have total admitted assets greater than $3 billion and small insurers have total admitted assets less than $1 billion.

We observe in Figure 5 that the mean value of reinsurance demand increases steadily from about 37% to 49% over the period, with a small decrease during the years 2004–2008. Small insurers seem to use larger amounts of reinsurance to mitigate risk as time increases. During the same period the average demand for reinsurance by large insurers fluctuates heavily between 33.5% in 1990 to 28.5% in 2020. This seems to indicate that large insurers use other diversification instruments than reinsurance.

Another potential explanation for the capital capacity increase is related to the relative growth of insurance premiums over time. Figure 7 presents four premium indexes over the period 1998–2021. We observe that the general P&C Premium Index is very similar to the CPI Index during the period. In fact, the mean CPI Index is significantly higher, at 5%. The Life Premium Index is statistically lower than the other three indexes, while the Home P&C Premium Index is statistically higher. The mean and variance values are presented in Table 7. So, home insurance premiums could have been a source of capital increase, particularly for states with extreme weather and wildfire events.

Table 7: Mean and variance of different indexes during the period 1998–2021

	P&C Premium Index	CPI	Life Premium Index	Home P&C Premium Index
Mean	129.39	132.79	104.58	167.02
Variance	320.92	354.56	12.69	1,307.70

Source: Dionne et al. (2022).

Figure 8 shows the evolution in the number of mergers and acquisitions in the life and non-life industries between 1990 and 2021. We observe a parallel trend before 2012 and then a significant relative decrease in the life insurance industry. Dionne et al. (2022) are studying the causes of this structural change over time. It may be that climate change affected the P&C insurance industry more than the life insurance industry during these years. Other explanatory market causes are also investigated.

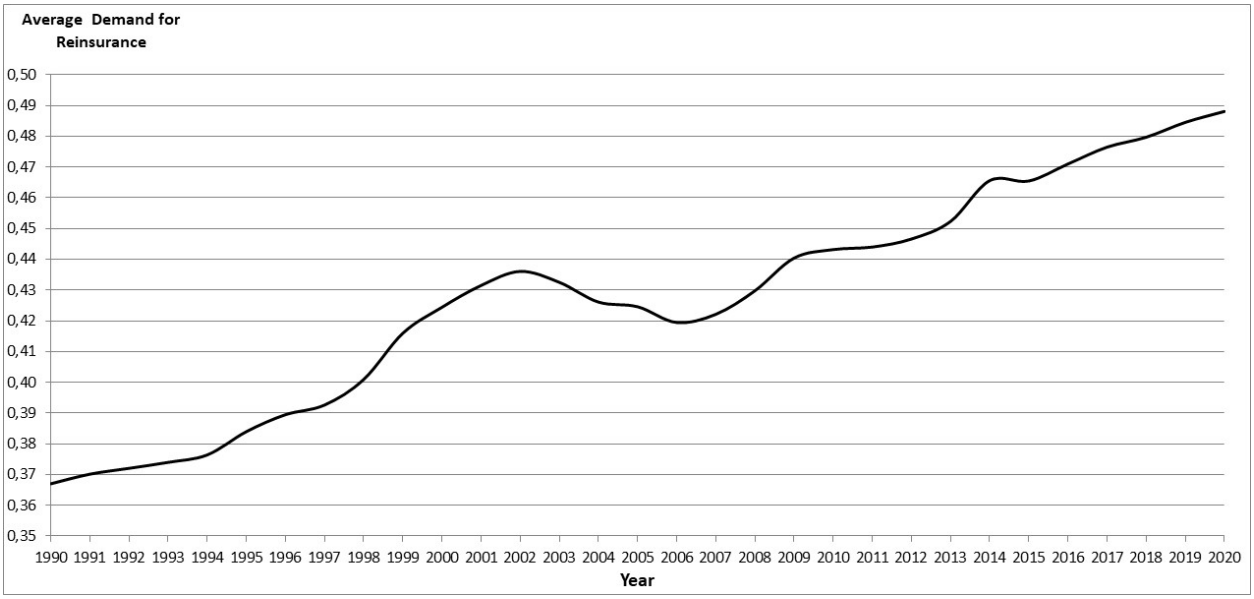

FIGURE 5 Demand for reinsurance by all insurers

Source: Desjardins et al. (2022).

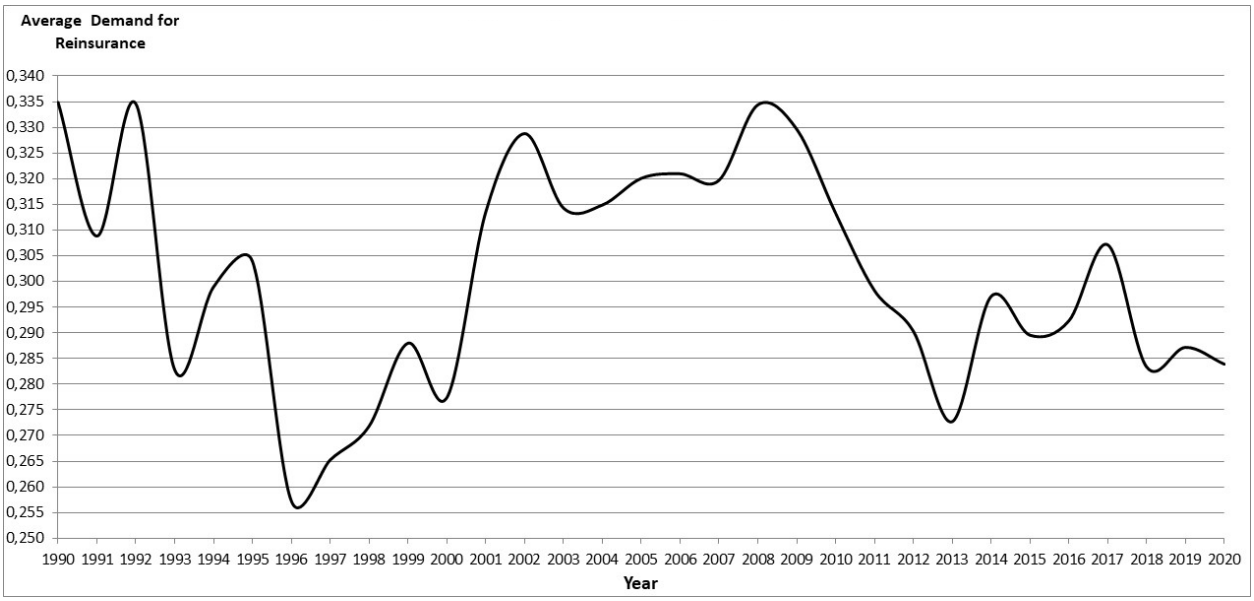

FIGURE 6 Demand for reinsurance by large insurers

Source: Desjardins et al. (2022).

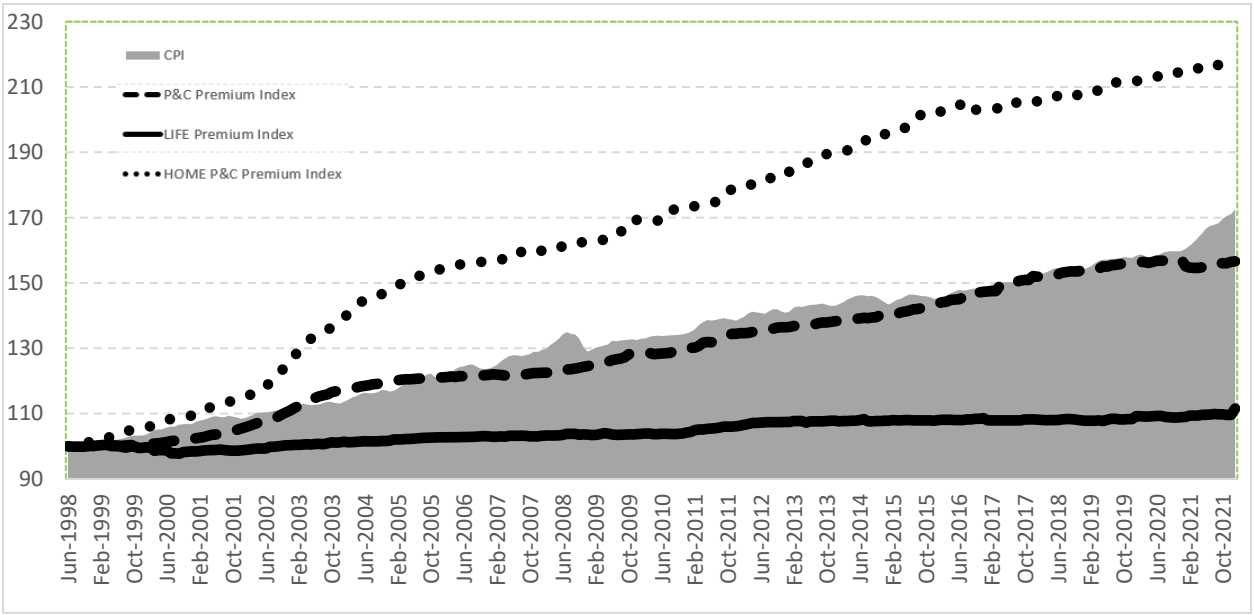

FIGURE 7 Increase in different premium indexes during the 1998–2021 period

Source: Dionne et al. (2022).

Additional capital regulation for the property and liability insurance industry was also introduced after the 2007–2009 financial crisis, even though the insurance industry was not directly affected, with few exceptions. For example, in 2012, the NAIC adopted The Risk Management and Own

Risk Solvency (ORSA) Model Act, which includes new economic risk measures of capital, as compared to before, when capital regulation was mainly based on accounting risk measures. New capital adequacy tests were also proposed to detect insurers that may not be adequately capitalized (Hartwig et al., 2015). These regulatory measures may have increased the average capital in the insurance industry.

Finally, some insurers may have reduced their financial responsibility for weather risk events because these events are more severe and frequent (Hunter, 2015). This last potential explanation would account for the lower relative increase in the net insured losses incurred when compared to total capital.

Overall, the evolution in P&C insurance capital during our period of analysis may have various explanations, including a combination of all of these. Future research is underway to identify the most significant explanation (Dionne et al., 2022).

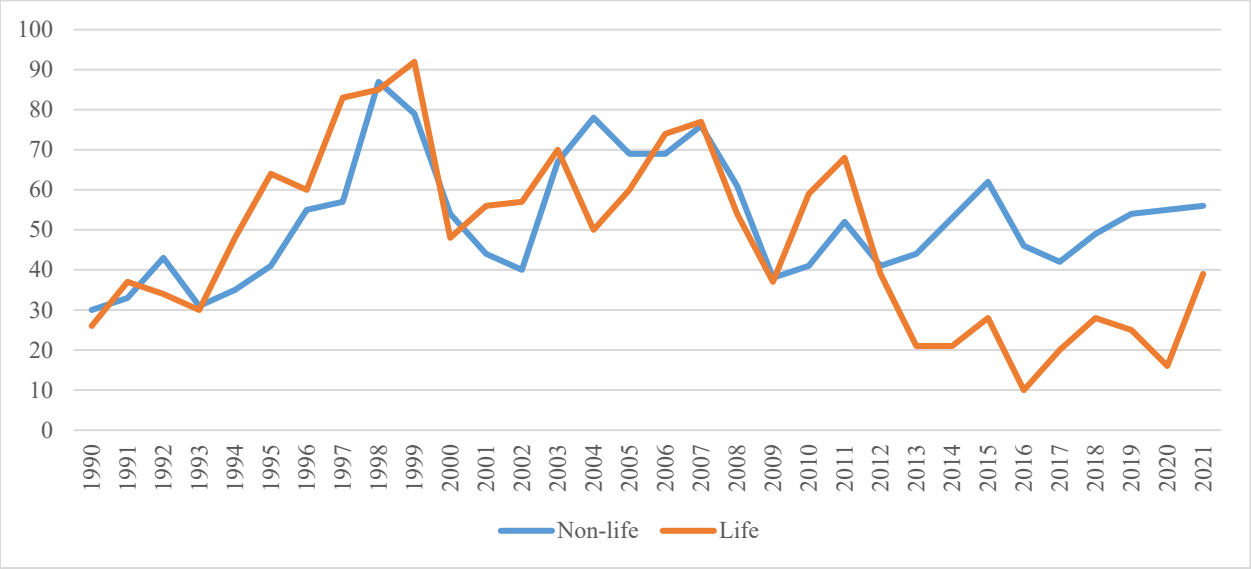

FIGURE 8 Mergers and acquisitions in the life insurance and P&C insurance industries
Source: Dionne et al. (2022).

7. Conclusion

The main objective of this study was to estimate the observed capacity of the U.S. property liability insurance industry to cover catastrophic losses in 2020 and verify how this capacity has evolved since 1997. We also presented all the important steps in data management and model estimation for those wanting to replicate the analysis or update the results, given that climate risk will undoubtedly become an increasingly important research subject over the coming years.

Cummins et al. (2002) use Borch's theorem as a starting point for defining industry capacity. They extend the theorem to a limited liability framework with risk neutrality. Capacity maximization is obtained when each insurer has an underwriting portfolio that is perfectly correlated with the industry's aggregate loss. At Pareto optimality, the industry would pay 100 percent of losses, up to the point where industry net premiums and equity are exhausted. This theoretical result does not consider the different frictions in the insurance market, including transaction costs, asymmetric information, and insurers' relative exposure to climate risks. Moreover, insurers are unevenly capitalized, such that some may go bankrupt for relatively low levels of industry losses. Finally, most insurers are not perfectly diversified geographically and may have their exposures concentrated in a subset of states that are disproportionately exposed to weather events. The estimated correlations should consider all these imperfections and be used to estimate the industry's real capacity.

Equity capital in the U.S. insurance industry increased from $355 billion in 1997 to $1.1 trillion in 2020 in the FTS sample, and the ratio of net losses over capital decreased from 57% to 42%, indicating a better capitalization in 2020. These ratios do not necessary measure the capacity of the insurance industry to cover additional unforeseen large events in a given year, because they do not consider the correlations between individual loss and aggregate loss.

Although the insurance industry's available capital has increased significantly since 1997, the market's ability to adequately insure catastrophic risks can be still problematic. The total available capital is earmarked for all types of insurable risks, not only disasters.

The industry response curves for 2020 are presented in Figure 3 for the FTS data. The curves assume that insurer losses are normally distributed and are estimated over a period of 10 years.

The figure shows the response curves for industry losses going from $460 billion (total losses in 2020) to a maximum of $1.1 trillion (total capital in 2020). As documented in Table 4, results with detrended parameters indicate that the insurance industry can cover 98% of a $200 billion loss and 94% of a $300 billion loss. Table 4 also indicates that the capacity for a $300 billion loss would have been 71% in 1997 (74% in 2005 and less than 90% in 2014). Table 5 and Table 6 show the robustness of the results from two other samples.

Table 4 shows that the capacity available to groups and unaffiliated companies is always higher than for all companies with FTS data. The increased capacity can be attributed to the higher absolute value of industry capitalization and, probably, the higher concentration of equity among the largest reinsurers as a result of consolidations. Other possible explanations are under investigation, as discussed in Section 6.

Many extensions of our analysis can be considered. Reinsurance is important, to diversify climate risks around the world over time (Cummins and Weiss, 2000, 2004). To date, the two levels of industry capacity have been studied separately in the literature. It has been documented that the presence of reinsurance can affect insurers' behavior (Desjardins et al., 2022). It would be interesting to analyze how insurers with more reinsurance coverage can obtain more capital and be more aggressive in tackling weather events. The opposite causality link is also of interest.

Assuming normality for catastrophic losses is a strong assumption. Cummins et al. (2002) assumed a normal distribution to simplify the aggregation of individual losses. The true empirical distribution should have a loss distribution with a relatively high probability for extreme outcomes. Fat tails imply that extreme observations strongly influence expected future risk. By using the same assumption in this study, for replication purposes, we may have overestimated the industry's capacity.

Cummins and Weiss (2000) explicitly consider the effect of reinsurer industry consolidation on the industry's capacity to cover catastrophe risks and verify a positive statistical link. Two research questions can be considered for the insurance industry: Is catastrophe risk a causal factor of industry consolidation? If so, how could this consolidation affect the insurance industry's capacity to cover disaster risks, improve insurer value, and modify the demand for reinsurance?

Another issue concerns life insurance. Are life insurers prepared to deal with this increasing risk? How could extreme losses related to climate risks and involving many deaths affect the future viability of life insurers' current business and investment portfolios? Another interesting research topic is how life insurers manage their investments in green technologies, since these important investors can influence global warming in the long run. Other financial market participants can also affect climate risk coverage, as well as global warming, in the long run.

Finally, the starting point of Cummins et al. (2000) is coverage for the "big one." But many big ones, in a given year, or even simultaneously, must be considered in the near future, for instance a hurricane in Florida and an earthquake in California. This requires a more dynamic view of the evolution of industry capacity, particularly for losses associated to climate risk, because many of these losses are related to global warming, which, it is suspected will increase both the frequency and severity of weather disasters.

References

Aerts, J.C.J.H., Wouter Botzen, W.J., Emanuel, K., Lin, N., de Moel, H., Michel-Kerjan, E.O., 2014. Evaluating flood resilience strategies for coastal megacities. *Science* 344, 6183, 473-475.

Akhigbe, A., Madura, J., 2001. Intra-industry signals resulting from insurance company mergers. *The Journal of Risk and Insurance* 68, 489-506.

American Academy of Actuaries, 2022, Insurance-Linked Securities and catastrophe Bonds, 35 p.

Anderson, M. and Gardiner, D., 2008. Managing the risks and opportunities of climate change: A practical toolkit for investors. Ceres and the Investor Network on Climate Risks, Boston, MA.

AON, 2022. Weather, climate and catastrophe insight.

Arrow, K., 1982. Risk perception in psychology and economics. *Economic Inquiry* 20, 1-9.

Baldauf, M., Garlappi, L., Yannelis, C., 2020. Does climate change affect real estate prices? Only if you believe in it. *The Review of Financial Studies* 33, 3, 1256-1295.

Bauer, D., Phillips, R.D., Zanjani, G.H., 2013. Financial pricing of insurance. In: G. Dionne, (Ed.), *Handbook of Insurance*, 2nd Edition, Springer, New York, 627-645.

Berger, A., Cummins, D., Weiss, M., Zi, H., 2000. Conglomeration versus strategic focus: Evidence from the insurance industry. *Journal of Financial Intermediation* 9, 323-362.

Bergesio, A., Koch-Medina, P., Munari, C., 2021. Limited liability and the demand for coinsurance by individuals and corporations. *Swiss Finance Institute Research Paper* No. 21-57.

Bernard, C., 2013. Risk sharing and pricing in the reinsurance market. In: G. Dionne, (Ed.), *Handbook of Insurance*, 2nd Edition. Springer, New York, 603-626.

Berz, G.A., 1997. Natural disasters and the greenhouse effect: Impact on the insurance industry and possible countermeasures. *The Geneva Papers on Risk and Insurance – Issues and Practice* 22, 85, 501-514.

Borch, K., 1960. The safety loading of reinsurance premiums. *Scandinavian Actuarial Journal* 3-4, 163-184.

Borch, K., 1962. Equilibrium in a reinsurance market. *Econometrica* 30, 3, 424-444. Reprinted in Dionne, G. and Harrington, S., (1992) *Foundations of Insurance Economics Readings in Economics and Finance*, Springer, 230-250.

Born, P., Viscusi, W.K., 2006. The catastrophic effects of natural disasters on insurance markets. *Journal of Risk and Uncertainty* 33, 55-72.

Born, P.H., Klimaszewski-Blettner, B., 2013. Should I stay or should I go? The impact of natural disasters and regulation on U.S. property insurers' supply decisions. *The Journal of Risk and Insurance* 80, 1, 1-36.

Boubakri, N., Dionne, G., Triki, T., 2008. Consolidation and value creation in the insurance industry: The role of governance. *Journal of Banking and Finance* 32, 56-68.

Caillaud, B., Dionne, G., Jullien, B., 2000. Corporate insurance with optimal financial contracting. *Economic Theory* 16, 77-105.

Carayannopoulos, P., Kanj, O., Perez, M.F., 2022. Pricing dynamics in the market for catastrophe bonds. *The Geneva Papers on Risk and Insurance – Issues and Practice* 47, 172-202.

Carrillo, G., Telljohann, D., Nyce, C., 2022. The 30th anniversary of hurricane Andrew: Evolution of the Florida homeowners insurance market. Forthcoming in *Risk Management and Insurance Review*. https://onlinelibrary.wiley.com/doi/10.1111/rmir.12222.

Charpentier, A., Barry, L., Molly, R.J., 2022. Insurance against natural catastrophes: balancing actuarial fairness and social solidarity. *The Geneva Papers on Risk and Insurance – Issues and Practice* 47, 50-78.

Chen, H., Cummins, J.D., Sun, T., Weiss, M., 2020. The reinsurance network among property-casualty insurers in solvency risk and contagion. *Journal of Risk and Insurance* 87, 253-284.

Collier, B.L., Schwartz, D., Kunreuther, H.C., Michel-Kerjan, E.O., 2021. Insuring large stakes: A normative and descriptive analysis of households' flood insurance coverage. *Journal of Risk and Insurance*, online publication.

Cummins, J.D., Dionne, G., Gagné, R., Nouira, A., 2009. Efficiency of insurance firms with endogenous risk management and financial intermediation activities. *Journal of Productivity Analysis* 32, 2, 145-159.

Cummins, J.D., Dionne, G., Gagné, R., Nouira, A., 2021. The costs and benefits of reinsurance. *Geneva Papers on Risk and Insurance – Issues and Practice* 46, 177-199.

Cummins, J.D., Doherty, N., Lo, A., 1999a. Can insurers pay for the "big one"? Measuring the capacity of the insurance market to respond to catastrophic losses? Working paper, Wharton School, University of Pennsylvania.

Cummins, J.D., Doherty, N., Lo, A., 2002. Can insurers pay for the "big one"? Measuring the capacity of the insurance market to respond to catastrophic losses. *Journal of Banking and Finance* 26, 2-3, 557-583.

Cummins, J.D., Phillips, R.D., Smith, S.D., 1997. Corporate hedging in the insurance industry: The use of financial derivatives by U.S. insurers. *North American Actuarial Journal* 1, 13-40.

Cummins, J.D., Phillips, R.D., Smith, S.D., 2000. Financial risk management in the insurance industry. In: G. Dionne, (Ed.), *Handbook of Insurance,* Kluwer Academic Publishers, Boston, 565-591.

Cummins, J.D., Phillips, R.D., Smith, S.D., 2001. Derivatives and corporate risk management: participation and volume decisions in the insurance industry. *The Journal of Risk and Insurance* 68, 51-91.

Cummins, J.D., Tennyson, S., Weiss, M., 1999b. Consolidation and efficiency in the US life insurance industry. *The Journal of Banking and Finance* 23, 325-357.

Cummins, J.D., Trainar, P., 2009. Securitization, insurance, and reinsurance. *The Journal of Risk and Insurance* 76, 463-492.

Cummins, J.D., Weiss, M., 2000. The global market for reinsurance: Consolidation, capacity, and efficiency. Brookings-Wharton Papers on Financial Services.

Cummins, J.D., Weiss, M., 2004. Consolidation in the European insurance industry: Do mergers and acquisitions create value for shareholders? Working Paper, The Wharton Financial Institutions Center.

Cummins, J.D., Weiss, M.A., 2009. Convergence of insurance and financial markets: Hybrid and securitized risk-transfer solutions. *The Journal of Risk and Insurance* 76, 3, 493-545.

Cummins, J.D., Xie, X. 2006. Mergers and acquisitions in the US property-liability insurance industry: Productivity and efficiency effects. Working paper, The Wharton School.

Deloitte, 2020. Climate risk: Regulators sharpen their forces. 20 p.

Desjardins, D., Dionne, G., Koné, N., 2022. Reinsurance demand and liquidity creation: A search for bicausality. *Journal of Empirical Finance* 66, 137-154.

Dionne, G., 2015. Policy Making and Climate Risk Insurability: How Can (Re)Insurers Contribute to Economic Resilience in Climate Risk Events? Working paper 15-06, Canada Research Chair in Risk Management, HEC Montréal.

Dionne, G., Fenou A., Mnasri, M., 2022. Consolidation of the US Property and Liability insurance industry: Is climate risk a causal factor? Working paper in preparation, Canada Research Chair in Risk Management, HEC Montréal.

Dixon, L., Clancy, N., Seabury, S.A., Overton, A., 2006. Rand Corporation report: The national flood insurance program's market penetration rate.

Drexler, A., Rosen, R., 2022. Exposure to catastrophe risk and use of reinsurance: an empirical evaluation for the U.S. *The Geneva Papers on Risk and Insurance – Issues and Practice* 47, 103-124.

Ernst and Young, 2008. Strategic business risk: Insurance.

GAO (Government Accountability Office), 2007. Natural disasters: Public policy options for changing the federal role in natural catastrophe insurance. https://www.gao.gov/new.items/d087.pdf.

Gatzert, N., Reichel, P., 2022. Awareness of climate risks and opportunities: empirical evidence on determinants and value from the U.S. and European insurance industry. *The Geneva Papers on Risk and Insurance – Issues and Practice* 47, 5-26.

Gollier, C., 2005. Some aspects of the economics of catastrophe risk insurance. CESifo Working Paper Series, No. 1409. Also available on SSRN: https://ssrn.com/abstract=668384.

Götze, T., Gürtler, M., 2022. Risk transfer beyond reinsurance: the added value of CAT bonds. *The Geneva Papers on Risk and Insurance – Issues and Practice* 47, 125-171.

Grenier, R., 2019. The role of catastrophe models in the evolution of the flood insurance market. Air Worldwide Corporation.

Grislain-Letrémy, C., Villeneuve, B., 2019. Natural disasters, land-use, and insurance. *The Geneva Papers on Risk and Insurance Theory* 44, 1, 54-86.

Hallegate, S., 2012, A cost effective solution to reduce losses in developing countries: Hydro-meteorological services, early warning and evacuation, World Bank Policy RES. Work. Working paper 6058.

Hallegate, S., 2014. Economic resilience: definition and measurement. The World Bank, Climate Change Group, Office of the Chief Economist. https://openknowledge.worldbank.org/handle/10986/18341.

Hartwig, R.P., Weisbart, S., Lynch, J., 2015. Global insurance capital standards: Origin, perspectives and impact on U.S. markets. Document, Insurance Information Institute, 35 p.

Hong, H., Karolyi, G.A., Scheinkman, J.A., 2020. Climate finance. *The Review of Financial Studies* 33, 3, 1011-1023.

Hoyt, R.E., Liebenberg, A.P., 2011. The value of enterprise risk management. *Journal of Risk and Insurance* 78, 4, 795-822.

Hunter, R., 2012. The insurance industry's incredible disappearing weather catastrophe risk. Document, Consumer Federation of America, 18 p.

Issler, P., Stanton, R., Vergara-Alert, C., Wallace, N., 2020. Mortgage markets with climate-change risk: Evidence from wildfires in California. Working paper, University of California, Berkeley.

Jametti, M., von Ungern-Sternberg, T., 2010. Risk selection in natural-disaster insurance. *Journal of Institutional and Theoretical Economics* 166, 2, 344-364.

Jametti, M., von Ungern-Sternbert, T., 2010. Risk selection in natural-disaster insurance. *Journal of Institutional and Theoretical Economics* 166, 2, 344-364.

Kelly, G., 2015. Why insurers fail: The role of capital in weathering crisis. Property and Casualty Insurance Compensation Corporation (PACICC) report, 31 p.

Kessler, D., 2015. Conference at the SCOR Scientific Seminar About Climate Risks, Paris, June. https://www.scor.com/en/media/news-press-releases/scientific-seminar-about-climate-risks.

Klein, R.W., Wang, S., 2009. Catastrophe risk financing in the United States and the European Union: A comparative analysis of alternative regulatory approaches. *The Journal of Risk and Insurance* 76, 3, 607-637.

Kousky, C., 2018. Financing flood losses: A discussion of the National Flood Insurance Program. *Risk Management and Insurance Review* 21, 11-32.

KPMG, 2018. Accelerated evolution: M&A, transformation and innovation in the insurance industry. Report, 34 p.

Kunreuther H., 2018. All-hazards homeowners insurance: Challenges and opportunities. *Risk Management and Insurance Review* 21, 1, 141-155.

Lakdawalla, D., Zanjani, G., 2012. Catastrophe bonds, reinsurance, and the optimal collateralization of risk transfer. *The Journal of Risk and Insurance* 79, 2, 449-476.

Lamb, R.P., 1995. An exposure-based analysis of property-liability insurer stock values around hurricane Andrew. *Journal of Risk and Insurance* 62, 1, 111-123.

Landry, C.E., Jahan-Parvar, M.R., 2011. Flood insurance coverage in the costal zone. *The Journal of Risk and Insurance* 78, 361-388.

Lemaire, J., 1977. Échange de risques et théorie des jeux. *Astin Bulletin* 9, 165-180.

Lemaire, J., 1991. Borch's theorem: A historical survey of applications. In: H. Loubergé (Ed.), *Risk, Information and Insurance*. Kluwer Academic Pubishers, 15-37.

Louaas, A., Picard, P., 2021. Optimal insurance coverage of low-probability catastrophic risks. *The Geneva Risk and Insurance Review* 46, 61-88.

Michel-Kerjan, E., 2012. How resilient is your country? Nature, 491, p. 497. https://www.nature.com/news/how-resilient-is-your-country-1.11861.

Michel-Kerjan, E., Czajkowski, J., Kunreuther, H., 2015. Could flood insurance be privatized in the United States? A primer. *The Geneva Papers on Risk and Insurance – Issues and Practice* 40, 179-208.

Mills, E., 2009. A global review of insurance industry responses to climate change. *The Geneva Papers* 34, 323-359.

Murfin, J., Spiegel, M., 2020. Is the risk of sea level rise capitalized in residential real estate? *The Review of Financial Studies* 33, 3, 1217-1255.

NAIC, 2020. Assessment of and insights from NAIC climate risk disclosure. Data, 44 p.

NASA, 2005. What's the difference between weather and climate? https://www.nasa.gov/mission_pages/noaa-n/climate/climate_weather.html.

Postal, A.D., 2008. Flood rating system flawed, GAO warms. *National Underwriter: Property and Casualty*, Report, December.

Powell, L.S., Sommer, D.W., 2007. Internal versus external capital markets in the insurance industry: The role of reinsurance. *Journal of Financial Services Research* 31, 173-188.

Robinson, P.J., Botzen, W.J.W., 2022. Setting descriptive norm nudges to promote demand for insurance against increasing climate change risk. *The Geneva Papers on Risk and Insurance – Issues and Practice* 47, 27-49.

Shao, J., 2022. Model assessment of public-private partnership flood insurance systems: an empirical study of Japan. *The Geneva Papers on Risk and Insurance – Issues and Practice* 47, 79-102.

Shelor, R.M., Anderson, D.C., Cross, M.L., 1992. Gaining from loss-property liability insurer stock values in the aftermath of the 1989 California earthquake. *Journal of Risk and Insurance* 59, 3, 476-488.

Sigma, 2009. Natural catastrophes and man-made disasters in 2008: North America and Asia suffer heavy losses. https://www.preventionweb.net/files/8841_Sigma22009e.pdf.

Sigma, 2015. Natural catastrophes and man-made disasters in 2014: Convective and winter storms generate most losses. https://www.swissre.com/institute/research/sigma-research/sigma-2015-02.html.

Sigma, 2022. Natural catastrophes in 2021: The floodgates are open. https://www.swissre.com/dam/jcr:326182d5-d433-46b1-af36-06f2aedd9d9a/swiss-re-institute-sigma-natcat-2022.pdf.

Swiss Re, 1998. The global reinsurance market in the midst of consolidation. *Sigma 9*, Zurich.

Swiss Re, 2020. 15 years after Katrina: Would we be prepared today? https://www.swissre.com/dam/jcr:a835acae-c433-4bdb-96d1-a154dd6b88ea/hurrican-katrina-brochure-usletter-web.pdf

Wagner, K., 2022. Adaptation and adverse selection in markets for natural disaster insurance. *American Economic Journal: Economic Policy* 14, 3, 380-421.

Weiss, M.A., Chung, J.H., 2004. U.S. reinsurance prices, financial quality, and global capacity. *The Journal of Risk and Insurance* 71, 3, 437-467.

Weston, F., Mitchell, M., Mulherin, H., 2004. *Takeovers, Restructuring, and Corporate Governance*. Prentice Hall finance series.

Appendix

Additional theoretical analysis

Borch (1960, 1962) presents the basic model of risk sharing between insurance firms. For simplicity, we limit the presentation to an economy with two insurers. The generalization is straightforward. In fact, the Borch model can be viewed as a principal-agent model. The objective of the allocation program is to maximize the welfare of one insurer under two constraints: the other insurer must participate, and total resources are limited. Suppose that the welfare of insurer *i*, i = 1,2, is measured by (1) in Section 4.

A treaty between insurer *i* and insurer *j* can be written as

$$L^P \equiv L_i^P\left(L_i, L_j\right) + L_j^P\left(L_i, L_j\right) = L_i + L_j \equiv L \tag{A1}$$

since all claims must be paid under full liability. The maximization program for obtaining the best treaty can be written as

$$\underset{L_1^P\left(\overline{L}\right) L_2^P\left(\overline{L}\right)}{\text{Max}} \int_0^\infty \int_0^\infty U_1\left(Q_1 - L_1^P\left(L_1, L_2\right)\right) dF\left(L_1, L_2\right), \tag{A2}$$

under these constraints:

$$k_2\left(\int_0^\infty \int_0^\infty U_2\left(Q_2 - L_2^P\left(L_1, L_2\right)\right) dF\left(L_1, L_2\right) - U_2\left(L_2\right) = 0\right) \tag{A3}$$

$$k_3\left(L_1^P\left(L_1, L_2\right) + L_2^P\left(L_1, L_2\right) - L_1 - L_2 = 0\right). \tag{A4}$$

Parameters $k_1 = 1,\ k_2 > 0,\ k_3 > 0,$ and $L_i^P\left(\overline{L}\right)$ is written for $L_i^P\left(L_i, L_j\right)$.

At the optimum, the functions $L_1^P\left(\overline{L}\right)$ and $L_2^P\left(\overline{L}\right)$ must satisfy

$$U_1'\left(Q_1 - L_1^P\left(L_1, L_2\right)\right) = k_2 U_2'\left(Q_2 - L_2^P\left(L_1, L_2\right)\right) \tag{A5}$$

$$L_1^P\left(L_1, L_2\right) + L_2^P\left(L_1, L_2\right) = L_1 + L_2. \tag{A6}$$

As shown by Lemaire (1977) with exponential utilities,

$$L_i^P(L_1, L_2) = q_i L + L_i(0). \tag{A7}$$

where the quota share of insurer *i* is equal to $q_i = c_i^{-1} / \left(c_1^{-1} + c_2^{-1}\right)$, c_i is the constant risk-aversion parameter of insurer *i,* and $L_i(0)$ is a side payment to compensate the less risk-averse insurer and obtain its participation in the treaty. Moffet (1977) interprets q_i as a coinsurance contract and show that a deductible contract cannot be optimal under the assumptions used in the program, particularly assuming that transaction costs between insurers are very low.

Cummins et al. (2002) assume risk neutrality and limited liability for each insurer. Without a treaty, the payoff of insurer *i* is equal to

$$T_i = \text{Max}\left(E(L_i) + Q_i - L_i, 0\right) \tag{A8}$$

or

$$T_i = \int_0^{z_i} \left(E(L_i) + Q_i - L_i\right) dF(L_i) \tag{A9}$$

where $z_i \equiv E(L_i) + Q_i$.

It is clear that we cannot directly apply the Borch (1960) maximization program to this environment because the resource constraint will not be satisfied in all states of the world. In fact, under limited liability, we must write

$$L^P \equiv E(L) + \sum_{i=1}^{2} Q_i \leq L_1 + L_2 \equiv L, \tag{A10}$$

with strict equality only when both insurers can pay L. Moreover, Cummins et al. (2002) do not show that the optimal form of the treaty is proportional or like a coinsurance contract. They assume this form of contract following the Borch (1962) result to obtain their condition of maximal compensation. More recently, Bergesio et al. (2021) show that a limited liability firm can buy a coinsurance contract at the optimum. However, they also assume this contract form instead of explicitly deriving it. Developing the optimal form of the treaty under limited liability and risk neutrality is beyond the scope of this article.[9] For our purpose of updating the results of Cummins

[9] For the derivation of contract forms with ex-post moral hazard and risk-neutral entrepreneurs, see Caillaud et al. (2000).

et al. (2002), we assume that each insurer's compensation is proportional to the aggregate loss so long as all insurers can pay, as in Cummins et al. (2002). Otherwise, the industry capacity falls short of the total claims.

A re-examination of the U.S. insurance market's capacity to pay catastrophe losses

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4 November 2022

Online appendix

Online appendix OA1

Table OA1.1: NFTS Sample 1
Summary statistics: Net losses and loss expenses incurred by year (1990–2020)
($000 omitted)

Year	N	Sum	Mean	Std	Max
1990	2,214	177,715,603	80,269.02	517,537.57	16,958,127
1991	2,241	182,530,805	81,450.60	524,570.85	17,027,661
1992	2,255	198,401,990	87,983.14	594,516.08	18,314,940
1993	2,252	190,413,917	84,553.25	554,470.02	19,155,972
1994	2,267	208,572,216	92,003.62	625,799.82	21,810,622
1995	2,280	204,910,538	89,873.04	600,634.17	21,432,510
1996	2,285	215,009,405	94,096.02	619,391.36	21,454,575
1997	2,286	209,800,900	91,776.42	594,148.82	20,713,399
1998	2,277	221,006,627	97,060.44	613,220.30	21,053,347
1999	2,213	227,814,550	102,943.76	637,275.50	21,203,854
2000	2,165	241,115,798	111,369.88	702,301.10	23,335,985
2001	2,137	265,470,813	124,225.93	770,202.56	25,798,108
2002	2,103	265,383,948	126,193.03	799,293.80	27,672,128
2003	2,101	277,826,866	132,235.54	815,773.37	27,807,298
2004	2,143	291,800,571	136,164.52	807,959.99	27,059,473
2005	2,152	311,568,085	144,780.71	907,532.39	29,846,734
2006	2,193	294,508,283	134,294.70	792,433.87	25,459,006
2007	2,223	312,562,459	140,603.90	821,870.35	26,371,754
2008	2,246	356,466,021	158,711.50	912,082.83	28,142,990
2009	2,207	325,036,521	147,275.27	883,359.23	28,701,847
2010	2,163	323,710,757	149,658.23	910,450.20	29,717,899
2011	2,119	358,938,218	169,390.38	988,525.45	30,474,865
2012	2,069	347,978,308	168,186.71	971,028.53	30,204,525
2013	2,016	334,899,331	166,120.70	982,821.13	31,447,613
2014	1,923	349,123,503	181,551.48	1,078,925.03	32,970,073
2015	1,953	363,651,857	186,201.67	1,115,894.90	34,203,391
2016	1,911	388,339,598	203,212.77	1,247,026.09	38,768,776
2017	1,864	425,020,127	228,015.09	1,327,374.43	38,816,047
2018	1,825	443,081,776	242,784.53	1,319,597.25	36,187,577
2019	1,805	454,609,413	251,861.17	1,361,103.60	36,311,052
2020	1,787	461,350,387	258,170.33	1,319,821.69	31,865,776

Note: NFTS: Non Full Time Sample.

Table OA1.2: NFTS Sample 1
Summary statistics: Equity capital by year (1990–2020)
($000 omitted)

Year	N	Sum	Mean	Std	Min	Max
1990	2,214	168,699,803	76,196.84	472,348.72	8.34	17,889,083
1991	2,241	186,953,810	83,424.28	510,424.41	3.46	19,721,100
1992	2,255	195,366,490	86,637.02	500,682.73	58.07	18,751,400
1993	2,252	218,854,119	97,182.11	571,898.35	39.87	21,269,733
1994	2,267	228,726,898	100,894.09	573,638.35	64.39	21,143,917
1995	2,280	271,399,696	119,034.95	713,469.10	61.41	25,119,972
1996	2,285	302,009,404	132,170.42	853,921.86	3.31	30,053,793
1997	2,286	373,035,693	163,182.72	1,114,775.27	57.68	37,608,322
1998	2,277	408,329,034	179,327.64	1,219,263.15	0.56	41,766,158
1999	2,213	411,257,453	185,837.08	1,293,516.87	25.09	45,762,499
2000	2,165	382,656,656	176,746.72	1,226,322.77	10.79	43,690,982
2001	2,137	357,016,769	167,064.47	1,047,019.00	143.50	37,989,956
2002	2,103	354,836,839	168,728.88	956,411.83	64.29	31,600,585
2003	2,101	425,132,845	202,347.86	1,220,459.15	44.44	39,980,587
2004	2,143	477,012,027	222,590.77	1,388,012.85	0.77	46,144,211
2005	2,152	520,451,388	241,845.44	1,489,481.92	107.24	50,187,253
2006	2,193	590,617,960	269,319.64	1,735,785.29	246.48	58,034,268
2007	2,223	635,480,464	285,866.16	1,849,520.83	147.83	63,577,269
2008	2,246	573,351,953	255,276.92	1,553,939.71	18.16	53,273,952
2009	2,207	637,141,361	288,691.15	1,791,981.96	161.83	58,180,271
2010	2,163	681,298,430	314,978.47	2,233,559.24	7.94	68,437,054
2011	2,119	677,006,054	319,493.18	2,268,255.59	45.51	70,155,428
2012	2,069	717,940,204	346,998.65	2,521,352.06	15.41	78,861,515
2013	2,016	788,520,342	391,131.12	3,007,903.53	0.13	97,226,052
2014	1,923	803,479,225	417,825.91	3,106,439.27	1.15	93,997,652
2015	1,953	817,507,744	418,590.76	3,058,316.60	1.85	89,828,619
2016	1,911	855,520,039	447,681.86	3,355,687.24	77.63	101,285,906
2017	1,864	913,820,807	490,247.21	4,003,976.83	77.10	128,562,566
2018	1,825	902,810,027	494,690.43	3,991,042.47	106.64	122,471,087
2019	1,805	1,034,756,900	573,272.54	5,092,094.30	256.15	167,718,679
2020	1,787	1,109,446,600	620,843.07	5,648,877.36	167.44	187,762,294

Note: NFTS: Non Full Time Sample.

Table OA1.3: FTS Sample 1
Summary statistics: Net losses and loss expenses incurred by year (1990–2020)
($000 omitted)

Year	N	Sum	Mean	Std	Max
1990	1,389	171,374,407	123,380	649,457	16,958,127
1991	1,444	176,052,958	121,920	649,801	17,027,661
1992	1,461	190,313,741	130,263	734,674	18,314,940
1993	1,488	181,856,782	122,216	678,362	19,155,972
1994	1,503	198,108,492	131,809	764,545	21,810,622
1995	1,560	195,420,453	125,270	722,705	21,432,510
1996	1,624	206,486,353	127,147	731,219	21,454,575
1997	1,667	201,252,911	120,728	692,404	20,713,399
1998	1,677	210,282,050	125,392	710,668	21,053,347
1999	1,663	216,479,256	130,174	73,1245	21,203,854
2000	1,639	229,485,981	140,016	80,2925	23,335,985
2001	1,636	256,830,748	156,987	87,6945	25,798,108
2002	1,615	257,085,229	159,186	90,8798	27,672,128
2003	1,595	268,3442,00	168,241	93,2563	27,807,298
2004	1,596	279,0725,93	174,858	93,0456	27,059,473
2005	1,578	301,274,767	190,922	105,5190	29,846,734
2006	1,589	285,720,875	179,812	92,6317	25,459,006
2007	1,604	300,912,718	187,601	96,0956	26,371,754
2008	1,626	345,168,298	212,281	1,065,100	28,142,990
2009	1,613	316,309,049	196,100	1,028,716	28,701,847
2010	1,596	315,294,344	197,553	1,055,586	29,717,899
2011	1,609	351,449,025	218,427	1,129,794	30,474,865
2012	1,612	341,523,488	211,863	1,096,009	30,204,525
2013	1,604	327,588,106	204,232	1,098,294	31,447,613
2014	1,574	343,463,626	218,211	1,189,212	32,970,073
2015	1,632	357,822,910	219,254	1,217,658	34,203,391
2016	1,609	381,780,711	237,278	1,355,884	38,768,776
2017	1,591	419,052,497	263,389	1,433,222	38,816,047
2018	1,548	437,005,166	282,303	1,428,620	36,187,577
2019	1,531	448,059,984	292,658	1,473,351	36,311,052
2020	1,509	455,137,413	301,615	1,431,263	31,865,776

Note: FTS: Full Time Sample.

Table OA1.4: FTS Sample 1
Summary statistics: Equity capital by year (1990–2020)
($000 omitted)

Year	N	Sum	Mean	Std	Min	Max
1990	1,389	158,546,901	114,144.64	592,570.59	8.34	17,889,083
1991	1,444	173,829,187	120,380.32	630,474.05	3.46	19,721,100
1992	1,461	177,377,546	121,408.31	606,605.98	58.07	18,751,400
1993	1,488	199,444,022	134,034.96	688,739.67	46.89	21,269,733
1994	1,503	208,409,100	138,662.08	692,173.81	0.67	21,143,917
1995	1,560	251,900,679	161,474.79	850,780.97	61.41	25,119,972
1996	1,624	286,667,232	176,519.23	1,008,369.56	3.31	30,053,793
1997	1,667	355,097,195	213,015.71	1,300,376.16	118.38	37,608,322
1998	1,677	386,753,275	230,622.11	1,415,157.58	251.35	41,766,158
1999	1,663	389,497,489	234,213.76	1,486,770.79	25.09	45,762,499
2000	1,639	362,829,587	221,372.54	1,405,263.36	10.79	43,690,982
2001	1,636	340,892,569	208,369.54	1,192,500.53	204.58	37,989,956
2002	1,615	334,593,012	207,178.34	1,086,254.63	64.29	31,600,585
2003	1,595	403,289,846	252,846.30	1,394,916.36	165.53	39,980,587
2004	1,596	454,269,314	284,629.90	1,601,547.77	0.77	46,144,211
2005	1,578	496,797,400	314,827.25	1,731,283.16	107.24	50,187,253
2006	1,589	568,217,331	357,594.29	2,030,838.99	246.48	58,034,268
2007	1,604	612,255,763	381,705.59	2,168,536.61	345.91	63,577,269
2008	1,626	549,738,270	338,092.42	1,818,159.44	65.92	53,273,952
2009	1,613	611,689,263	379,224.59	2,087,473.24	161.83	58,180,271
2010	1,596	657,498,627	411,966.56	2,592,473.12	265.60	68,437,054
2011	1,609	655,961,572	407,682.77	2,595,877.20	67.60	70,155,428
2012	1,612	697,411,163	432,637.20	2,849,514.46	15.41	78,861,515
2013	1,604	761,466,077	474,729.48	3,364,615.16	0.13	97,226,052
2014	1,574	780,443,239	495,834.33	3,426,861.01	1.15	93,997,652
2015	1,632	793,579,779	486,262.12	3,338,676.08	1.85	89,828,619
2016	1,609	827,568,694	514,337.29	3,649,783.39	77.63	101,285,906
2017	1,591	888,790,475	558,636.38	4,327,584.27	77.10	128,562,566
2018	1,548	880,890,563	569,050.75	4,327,085.99	186.58	122,471,087
2019	1,531	1,013,362,400	661,895.76	5,522,467.07	256.15	167,718,679
2020	1,509	1,085,524,198	719,366.60	6,140,746.89	167.44	187,762,294

Note: NFTS: Non Full Time Sample.

Table OA1.5: FTS Sample 1
Distribution of net losses
($000 omitted)

Year	L_{t-9}	L_{t-8}	L_{t-7}	…	L_{t-2}	L_{t-1}	L_t	$\bar{L}$	$\hat{\sigma}$
1990	74,414,479	83,740,459	92,568,162	…	146,335,428	163,586,889	171,374,407	120,997,141	32,893,055.73
1991	83,456,062	92,599,368	106,045,142	…	162,886,621	169,301,376	176,052,958	130,724,318	32,217,730.24
1992	92,647,718	106,321,361	116,924,431	…	167,742,711	172,767,662	190,313,741	140,897,569	32,042,208.09
1993	106,624,102	117,284,584	120,830,527	…	170,884,525	187,390,339	181,856,782	148,902,402	28,846,066.45
1994	117,281,706	120,793,434	130,361,714	…	183,781,628	178,171,262	198,108,492	157,097,641	27,643,200.16
1995	121,330,023	130,267,248	143,809,787	…	177,237,140	197,522,574	195,420,453	164,868,005	25,900,783.31
1996	130,295,151	143,751,177	162,636,588	…	195,939,244	193,721,909	206,486,353	172,613,282	23,588,685.04
1997	142,545,496	161,646,113	166,091,936	…	191,438,008	204,564,120	201,252,911	178,221,256	19,675,467.40
1998	161,030,019	165,514,511	166,444,345	…	202,457,275	198,605,104	210,282,050	183,617,601	17,287,699.41
1999	164,989,834	166,273,270	178,394,896	…	198,414,779	210,943,074	216,479,256	188,953,956	18,295,004.65
2000	161,832,267	173,916,592	166,783,739	…	211,492,329	217,357,930	229,485,981	192,871,403	22,179,899.89
2001	170,383,410	164,129,958	185,343,855	…	220,814,423	233,343,042	256,830,748	202,341,328	29,145,364.27
2002	163,329,224	185,170,740	183,094,367	…	239,890,904	259,079,558	257,085,229	213,964,782	32,445,457.63
2003	183,262,364	181,666,295	195,65,1689	…	258,870,910	248,895,008	268,3442,00	222,000,642	31,991,873.91
2004	181,247,887	195,657,075	195,804,754	…	249,198,170	255,045,500	279,0725,93	231,160,175	32,415,738.51
2005	195,532,170	196,212,105	218,380,744	…	253,15,6354	266,200,435	301,2747,67	242,564,434	32,958,429.10
2006	194,896,671	217,107,302	229,258,222	…	260,102,398	288,520,118	285,720,875	249,191,819	28,869,336.95
2007	218,297,148	230,639,185	249,137,841	…	284,400,126	276,740,621	300,912,718	258,96,9515	24,580,575.94
2008	230,948,463	250,138,181	265,457,113	…	272,743,918	296,362,660	345,168,298	270,728,397	32,043,915.65
2009	249,301,425	264,911,266	252,434,049	…	291,826,043	339,738,585	316,309,049	277,301,757	30,573,897.58
2010	260,192,930	248,596,078	246,233,069	…	334,570,606	308,943,902	315,294,344	279,551,041	31,069,883.52
2011	254,896,045	252,473,633	256,596,353	…	306,270,626	312,770,589	351,449,025	290,960,149	34,928,416.37
2012	251,604,283	256,078,212	277,317,579	…	311,243,831	344,377,981	341,523,488	298,102,377	34,861,517.93
2013	256,171,787	277,855,414	263,854,070	…	344,027,261	332,653,260	327,588,106	304,544,226	30,868,455.06
2014	275,473,365	261,702,820	281,133,928	…	330,284,145	319,968,627	343,463,626	309,745,108	28,175,246.69
2015	262,810,797	283,430,758	324,298,418		321,953,494	339,536,074	357,822,910	319,299,665	28,552,556.11
2016	281,248,062	322,324,631	301,047,232		338,865,315	353,057,645	381,780,711	329,007,328	28,103,904.50
2017	320,898,234	299,501,944	302,693,023		352,497,619	376,839,754	419,052,497	341,203,579	35,533,124.90
2018	299,397,701	305,594,617	339,504,878		376,006,361	411,181,111	437,005,166	351,538,030	44,529,762.03
2019	303,558,374	337,364,597	326,187,667		408,728,464	429,581,444	448,059,984	363,597,133	49,743,873.74
2020	336,081,747	324,629,134	314,403,406		427,517,806	443,105,545	455,137,413	376,422,733	52,513,340.78

Note: Sum of the observed losses of company *i* incurred in year *t–9* up to *t* (L_{t-9}, … L_t). $\bar{L}$ and $\hat{\sigma}$ of losses for the industry by year (1990–2020).

Table OA1.6: ($\hat{\sigma}_i$) FTS Sample 1
($000 omitted)

Year	N	Mean	Std	Min	Max
1990	1,389	28,896.89	153,266.69	1.90	4,117,902.16
1991	1,444	28,285.71	153,603.01	1.52	4,175,781.98
1992	1,461	29,001.89	163,666.97	1.32	4,184,769.02
1993	1,488	28,271.59	155,126.49	0.70	4,047,432.60
1994	1,503	28,031.22	153,805.97	6.11	4,160,714.72
1995	1,560	27,289.46	143,088.30	5.86	4,038,217.10
1996	1,624	26,691.71	126,921.89	7.04	3,531,777.62
1997	1,667	25,357.20	107,760.08	6.26	2,859,433.91
1998	1,677	24,385.01	94,739.98	6.07	2,403,336.98
1999	1,663	24,602.95	91,232.49	2.53	2,056,463.79
2000	1,639	26,284.24	97,870.52	3.52	2,142,909.44
2001	1,636	29,277.32	110,785.74	0.97	2,408,613.36
2002	1,615	31,747.85	121,748.78	0.32	2,825,926.51
2003	1,595	34,310.36	126,525.62	0.32	2,826,442.64
2004	1,596	36,925.36	131,901.68	5.08	2,847,132.67
2005	1,578	39,687.63	146,392.88	0.67	3,301,741.99
2006	1,589	39,690.58	140,673.87	0.67	2,822,807.25
2007	1,604	39,863.78	139,858.88	0.67	2,595,686.90
2008	1,626	44,203.38	153,565.17	5.95	2,339,542.42
2009	1,613	43,552.17	151,460.50	1.03	1,957,636.38
2010	1,596	41,513.42	145,298.42	1.16	2,006,493.32
2011	1,609	43,143.13	153,674.77	0.67	2,483,517.16
2012	1,612	42,065.40	147,767.89	0.67	2,369,475.80
2013	1,604	40,145.20	140,878.39	5.33	2,261,733.09
2014	1,574	39,122.05	154,097.32	0.57	3,419,126.79
2015	1,632	39,291.84	173,303.39	0.95	4,486,420.20
2016	1,609	40,432.54	201,018.55	0.47	5,194,632.04
2017	1,591	44522.55	226,404.97	0.32	6,170,229.88
2018	1,548	49,860.80	241,902.79	0.32	6,760,598.56
2019	1,531	51,999.15	249,680.68	0.32	7,041,168.30
2020	1,509	53,481.45	243,722.37	0.32	6,800,905.57

Note: Standard deviation of losses for a company by year (1990–2020).

Table OA1.7: ($\hat{\rho}_i$) FTS Sample 1

Year	N	Mean	Std	Min	Max
1990	1,389	0.5996	0.4984	-0.9138	0.9967
1991	1,444	0.5720	0.5153	-0.9281	0.9970
1992	1,461	0.5505	0.5176	-0.9385	0.9974
1993	1,488	0.5172	0.5262	-0.9816	0.9924
1994	1,503	0.5085	0.5442	-0.9721	0.9919
1995	1,560	0.5034	0.5490	-0.9712	0.9908
1996	1,624	0.4866	0.5569	-0.9303	0.9853
1997	1,667	0.4390	0.5859	-0.9579	0.9862
1998	1,677	0.4151	0.5987	-0.9718	0.9836
1999	1,663	0.4071	0.5952	-0.9523	0.9823
2000	1,639	0.4143	0.5882	-0.9399	0.9909
2001	1,636	0.4505	0.5600	-0.9416	0.9909
2002	1,615	0.4629	0.5558	-0.9536	0.9960
2003	1,595	0.4619	0.5492	-0.9699	0.9925
2004	1,596	0.4681	0.5327	-0.9564	0.9900
2005	1,578	0.4606	0.5235	-0.9447	0.9922
2006	1,589	0.4277	0.5247	-0.9100	0.9830
2007	1,604	0.3964	0.5265	-0.9245	0.9765
2008	1,626	0.3975	0.5087	-0.8969	0.9773
2009	1,613	0.3633	0.5344	-0.8786	0.9757
2010	1,596	0.3683	0.5427	-0.9556	0.9765
2011	1,609	0.4105	0.5590	-0.9363	0.9895
2012	1,612	0.4181	0.5593	-0.9606	0.9839
2013	1,604	0.3838	0.5450	-0.9173	0.9677
2014	1,574	0.4039	0.5000	-0.8938	0.9644
2015	1,632	0.3974	0.4970	-0.8992	0.9740
2016	1,609	0.3875	0.5015	-0.9024	0.9801
2017	1,591	0.4329	0.5129	-0.9589	0.9813
2018	1,548	0.4767	0.5218	-0.9776	0.9832
2019	1,531	0.4854	0.5263	-0.9830	0.9926
2020	1,509	0.4668	0.5402	-0.9929	0.9921

Note: Correlation coefficient between company *i*'s losses and the industry losses by year (1990–2020).

Table OA1.8: ($det\hat{\sigma}_i$) FTS Sample 1
($000 omitted)

Year	N	Mean	Std	Min	Max
1990	1,389	10,725.43	36,358.13	1.18	707,207.31
1991	1,444	10,644.01	33,107.90	1.23	510,089.40
1992	1,461	12,054.57	46,534.36	0.94	1,131,199.48
1993	1,488	13,233.55	51,719.14	0.57	1,258,690.85
1994	1,503	13,418.34	51,782.24	5.80	1,255,141.69
1995	1,560	13,292.76	54,485.09	5.27	1,357,146.75
1996	1,624	13,189.24	53,465.60	6.00	1,372,895.41
1997	1,667	13,110.83	56,459.72	5.77	1,464,568.60
1998	1,677	13,343.78	55,477.03	5.22	13,55,153.35
1999	1,663	13,724.02	57,107.97	2.44	1,325,129.18
2000	1,639	14,704.94	58,948.87	3.38	1,208,974.12
2001	1,636	16,236.37	65,147.14	0.77	1,413,865.68
2002	1,615	17,404.10	69,619.16	0.29	1,699,290.42
2003	1,595	19,254.78	73,631.27	0.27	1,641,447.78
2004	1,596	20,276.28	72,043.03	4.41	1,046,982.82
2005	1,578	21,568.18	76,328.53	0.50	1,335,272.97
2006	1,589	21,587.37	77,857.41	0.50	1,353,014.05
2007	1,604	22,025.38	82,061.92	0.50	1,579,697.25
2008	1,626	25,487.28	95,739.56	4.54	1,714,096.76
2009	1,613	26,191.50	96,580.23	0.93	1,597,155.77
2010	1,596	26,020.38	96,160.44	1.11	1,651,997.08
2011	1,609	25,762.17	92,713.73	0.64	1,776,210.43
2012	1,612	24,949.79	90,806.59	0.62	1,689,905.59
2013	1,604	25,309.53	96,704.64	4.69	1,863,772.96
2014	1,574	25,818.21	107,436.31	0.54	2,0408,39.11
2015	1,632	24,632.51	97,704.53	0.81	1,878,516.44
2016	1,609	23,644.81	99,665.42	0.47	2,089,036.67
2017	1,591	24,386.03	98,191.02	0.30	1,948,005.82
2018	1,548	25,392.86	91,481.23	0.31	1,606,395.66
2019	1,531	26,424.46	93,703.10	0.32	1,345,644.65
2020	1,509	28,043.87	106,060.33	0.32	1,974,576.45

Note: Detrended standard deviation of losses for a company by year (1990–2020).

Table OA1.9: ($det\hat{\rho}_i$) FTS Sample 1

Year	N	Mean	Std	Min	Max
1990	1,389	0.2020	0.4308	-0.9210	0.9654
1991	1,444	0.1696	0.3666	-0.9140	0.9497
1992	1,461	0.1576	0.3550	-0.8516	0.8855
1993	1,488	0.0822	0.4071	-0.8278	0.9336
1994	1,503	0.1064	0.3829	-0.8121	0.8649
1995	1,560	0.0785	0.4507	-0.9411	0.8798
1996	1,624	0.1116	0.3703	-0.7928	0.8750
1997	1,667	0.1257	0.2949	-0.8784	0.8786
1998	1,677	0.1460	0.2634	-0.7633	0.8850
1999	1,663	0.1169	0.2648	-0.8019	0.8629
2000	1,639	0.1267	0.3323	-0.8331	0.8939
2001	1,636	0.1898	0.4559	-0.8794	0.9336
2002	1,615	0.1400	0.3675	-0.8739	0.9405
2003	1,595	0.1084	0.3746	-0.8803	0.9450
2004	1,596	0.0124	0.4518	-0.8877	0.9185
2005	1,578	0.0545	0.4367	-0.9248	0.9380
2006	1,589	0.0308	0.4824	-0.9093	0.9160
2007	1,604	0.0891	0.4211	-0.9270	0.9461
2008	1,626	0.1760	0.5158	-0.8990	0.9782
2009	1,613	0.1781	0.4872	-0.8561	0.9492
2010	1,596	0.1727	0.4424	-0.8937	0.9414
2011	1,609	0.2120	0.3531	-0.8162	0.9433
2012	1,612	0.1746	0.3142	-0.8069	0.8978
2013	1,604	0.1481	0.3848	-0.8110	0.9172
2014	1,574	0.1621	0.3728	-0.7425	0.8999
2015	1,632	0.1571	0.4035	-0.8010	0.9262
2016	1,609	0.1924	0.3552	-0.7835	0.9462
2017	1,591	0.2791	0.4496	-0.8749	0.9703
2018	1,548	0.2522	0.5055	-0.9404	0.9636
2019	1,531	0.2670	0.5085	-0.9369	0.9790
2020	1,509	0.2419	0.4857	-0.9657	0.9845

Note: Detrended correlation coefficient between company *i*'s losses and the industry losses by year (1990–2020).

Table OA1.10a: FTS Sample 1
Tobit censored (Lb=0) model
Standard deviations: Net losses incurred 1997

Variable	Companies Raw	Companies Detrended	Group Raw	Group Detrended
Intercept	0.1490 7.69	-0.1919 -11.29	0.2099 4.57	0.1017 4.67
Ln (equity capital)	0.0231 10.19	0.0120 10.00	0.0403 7.34	0.0184 7.07
Ln (net losses incurred)	0.0039 2.16	0.0016 1.66	0.0016 0.35	0.0010 0.46
Short / Asset	0.0837 4.97	0.0431 4.83	0.1362 4.05	0.0649 4.07
Liquid asset / Asset	-0.0389 -1.79	-0.0237 -2.06	-0.0423 -0.81	-0.0242 -0.98
Sigma	0.0975 57.74	0.0515 57.73	0.1622 41.88	0.0769 41.88
Log likelihood	1,515	2,578	351	1,006
AIC	-3,019	-5,144	-690	-1,999
No. of observations	1,667	1,667	877	877

Note: Short = Cash + cash equivalent and short-term investment; Liquid asset = bond + stock + short. Lb is for lower bond. The dependent variable is the standard deviation of net losses incurred. For each variable, we report the regression coefficient and the *t*-ratio.

Table OA1.10b: FTS Sample 1
Tobit censored (Lb=0) model
Standard deviations: Net losses incurred 2005

Variable	Companies Raw	Companies Detrended	Group Raw	Group Detrended
Intercept	0.1952 9.39	-0.3165 -14.58	0.3666 6.43	0.1891 6.39
Ln (equity capital)	0.0353 11.62	0.0194 12.22	0.0629 8.05	0.0334 8.26
Ln (net losses incurred)	0.0058 2.37	0.0016 1.27	0.0048 0.72	0.0005 0.14
Short / Asset	0.1117 5.28	0.0501 4.52	0.2186 4.35	0.1084 4.16
Liquid asset / Asset	-0.0401 -1.61	-0.0302 -2.31	-0.1309 -1.91	-0.0729 -2.05
Sigma	0.1270 56.17	0.0665 56.17	0.2356 41.30	0.1222 41.30
Log likelihood	1,017	2,038	23	583
AIC	-2,022	-4,065	-33	-1,153
No. of observations	1,578	1,578	853	853

Note: Short = Cash + cash equivalent and short-term investment; Liquid asset = bond + stock + short. Lb is for lower bond. The dependent variable is the standard deviation of net losses incurred. For each variable, we report the regression coefficient and the *t*-ratio.

Table OA1.10c: FTS Sample 1
Tobit censored (Lb=0) model
Standard deviations: Net losses incurred 2014

Variable	Companies Raw	Companies Detrended	Group Raw	Group Detrended
Intercept	0.1687 8.32	-0.4161 -13.74	0.3041 5.66	0.1896 5.80
Ln (equity capital)	0.0318 10.03	0.0219 9.79	0.0558 6.89	0.0333 6.76
Ln (net losses incurred)	0.0081 2.99	0.0045 2.31	0.0087 1.17	0.0048 1.07
Short / Asset	0.1147 4.65	0.0745 4.27	0.2026 3.70	0.1115 3.35
Liquid asset / Asset	-0.0033 -0.95	-0.0140 -0.80	-0.0842 -1.29	-0.0584 -1.47
Sigma	0.1361 57.74	0.0962 56.10	0.2437 41.08	0.1484 41.08
Log likelihood	-1,800	1,451	-6	413
AIC	906	-2,890	24	-813
No. of observations	1,574	1,574	844	844

Note: Short = Cash + cash equivalent and short-term investment; Liquid asset = bond + stock + short. Lb is for lower bond. The dependent variable is the standard deviation of net losses incurred. For each variable, we report the regression coefficient and the *t*-ratio.

Table OA1.10d: FTS Sample 1
Tobit censored (Lb=0) model
Standard deviations: Net losses incurred 2020

Variable	Companies Raw	Companies Detrended	Group Raw	Group Detrended
Intercept	0.2520 8.12	-0.4745 -15.72	0.4290 5.26	0.2014 7.49
Ln (equity capital)	0.0548 9.62	0.0286 11.95	0.1012 6.94	0.0439 9.14
Ln (net losses incurred)	0.0035 0.75	0.0005 0.24	-0.0015 -0.12	-0.0016 -0.40
Short / Asset	0.1366 3.61	0.0664 4.19	0.3182 3.47	0.1191 3.94
Liquid asset / Asset	-0.0729 -1.93	-0.0337 -2.13	-0.1428 -1.44	-0.0771 -2.36
Sigma	0.2187 54.93	0.0917 54.93	0.4068 41.01	0.1340 41.01
Log likelihood	152	1,465	-437	497
AIC	-293	-2,917	886	-981
No. of observations	1,509	1,509	841	841

Note: Short = Cash + cash equivalent and short-term investment; Liquid asset = bond + stock + short. Lb is for lower bond. The dependent variable is the standard deviation of net losses incurred. For each variable, we report the regression coefficient and the *t*-ratio.

Table OA1.11a: FTS Sample 1
Tobit censored (Lb=-1 Ub=1) model
Correlation coefficient: Net losses incurred 1997

Variable	Companies Raw	Companies Detrended	Group Raw	Group Detrended
Intercept	0.6155	-0.2556	0.6311	0.2908
	4.74	-2.33	3.95	2.85
Ln (equity capital)	-0.1854	0.0190	-0.1413	0.0136
	-13.14	2.48	-7.83	1.18
Ln (net losses incurred)	0.2038	-0.0043	0.1747	0.0057
	15.94	-0.63	10.61	0.54
Short / Asset	-0.2251	-0.1419	-0.2748	-0.1130
	-2.42	-2.81	-2.83	-1.82
Total liability / Asset	-0.4826	0.0834	-0.3800	-0.0273
	-5.45	-1.76	-3.53	-1.83
Liquid asset / Asset	0.4003	0.0761	0.4446	-0.0809
	3.31	1.16	2.93	-0.83
Sigma	0.5370	0.2909	0.4651	0.2976
	57.74	57.74	41.88	41.78
Log likelihood	-1,329	-307	-573	-181
AIC	2,672	628	1,160	376
No. of observations	1,667	1,667	877	877

Note: Short = Cash + cash equivalent and short-term investment. Liquid asset = bond + stock + short. Lb and Ub are for lower bond and upper bond. The dependent variable is the correlation coefficient of net losses incurred. For each variable, we report the regression coefficient and the *t*-ratio.

Table OA1.11b: FTS Sample 1
Tobit censored (Lb=-1 Ub=1) model
Correlation coefficient: Net losses incurred 2005

Variable	Companies Raw	Companies Detrended	Group Raw	Group Detrended
Intercept	0.6000 5.61	-0.8631 -5.11	0.5953 4.18	0.1979 1.41
Ln (equity capital)	-0.1516 -12.32	0.0446 3.83	-0.1308 -8.24	0.0426 2.72
Ln (net losses incurred)	0.1982 17.61	-0.0054 -0.51	0.1689 11.22	-0.0206 -0.80
Short / Asset	-0.0315 -0.42	-0.0528 -0.74	-0.1854 -2.08	0.0206 0.23
Total liability / Asset	-0.1839 -2.15	0.1523 1.88	-0.1963 -1.79	0.0301 0.28
Liquid asset / Asset	0.3515 3.84	0.1314 1.52	0.3753 3.00	-0.1618 -1.31
Sigma	0.4529 57.74	0.4283 56.18	0.4168 41.30	0.4101 41.30
Log likelihood	-989	-901	-464	-542
AIC	1,992	1,816	942	917
No. of observations	1,578	1,578	853	853

Note: Short = Cash + cash equivalent and short-term investment. Liquid asset = bond + stock + short. Lb and Ub are for lower bond and upper bond. The dependent variable is the correlation coefficient of net losses incurred. For each variable, we report the regression coefficient and the *t*-ratio.

Table OA1.11c: FTS Sample 1
Tobit censored (Lb=-1 Ub=1) model
Correlation coefficient: Net losses incurred 2014

Variable	Companies Raw	Companies Detrended	Group Raw	Group Detrended
Intercept	0.7600 6.66	-0.3682 -2.53	0.8444 5.30	0.5688 4.62
Ln (equity capital)	-0.0953 -7.78	0.0301 3.11	-0.0875 -4.96	0.0108 0.79
Ln (net losses incurred)	0.1344 11.59	0.0074 0.81	0.1314 7.60	0.0292 2.19
Short / Asset	-0.4214 -5.07	-0.1676 -2.55	-0.3617 -3.60	-0.0359 -0.46
Total liability / Asset	-0.1707 -1.82	0.0085 0.12	-0.3479 -2.68	-0.1818 -1.81
Liquid asset / Asset	0.0359 0.39	-0.0816 -1.13	0.0416 0.32	-0.1818 -1.81
Sigma	0.4587 56.11	0.3621 56.11	0.4462 41.08	0.3444 41.08
Log likelihood	-1,007	-635	-516	-298
AIC	2,027	1,283	1,047	610
No. of observations	1,574	1,574	844	844

Note: Short = Cash + cash equivalent and short-term investment. Liquid asset = bond + stock + short. Lb and Ub are for lower bond and upper bond. The dependent variable is the correlation coefficient of net losses incurred. For each variable, we report the regression coefficient and the *t*-ratio.

Table OA1.11d: FTS Sample 1
Tobit censored (Lb=-1 Ub=1) model
Correlation coefficient: Net losses incurred 2020

Variable	Companies Raw	Companies Detrended	Group Raw	Group Detrended
Intercept	0.8806 7.36	-0.2092 -1.04	0.9784 6.06	0.5976 4.14
Ln (equity capital)	-0.0933 -6.18	-0.0160 -1.12	-0.1059 -5.21	-0.0258 -1.42
Ln (net losses incurred)	0.14.91 10.85	0.0670 5.19	0.1676 8.99	0.0840 5.04
Short / Asset	0.0093 0.11	-0.1831 -2.28	-0.0451 -0.40	-0.0054 -0.05
Total liability / Asset	-0.0757 -0.75	-0.0529 -0.56	-0.3499 -2.64	-0.4080 -3.45
Liquid asset / Asset	-0.0941 -1.00	0.1362 1.55	-0.0165 -0.13	0.0387 0.33
Sigma	0.4942 54.92	0.2600 57.11	0.4936 41.01	0.4413 41.01
Log likelihood	-1,077	-984	-600	-505
AIC	2,168	1,983	1,213	1,025
No. of observations	1,508	1,508	841	841

Note: Short = Cash + cash equivalent and short-term investment. Liquid asset = bond + stock + short. Lb and Ub are for lower bond and upper bond. The dependent variable is the correlation coefficient of net losses incurred. For each variable, we report the regression coefficient and the *t*-ratio.

Table OA1.12: ($\hat{\sigma}_i$) NFTS company Sample 1
Raw parameter estimates
($000 omitted)

Year	N	Mean	St	Min	Max
1990	2,214	38,262.78	122,647.24	1.9002924	4117,902.16
1991	2,241	37,257.02	124,521.22	1.5238839	4175,781.98
1992	2,255	38,491.61	133,002.82	1.3165612	4184,769.02
1993	2,252	36,727.27	127,275.28	0.6992059	404,7432.60
1994	2,267	36,419.91	126,388.33	6.1110101	416,0714.72
1995	2,280	34,511.77	119,377.04	5.8585171	4038,217.10
1996	2,285	31,921.98	107,770.91	7.0364132	353,1777.62
1997	2,286	29,353.53	92,700.48	6.2618776	285,9433.91
1998	2,277	27,553.65	82,005.49	6.0745370	240,3336.98
1999	2,213	27,112.82	79,766.38	2.5298221	205,6463.79
2000	2,165	28,947.64	85,853.00	3.5213634	214,2909.44
2001	2,137	31,521.77	97,563.02	0.9660918	240,8613.36
2002	2,103	34,955.22	107,517.57	0.3162278	282,5926.51
2003	2,101	36,983.62	111,073.02	0.3162278	282,6442.64
2004	2,143	39,145.19	114,745.54	5.0782762	284,7132.67
2005	2,152	42,452.05	126,396.80	0.6749486	330,1741.99
2006	2,193	41,618.41	120,717.28	0.6749486	282,2807.25
2007	2,223	41,733.10	119,734.33	0.6749486	259,5686.90
2008	2,246	46,170.06	131,774.17	5.9451194	233,9542.42
2009	2,207	46,099.45	130,553.41	1.0327956	195,7636.38
2010	2,163	43,566.03	125,713.44	1.1595018	200,6493.32
2011	2,119	44,877.34	134,718.38	0.6749486	248,3517.16
2012	2,069	43,282.95	131,184.67	0.6749486	236,9475.80
2013	2,016	41,625.23	1265,49.29	5.3343749	226,1733.09
2014	1,923	41,562.38	14,125.61	0.5676462	341,9126.79
2015	1,953	42,465.51	159,136.71	0.9486833	448,6420.20
2016	1,911	45,077.36	185,334.98	0.4714045	519,4632.04
2017	1,864	49,273.18	210,090.70	0.3162278	617,0229.88
2018	1,825	55,019.29	223,799.95	0.3162278	676,0598.56
2019	1,805	56,922.55	230,947.71	0.3162278	704,1168.30
2020	1,787	58,114.23	224,898.94	0.3162278	680,0905.57

Note: Standard deviation of the net losses and loss expense incurred for a company by year (1990–2020). NFTS: Non Full Time Sample.

Table OA1.13: ($\hat{\rho}_i$) NFTS company Sample 1
Raw parameter estimates

Year	N	Mean	Std	Min	Max
1990	2,214	0.5441727	0.4222848	-0.9137534	0.9967239
1991	2,241	0.5353007	0.4349050	-0.9280519	0.9969796
1992	2,255	0.5205230	0.4366218	-0.9384972	0.9974125
1993	2,252	0.4966674	0.4463094	-0.9815604	0.9937107
1994	2,267	0.4837493	0.4634369	-0.9721156	0.9920304
1995	2,280	0.4852563	0.4711936	-0.9712140	0.9908177
1996	2,285	0.4709582	0.4835533	-0.9302615	0.9933658
1997	2,286	0.4376478	0.5104966	-0.9579326	0.9890006
1998	2,277	0.4190612	0.5216771	-0.9717621	0.9836439
1999	2,213	0.4104522	0.5242314	-0.9523313	0.9822703
2000	2,165	0.4102226	0.5215430	-0.9398921	0.9909369
2001	2,137	0.4362449	0.5007022	-0.9416348	0.9929707
2002	2,103	0.4435981	0.4977894	-0.9536398	0.9975875
2003	2,101	0.4445977	0.4899440	-0.9698603	0.9924989
2004	2,143	0.4492404	0.4715302	-0.9564016	0.9900277
2005	2,152	0.4399406	0.4610354	-0.9446858	0.9922169
2006	2,193	0.4106590	0.4573220	-0.9099513	0.9829975
2007	2,223	0.3894431	0.4553844	-0.9245297	0.9764916
2008	2,246	0.3829737	0.4406763	-0.8968988	0.9772564
2009	2,207	0.3537403	0.4626468	-0.8785671	0.9756570
2010	2,163	0.3621326	0.4715820	-0.9556466	0.9764595
2011	2,119	0.3962341	0.4936443	-0.9363437	0.9894695
2012	2,069	0.4008681	0.5007567	-0.9605558	0.9839189
2013	2,016	0.3697069	0.4919099	-0.9172777	0.9676735
2014	1,923	0.3847622	0.4591986	-0.8938171	0.9644265
2015	1,953	0.3804337	0.4602265	-0.8991615	0.9740115
2016	1,911	0.3723453	0.4663885	-0.9023961	0.9801297
2017	1,864	0.4150154	0.4806087	-0.9589268	0.9812657
2018	1,825	0.4542618	0.4896486	-0.9775956	0.9831742
2019	1,805	0.4627841	0.4933521	-0.9830116	0.9925968
2020	1,787	0.4487483	0.5038403	-0.9929358	0.9920923

Note: Correlation coefficient between company *i*'s losses and the industry losses by year (1990–2020). NFTS: Non Full Time Sample.

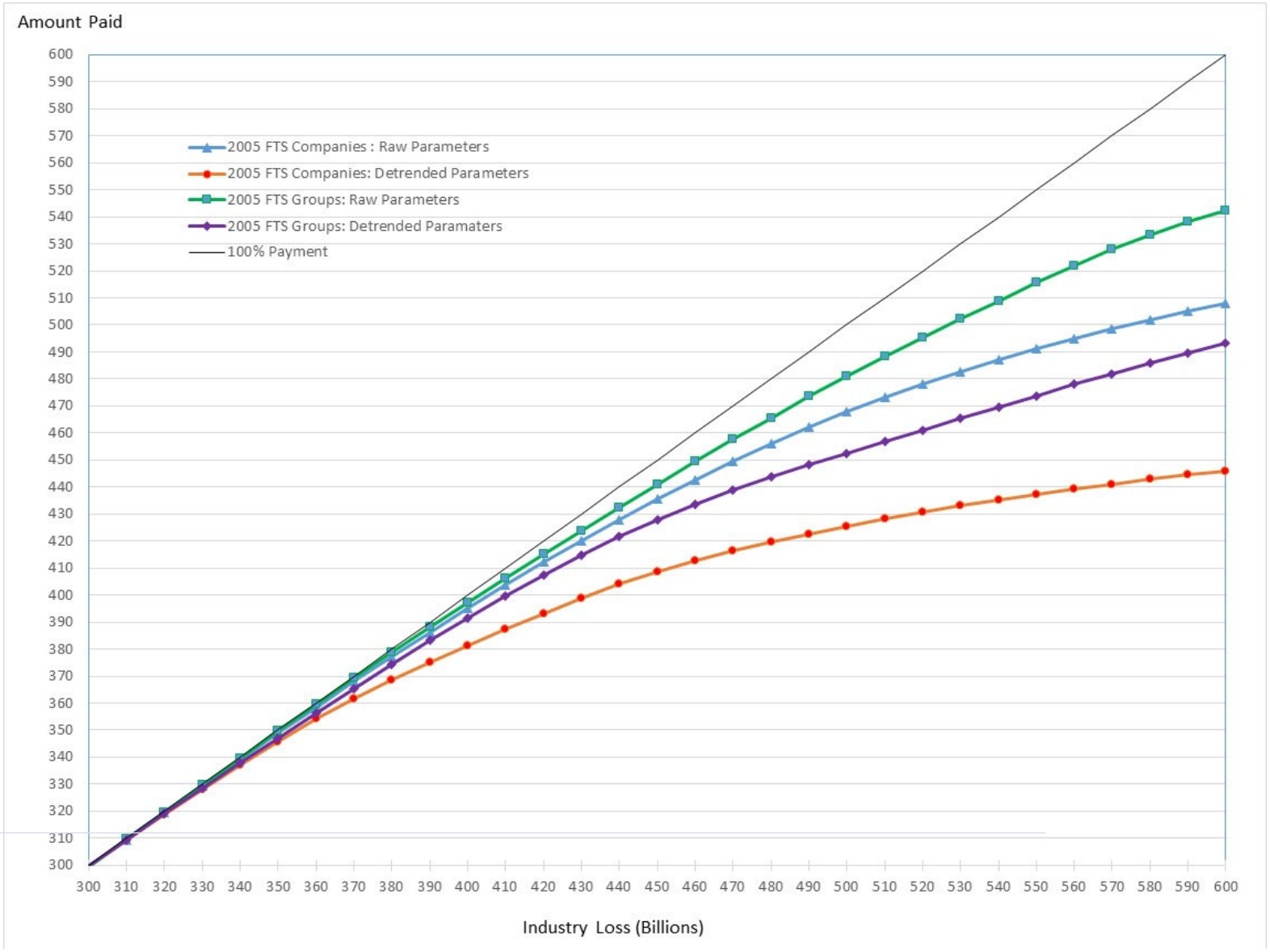

Figure OA1.1:Industry capacity, 2005 (FTS sample 1)

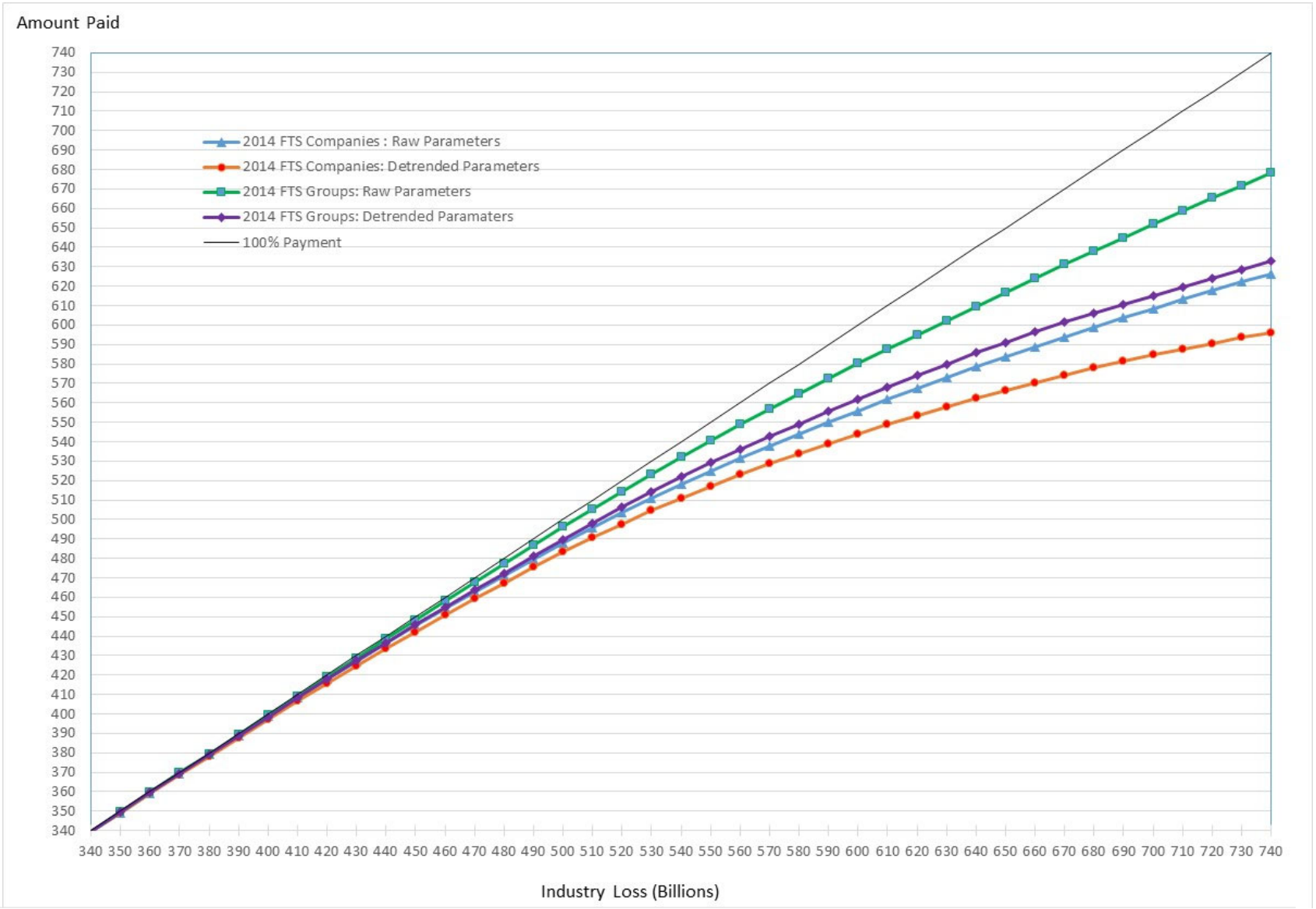

Figure OA1.2:Industry capacity, 2014 (FTS sample 1)

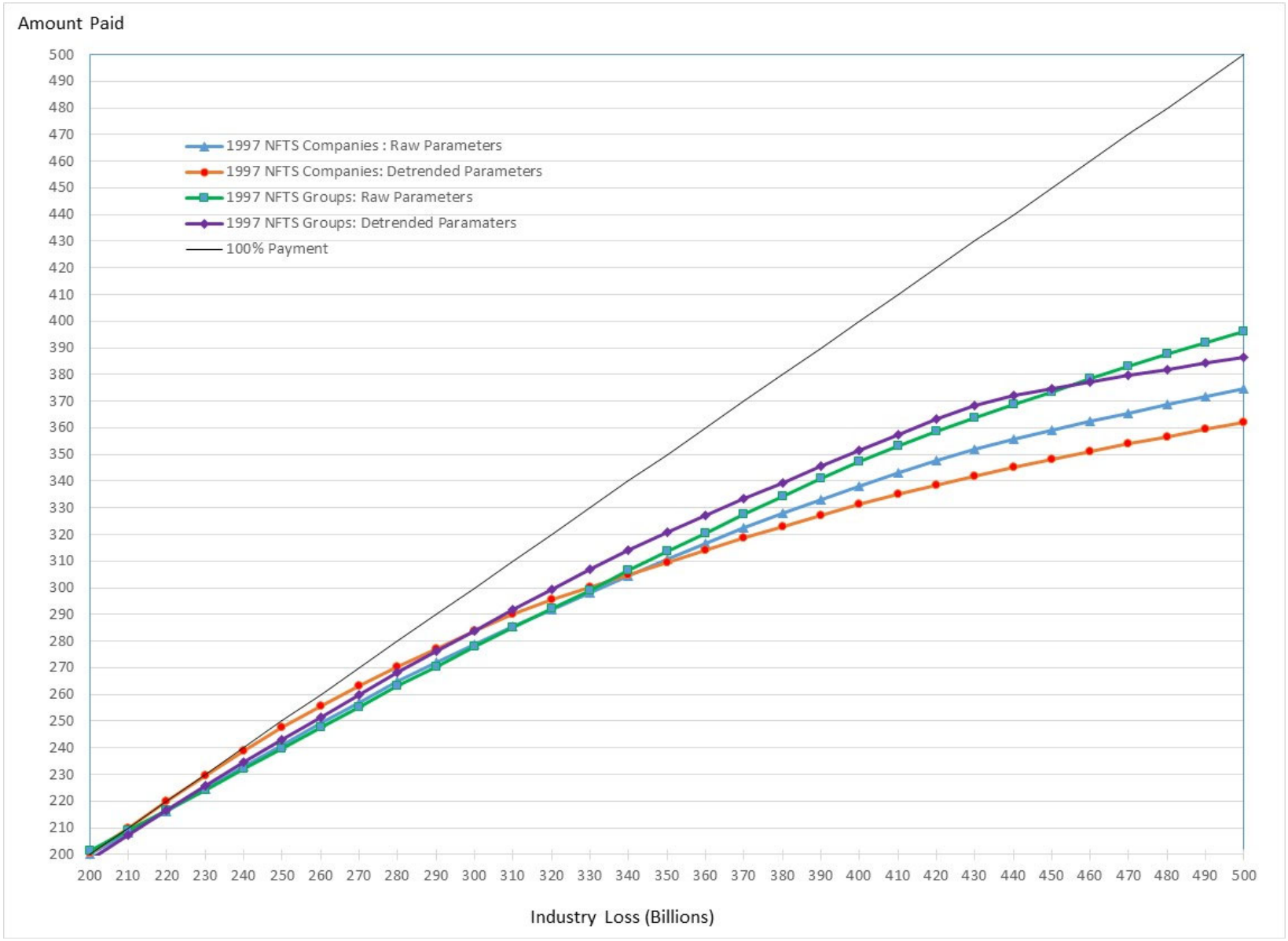

Figure OA1.3: Industry capacity, 1997 (NFTS sample 1)

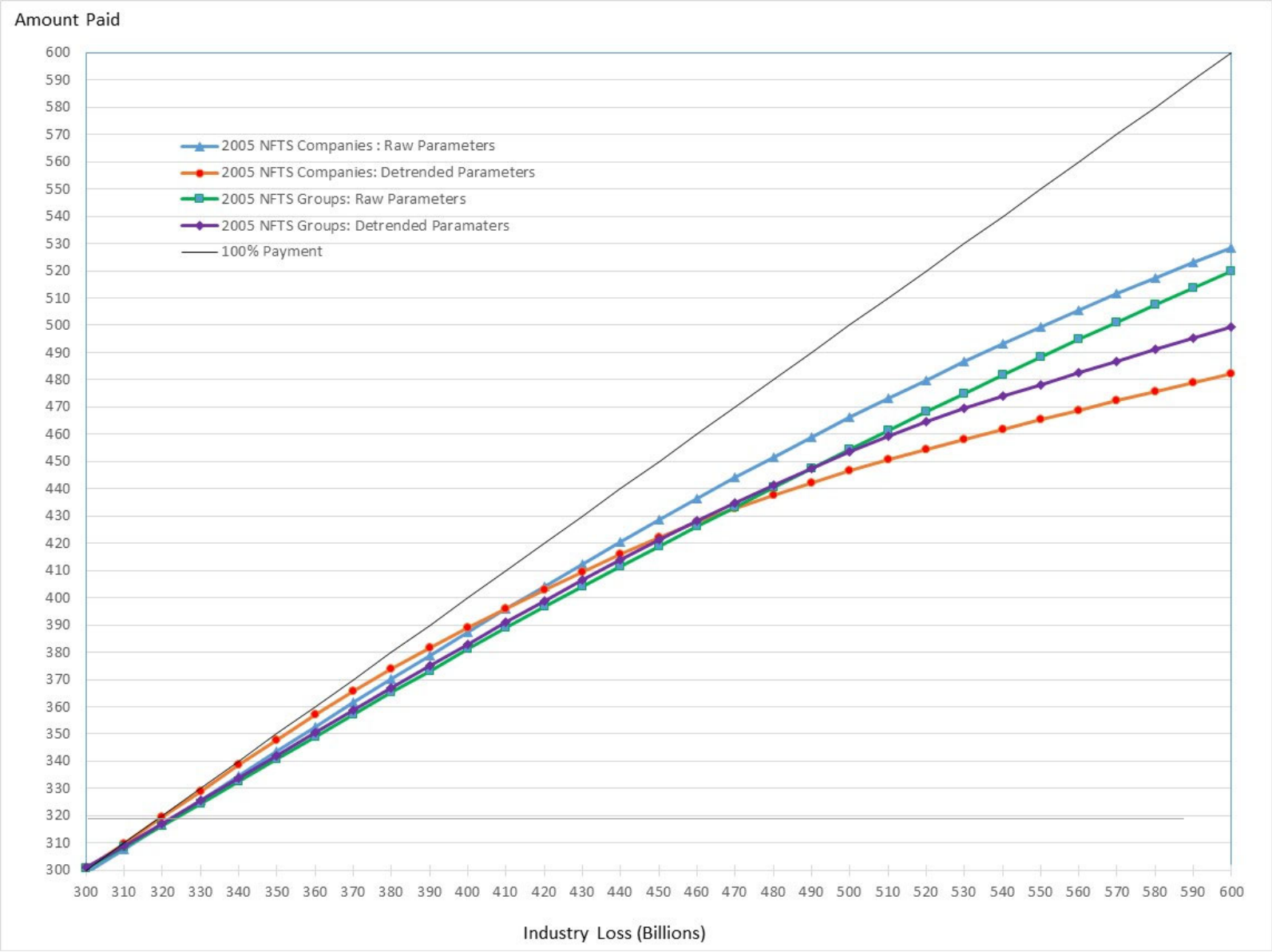

Figure OA1.4: Industry capacity, 2005 (NFTS sample 1)

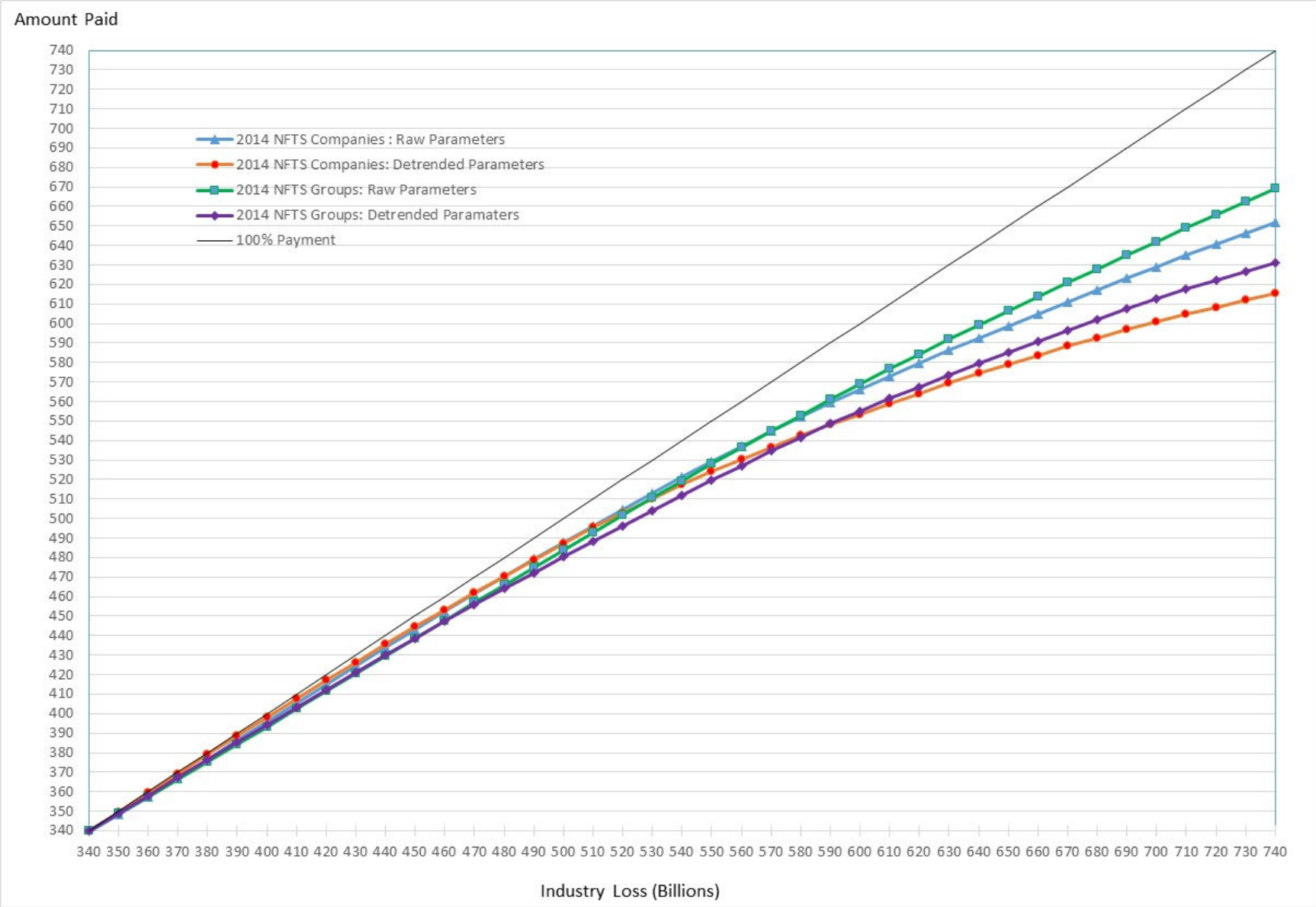

Figure OA1.5: Industry capacity, 2014 (NFTS sample 1)

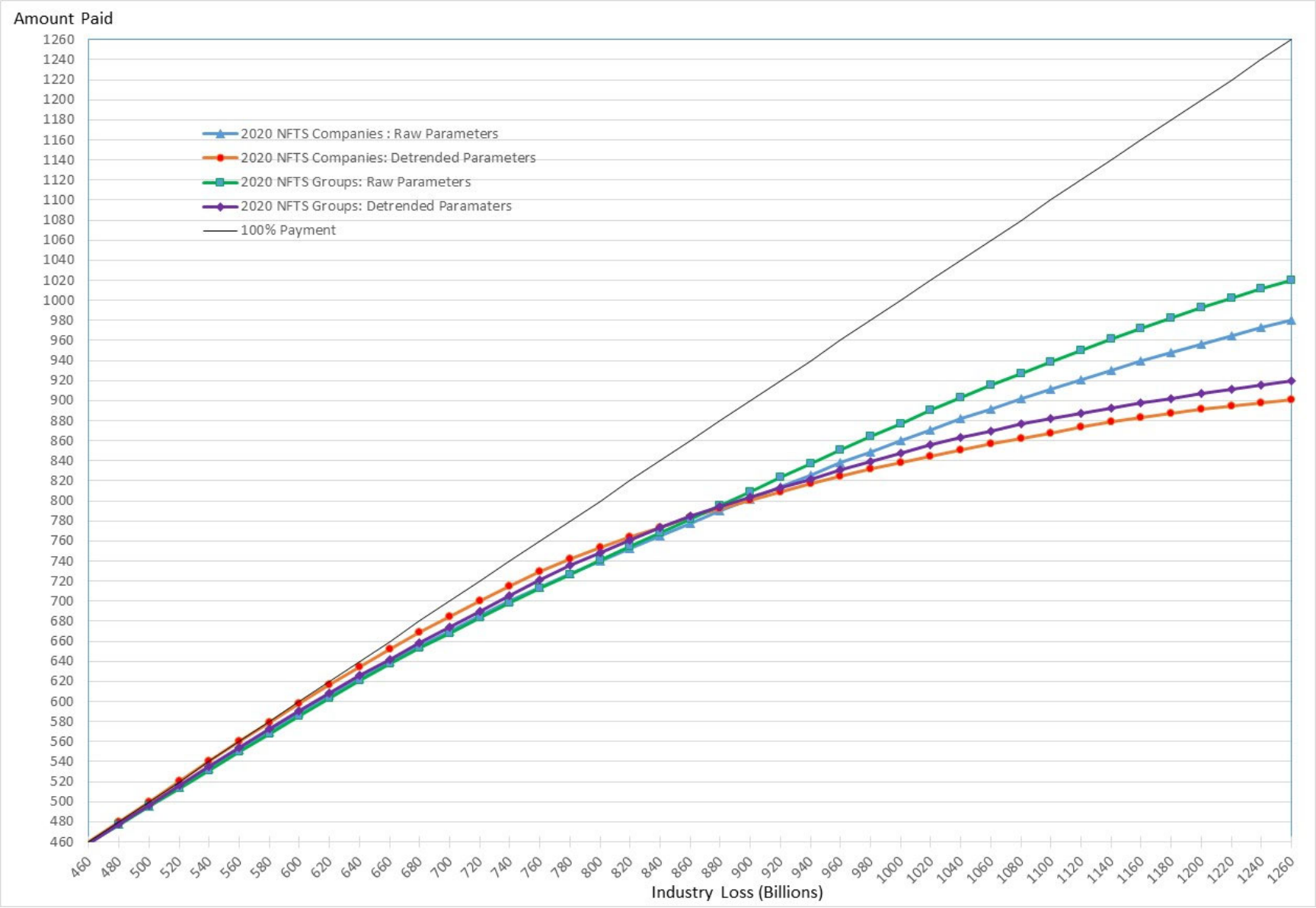

Figure OA1.6: Industry capacity, 2020 (NFTS sample 1)

Online appendix OA2 – Sample 2

Table OA2.1 and Table OA2.2 report net losses and equity capital for FTS and NFTS data for different years for all companies and groups and unaffiliated companies. We observe that the ratio of net losses over capital has decreased over the years in Table OA2.2. The net losses in 2005 are equal to $312 billion for 2,152 insurance companies. It increased to $461 billion for 1,787 insurers in 2020 while capital increased more rapidly during the same period. For example, in Table OA2.1 (Table OA2.2), the ratio was 60% (60%) in 2005 and 42% (42%) in 2020.

In 2005, the FTS Sample 2 increases by 46 companies compared to Sample 1 and by 31 and 61 companies in 2014 and in 2020 respectively. For group and unaffiliated companies, the increases in comparison to Sample 1 are respectively 13, 23 and 36.

Table OA2.1: FTS Sample 2
Summary statistics: Losses and equity capital
($000 omitted)

	Insurance industry FTS		Number of firms
Sample	Net losses incurred	Equity capital	
2005			
Groups & unaffiliated companies	301,056,222	500,640,175	866
All companies	301,056,222	500,640,175	1,624
2014			
Groups & unaffiliated companies	341,865,660	782,443,692	867
All companies	341,865,660	782,443,692	1,605
2020			
Groups & unaffiliated companies	455,145,860	1,087,840,856	877
All companies	455,145,860	1,087,840,856	1,570

Table OA2.2: NFTS Sample 2
Summary statistics: Losses and equity capital
($000 omitted)

Sample	Insurance industry FTS		Number of firms
	Net losses incurred	Equity capital	
2005			
Groups & unaffiliated companies	311,568,085	520,451,387	1,200
All companies	311,568,085	520,451,387	2,152
2014			
Groups & unaffiliated companies	349,123,503	803,479,225	1,064
All companies	349,123,503	803,479,225	1,923
2020			
Groups & unaffiliated companies	461,350,387	1,109,446,600	992
All companies	461,350,387	1,109,446,600	1,787

To estimate the industry observed response function, we need, for each company *i*, to calculate the standard deviation of the net losses ($\hat{\sigma}_i$) and the correlation coefficient between company *i*'s losses and the industry losses ($\hat{\rho}_i$). In Table OA2.3, on average, the detrended standard deviation is higher in 2014 than in 2005 and is higher in 2020 than in 2014, regardless the sample. This is not the same pattern for the detrended correlation coefficient. It is lower in 2014 than in 2005 and 2020 for Sample 2.

By inserting the financial characteristics of the NFTS firms into the estimated equations, we obtain fitted parameters of the standard deviation and correlation coefficient. We use these values for companies not in the FTS sample, called the NFTS estimates. On average, the detrented standard deviation are lowest than those from FTS sample, as so for Sample 1 and Sample 2.

The average value of the raw and detrended parameter estimates for all companies and groups and unaffiliated companies are presented in Table OA2.3 for FTS and NFTS data in Sample 2. The detrended standard deviations and correlations are higher in 2020.

As expected, detrending reduces the magnitudes of loss standard deviations and the correlations between companies and industry losses. Because detrending leads to larger reductions in correlations than the standard deviations, we expect the estimated loss payments

to be lower for the detrended parameter estimates than for the raw estimates. The standard deviation estimates tend to be larger for the companies' sample than for groups sample.

Table OA2.3: Detrended and raw parameter estimates:
Property-liability insurance industry with values from Sample 2

	Average				
Case	Detrended sigma × 10^8	Detrended correlation	Raw Sigma × 10^8	Raw Correlation	Number of firms
2005					
Insurance industry (FTS)					
Groups & unaffiliated companies	0.2928	0.2042	0.6211	0.4954	866
All companies	0.2136	0.1894	0.4092	0.4349	1,624
Insurance industry (NFTS)					
Groups & unaffiliated companies	0.3290	0.2168	0.7048	0.4812	1,201
All companies	0.1612	0.1735	0.4309	0.4334	2,152
2014					
Insurance industry (FTS)					
Groups & unaffiliated companies	0.3717	0.1097	0.5793	0.2760	867
All companies	0.2767	0.1240	0.4004	0.2587	1,605
Insurance industry (NFTS)					
Groups & unaffiliated companies	0.3986	0.1157	0.6318	0.2787	1,064
All companies	0.2309	0.1042	0.4230	0.2651	1,923
2020					
Insurance industry (FTS)					
Groups & unaffiliated companies	0.4015	0.1524	0.8217	0.3483	877
All companies	0.3005	0.1941	0.5470	0.3680	1,570
Insurance industry (NFTS)					
Groups & unaffiliated companies	0.4208	0.1635	0.8972	0.3496	992
All companies	0.2640	0.1734	0.2927	0.3675	1,787

Note: FTS: Full Time Sample. NFTS: Non Full Time Sample.

The response functions are calculated for various values of L, the total industry net loss. The response functions for the insurance industry Sample 2 are shown in figures OA2.1 to OA2.3 respectively for 2005, 2014 and 2020. This sample is composed of firms that have full time series (FTS). The horizontal axis measures possible values for aggregate insurance industry net losses. The vertical axis measures the expected payout of all firms considered.

The figures show the estimated amounts that would be paid for the industry losses, spanning from the actual expected losses adding unexpected losses for a given year: spanning from $300 billion

to $600 billion in 2005; from $340 billion to $740 billion in 2014; and from $460 billion to $1,260 billion in 2020. These limits were chosen for total losses and loss expenses for the US property-liability insurance industry and the total equity capital. Four response curves are shown in the figures based on raw and detrended parameters for group and company sample. Our main interpretation will be for detrented parameters for all companies.

Figure OA2.1 shows that in 2005, the response curve with detrented FTS data from Sample 2 begins to diverge from the 45° line approximatively at $350 billion and that the 2020 response curve begins to diverge from the 45° line approximatively at $620 billion (same amount as in Sample 1).

The corresponding numbers for realized capacity are presented in Table OA2.4. Realized capacity is obtained as the ratio, at the chosen loss level, of the value of the response curve E(L)Z to the value of the maximum curve E(L)C. We observe that all companies in the FTS Sample 2 were able to pay 96.5% of a $100 billion loss in 2005, but only 86.0% for a $200 billion loss. In 2020, the percentage is 99.4%. We observe that, in 2020, the industry seems to be able to cover 85.8% (86.3% NFTS) of a $400 billion event during a year.

Table OA2.4: Capacity from Sample 2 with detrented values

	%			
2005	100 billion	200 billion	300 billion	400 billion
Insurance industry (FTS)				
Groups & unaffiliated companies	99.5	96.9	91.3	84.9
All companies	96.5	86.0	73.2	62.4
Insurance industry (NFTS)				
Groups & unaffiliated companies	94.8	89.9	84.0	77.4
All companies	97.2	87.7	74.9	64.0

2014	%			
	100 billion	200 billion	300 billion	400 billion
Insurance industry (FTS)				
Groups & unaffiliated companies	99.4	97.5	93.3	88.5
All companies	99.6	92.3	84.8	77.3
Insurance industry (NFTS)				
Groups & unaffiliated companies	97.5	94.4	90.4	84.9
All companies	97.9	92.9	85.5	78.1

2020	%					
	100 billion	200 billion	300 billion	400 billion	500 billion	600 billion
Insurance industry (FTS)						
Groups & unaffiliated companies	99.9	98.9	96.3	93.5	90.5	86.9
All companies	99.4	97.3	92.3	85.8	79.4	73.0
Insurance industry (NFTS)						
Groups & unaffiliated companies	98.8	97.4	94.8	90.9	86.2	81.4
All companies	99.4	97.5	92.8	86.3	79.9	73.5

Tables OA2.5 to OA2.8 report net losses and capital for all years. We can see from Table OA2.5 and Table OA2.7 that the number of companies significantly decreases after 2015. Also, the mean of the net losses increases by year, with few exceptions. Summary statistics on equity capital, the other determinant for computing industry capacity, are presented in tables OA2.6 and OA2.8 for the same period.

Table OA2.5: NFTS Sample 2
Summary statistics: Net losses and loss expense incurred by year (1999–2020)
($000 omitted)

Year	N	Sum	Mean	Std	Min	Max
1999	2,210	227,802,694	103,078.14	637,697.63	1	21,203,854
2000	2,165	241,115,798	111,369.88	702,301.10	1	23,335,985
2001	2,137	267,248,292	125,057.69	771,214.06	1	25,798,108
2002	2,103	263,045,184	125,080.92	797,826.99	1	27,672,128
2003	2,099	275,236,093	131,127.25	814,389.38	1	27,807,298
2004	2,142	290,234,616	135,497.02	807,557.41	1	27,059,473
2005	2,152	311,568,085	144,780.71	907,532.39	1	29,846,734
2006	2,193	294,508,283	134,294.70	792,433.87	1	25,459,006
2007	2,223	312,562,459	140,603.90	821,870.35	1	26,371,754
2008	2,246	356,466,021	158,711.50	912,082.83	1	28,142,990
2009	2,207	325,036,521	147,275.27	883,359.23	1	28,701,847
2010	2,163	323,710,757	149,658.23	910,450.20	1	29,717,899
2011	2,119	358,938,218	169,390.38	988,525.45	1	30,474,865
2012	2,070	347,995,300	168,113.67	970,799.53	1	30,204,525
2013	2,015	334,896,552	166,201.76	983,058.36	1	31,447,613
2014	1,922	349,121,622	181,644.96	1,079,198.03	1	32,970,073
2015	1,952	363,650,313	186,296.27	1,11,6173.01	1	34,203,391
2016	1,911	388,339,598	203,212.77	1,24,7026.09	1	38,768,776
2017	1,867	425,020,601	227,648.96	1,326,338.40	1	38,816,047
2018	1,825	443,081,776	242,784.53	1,319,597.25	1	36,187,577
2019	1,805	454,609,413	251,861.17	1,361,103.60	1	36,311,052
2020	1,787	461,350,387	258,170.33	1,319,821.69	1	31,865,776

Note: NFTS: Non Full Time Sample.

Table OA2.6: NFTS Sample 2
Summary statistics: Equity capital by year (1999–2020)
($000 omitted)

Year	N	Sum	Mean	Std	Min	Max
1999	2,210	411,240,919	186,081.86	1,294,377.81	25.09	45,762,499
2000	2,165	382,656,656	176,746.72	1,226,322.77	10.79	43,69,0982
2001	2,137	357,299,727	167,196.88	1,047,016.79	143.50	37,989,956
2002	2,103	354,606,347	168,619.28	956,414.88	64.29	31,600,585
2003	2,099	424,775,535	202,370.43	1,221,028.77	44.44	39,980,587
2004	2,142	476,739,961	222,567.68	1,388,336.55	0.77	46,144,211
2005	2,152	520,451,388	241,845.44	1,489,481.92	107.24	50,187,253
2006	2,193	590,617,960	269,319.64	1,735,785.29	246.48	58,034,268
2007	2,223	635,480,464	285,866.16	1,849,520.83	147.83	63,577,269
2008	2,246	573,351,953	255,276.92	1,553,939.71	18.16	53,273,952
2009	2,207	637,141,361	288,691.15	1,791,981.96	161.83	58,180,271
2010	2,163	681,298,430	314,978.47	2,233,559.24	7.94	68,437,054
2011	2,119	677,006,054	319,493.18	2,268,255.59	45.51	70,155,428
2012	2,070	717,940,223	346,831.03	2,520,754.21	15.41	78,861,515
2013	2,015	788,520,341	391,325.23	3,008,637.56	2.81	97,226,052
2014	1,922	803,479,224	418,043.30	3,107,233.08	1.62	93,997,652
2015	1952	817,507,742	418,805.20	3,059,085.59	5.07	89,828,619
2016	1,911	855,520,039	447,681.86	3,355,687.24	77.63	101,285,906
2017	1,867	913,923,769	489,514.61	4,000,798.79	77.10	128,562,566
2018	1,825	902,810,027	494,690.43	3,991,042.47	106.64	122,471,087
2019	1,805	1,034,756,942	573,272.54	5,092,094.30	256.15	167,718,679
2020	1,787	1,109,446,572	620,843.07	5,648,877.36	167.44	187,762,294

Note: NFTS: Non Full Time Sample.

Table OA2.7: FTS Sample 2
Summary statistics: Net losses and loss expense incurred by year (1999–2020)
($000 omitted)

Year	N	Sum	Mean	Std	Min	Max
1999	1,544	212,438,498	137,590	757,791	1	21,203,854
2000	1,587	225,907,905	142,349	815,376	1	23,335,985
2001	1,607	253,852,110	157,966	884,635	1	25,798,108
2002	1,597	251,871,393	157,715	912,182	1	27,672,128
2003	1,590	263,898,977	165,974	932,012	1	27,807,298
2004	1,614	277,595,068	171,992	925,436	1	27,059,473
2005	1,624	301,056,223	185,379	1,040,565	1	29,846,734
2006	1,649	285,021,697	172,845	909,631	1	25,459,006
2007	1,670	305,571,487	182,977	944,153	1	26,371,754
2008	1,687	349,086,306	206,927	1,047,719	1	28,142,990
2009	1,682	317,512,832	188,771	1,007,971	1	28,701,847
2010	1,657	317,669,976	191,714	1,036,488	1	29,717,899
2011	1,654	352,088,151	212,871	1,114,624	1	30,474,865
2012	1,657	341,834,579	206,297	1,081,353	1	30,204,525
2013	1,650	328,008,464	198,793	1,083,151	1	31,447,613
2014	1,605	341,865,660	213,000	1,177,529	1	32,970,073
2015	1,652	355,257,530	215,047	1,210,053	1	34,203,391
2016	1,643	379,480,446	230,968	1,341,852	1	38,768,776
2017	1,626	416,136,535	255,927	1,418,030	1	38,816,047
2018	1,599	435,339,900	272,258	1,406,274	1	36,187,577
2019	1,584	446,855,787	282,106	1,449,262	1	36,311,052
2020	1,570	455,145,860	289,902	1,404,425	1	31,865,776

Note: FTS: Full Time Sample.

Table OA2.8: FTS Sample 2
Summary statistics: Equity capital by year (1999 – 2020)
($000 omitted)

Year	N	Sum	Mean	Std	Min	Max
1999	1,544	377,480,687	244,482	1,536,869	25	45,762,499
2000	1,587	356,613,757	224,709	1,424,376	11	43,690,982
2001	1,607	336,281,904	209,261	1,200,718	205	37,989,956
2002	1,597	332,190,630	208,009	1,090,473	64	31,600,585
2003	1,590	401,918,481	252,779	1,395,280	178	39,980,587
2004	1,614	454,092,007	281,346	1,591,076	1	46,144,211
2005	1,624	500,640,175	308,276	1,707,467	107	50,187,253
2006	1,649	570,139,430	345,749	1,994,003	246	58,034,268
2007	1,670	618,632,479	370,439	2,126,157	346	63,577,269
2008	1,687	558,533,592	331,081	1,785,998	18	53,273,952
2009	1,682	620,945,162	369,171	2,045,296	162	58,180,271
2010	1,657	668,415,731	403,389	2,545,199	266	68,437,054
2011	1,654	657,117,910	397,290	2,557,653	68	70,155,428
2012	1,657	698,883,584	421,776	2,808,191	18	78,861,515
2013	1,650	762,244,817	461,967	3,315,283	3	97,226,052
2014	1,605	782,443,692	487,504	3,391,295	2	93,997,652
2015	1,652	792,376,136	479,647	3,316,182	5	89,828,619
2016	1,643	826,890,719	503,281	3,610,239	78	101,285,906
2017	1,626	885,922,479	544,848	4,279,545	77	128,562,566
2018	1,599	876,509,832	548,161	4,256,301	348	122,471,087
2019	1,584	1,008,161,393	636,466	5,429,071	256	167,718,679
2020	1,570	1,087,840,856	692,892	6,021,632	167	187,762,294

Note: FTS: Full Time Sample.

Table OA2.9: FTS Sample 2
($000 omitted)

Year	L_{t-9}	L_{t-8}	L_{t-7}	...	L_{t-2}	L_{t-1}	L_t	$\bar{L}$	$\hat{\sigma}$
1999	165,070,465	170,786,238	184,559,286	...	195,296,312	195,296,312	212,438,498	189,188,950	15,086,455.69
2000	169,044,072	182,945,640	175,071,000	...	204,056,437	204,056,437	225,907,905	194,024,959	16,917,085.67
2001	180,157,538	172,929,731	189,671,597	...	210,601,349	210,601,349	253,852,110	201,453,818	23,768,580.37
2002	170,489,993	187,214,152	184,695,417	...	223,615,354	223,615,354	251,871,393	206,650,371	27,876,263.67
2003	182,186,123	180,720,081	191,924,880	...	247,674,936	247,674,936	263,898,977	212,585,817	30,762,693.73
2004	180,717,787	191,686,565	187,613,988	...	249,584,084	249,584,084	277,595,068	222,366,403	35,073,580.34
2005	189,079,385	185,854,742	195,691,116	...	264,371,383	264,371,383	301,056,223	233,253,214	40,542,289.84
2006	184,255,757	193,931,510	202,213,799	...	277,984,038	277,984,038	285,021,697	241,321,486	40,446,703.10
2007	194,995,044	203,566,942	219,021,827	...	302,929,771	302,929,771	305,571,487	255,198,659	39,923,130.87
2008	203,130,587	218,956,067	245,963,471	...	288,675,720	288,675,720	349,086,306	270,846,560	43,859,714.49
2009	218,545,048	245,245,982	246,902,682	...	303,210,282	303,210,282	317,512,832	281,705,995	38,617,557.67
2010	242,227,275	244,167,692	261,959,350	...	346,196,652	346,196,652	317,669,976	290,007,323	33,708,500.25
2011	242,638,805	261,116,871	279,328,695	...	316,273,507	316,273,507	352,088,151	299,841,348	34,405,314.98
2012	259,705,338	277,829,914	298,305,935	...	314,543,576	314,543,576	341,834,579	308,125,942	29,817,333.68
2013	270,828,434	291,861,579	278,740,530	...	342,927,007	342,927,007	328,008,464	309,431,752	25,470,658.89
2014	288,309,451	275,423,468	288,637,587	...	331,967,567	331,967,567	341,865,660	312,610,604	23,467,858.46
2015	276,772,479	289,259,581	327,531,252		326,847,280	326,847,280	355,257,530	321,220,378	25,025,958.16
2016	285,742,186	319,393,996	298,815,048		339,508,063	339,508,063	379,480,446	326,154,782	27,685,472.28
2017	316,516,023	297,633,725	303,841,529		351,236,303	351,236,303	416,136,535	338,579,195	35,813,920.94
2018	294,846,357	300,754,974	332,201,422		377,036,313	377,036,313	435,339,900	348,724,284	46,787,638.49
2019	299,074,452	332,908,907	326,028,851		412,998,178	412,998,178	446,855,787	362,843,563	51,625,156.21
2020	329,207,928	322,613,672	316,855,527		431,989,804	431,989,804	455,145,860	377,105,854	54,409,930.12

Note: Sum of the observed losses of company *i* were incurred in year *t-9 up to t* ($L_{t-9,}$ ... L_t). Mean of $\bar{L}$ and $\hat{\sigma}$ of losses for the industry by year (1999–2020).

Table OA2.10: ($\hat{\sigma}_i$) FTS Sample 2
($000 omitted)

Year	N	Mean	Std	Min	Max
1999	1,544	26,774.97	90,884.93	2.92	1,887,885.58
2000	1,587	26,982.13	92,322.88	3.52	1,855,958.00
2001	1,607	29,591.51	103,418.28	4.97	2,066,663.63
2002	1,597	30,896.90	112,312.69	5.06	2,560,266.88
2003	1,590	33,703.91	122,554.42	3.97	2,806,037.96
2004	1,614	36,841.30	133,013.21	1.87	2,995,902.86
2005	1,624	40,915.22	151,152.87	0.70	3,422,909.26
2006	1,649	40,987.29	150,013.49	0.84	3,244,337.70
2007	1,670	42,595.97	146,446.10	0.95	2,888,558.78
2008	1,687	46,074.53	156,299.92	3.37	2,503,745.18
2009	1,682	44,656.56	147,912.05	0.95	1,864,819.90
2010	1,657	42,512.52	141,914.36	0.95	2,031,191.09
2011	1,654	42,007.39	142,784.27	0.95	2,540,712.37
2012	1,657	41,031.27	139,621.27	0.95	2,507,130.26
2013	1,650	40,151.10	139,458.39	0.95	2,305,921.62
2014	1,605	40,040.84	152,558.30	2.62	3,237,178.54
2015	1,652	41,091.38	176,521.87	2.16	4,527,884.46
2016	1,643	40,905.07	195,205.11	2.18	5,430,884.19
2017	1,626	45,859.72	226,003.67	2.21	6,471,322.48
2018	1,599	50,353.93	246,378.31	0.63	7,152,922.33
2019	1,584	53,758.50	259,416.98	0.32	7,557,199.84
2020	1,570	54,704.29	258,010.65	0.32	7,458,306.70

Note: Summary statistics: Standard deviation of the net losses and loss expense incurred for a company by year (1999–2020).

Table OA2.11 ($\hat{\rho}_i$) FTS Sample 2

Year	N	Mean	Std	Min	Max
1999	1,544	0.3705	0.5926	-0.9704	0.9715
2000	1,587	0.3387	0.6082	-0.9324	0.9808
2001	1,607	0.3510	0.5875	-0.9315	0.9924
2002	1,597	0.3726	0.5960	-0.9556	0.9923
2003	1,590	0.3881	0.5970	-0.9607	0.9960
2004	1,614	0.4146	0.5956	-0.9691	0.9958
2005	1,624	0.4349	0.5992	-0.9494	0.9970
2006	1,649	0.4355	0.5943	-0.9534	0.9922
2007	1,670	0.4196	0.5873	-0.9715	0.9914
2008	1,687	0.4098	0.5755	-0.9611	0.9924
2009	1,682	0.3711	0.5749	-0.9408	0.9792
2010	1,657	0.3380	0.5684	-0.9254	0.9766
2011	1,654	0.3272	0.5628	-0.9218	0.9750
2012	1,657	0.2849	0.5711	-0.9060	0.9663
2013	1,650	0.2483	0.5526	-0.8908	0.9602
2014	1,605	0.2587	0.5399	-0.9139	0.9645
2015	1,652	0.2683	0.5509	-0.9181	0.9763
2016	1,643	0.2763	0.5663	-0.9166	0.9884
2017	1,626	0.3304	0.5752	-0.9506	0.9909
2018	1,599	0.3734	0.5901	-0.9704	0.9933
2019	1,584	0.3842	0.5910	-0.9683	0.9939
2020	1,570	0.3680	0.5974	-0.9893	0.9932

Note: Summary statistics: Correlation coefficient between company *i*'s losses and the industry losses by year (1999–2020).

Table OA2.12 ($det\hat{\sigma}_i$) FTS Sample 2
($000 omitted)

Year	N	Mean	Std	Min	Max
1999	1,544	15,798.16	61,008.32	2.42	1,272,861.08
2000	1,587	15,662.30	57,834.02	3.48	1,107,651.96
2001	1,607	17,338.25	61,978.94	4.45	1,200,026.42
2002	1,597	17,355.34	61,533.16	4.28	1,484,939.05
2003	1,590	19,127.21	67,005.05	2.79	1,552,538.52
2004	1,614	19,932.05	67,633.61	1.49	1,331,008.48
2005	1,624	21,363.40	74,383.13	0.69	1,155,583.79
2006	1,649	21,703.47	82,753.86	0.79	1,751,475.90
2007	1,670	23,698.51	89,233.89	0.73	1,989,581.17
2008	1,687	26,215.40	97,727.73	3.16	1,916,812.61
2009	1,682	27,117.42	94,761.94	0.81	1,571,607.28
2010	1,657	27,101.86	94,103.59	0.87	1,349,008.72
2011	1,654	263,50.62	90,395.60	0.91	1,417,577.44
2012	1,657	26,158.76	90,288.02	0.93	1,574,857.32
2013	1,650	26,738.89	97,494.14	0.95	1,611,686.73
2014	1,605	27,666.94	112,710.31	2.21	2,429,124.08
2015	1,652	27,091.33	115,621.59	1.97	2,651,584.09
2016	1,643	25,035.16	108,121.21	1.95	2,701,452.59
2017	1,626	26,552.23	115,419.67	2.17	2,759,258.24
2018	1,599	27,241.44	110,994.39	0.58	2,351,454.89
2019	1,584	28,838.47	113,206.06	0.31	2,052,079.98
2020	1,570	30,046.08	126,283.29	0.30	2,665,761.81

Note: Summary statistics: Detrended Standard deviation of the net losses and loss expense incurred group and unaffiliated company by year (1999–2020).

Table OA2.13 ($det\ \hat{\rho}_i$) FTS Sample 2

Year	N	Mean	Std	Min	Max
1999	1,544	0.0639	0.2892	-0.9113	0.8791
2000	1,587	0.0891	0.3859	-0.8849	0.9062
2001	1,607	0.1676	0.5157	-0.9165	0.9580
2002	1,597	0.1927	0.4944	-0.9363	0.9480
2003	1,590	0.2140	0.4913	-0.9213	0.9719
2004	1,614	0.1994	0.4436	-0.9029	0.9617
2005	1,624	0.1894	0.4238	-0.9140	0.9613
2006	1,649	0.0900	0.3726	-0.8897	0.9629
2007	1,670	0.0815	0.4219	-0.8997	0.9724
2008	1,687	0.0909	0.3538	-0.9130	0.9225
2009	1,682	0.1448	0.3292	-0.8825	0.9015
2010	1,657	0.1400	0.3846	-0.8880	0.8960
2011	1,654	0.1508	0.3500	-0.8845	0.9175
2012	1,657	0.1303	0.3238	-0.6725	0.9169
2013	1,650	0.1201	0.3501	-0.7315	0.9034
2014	1,605	0.1240	0.3289	-0.7816	0.8887
2015	1,652	0.1176	0.3667	-0.7871	0.9252
2016	1,643	0.1613	0.3546	-0.8494	0.9574
2017	1,626	0.2215	0.4672	-0.9046	0.9710
2018	1,599	0.1937	0.5248	-0.9577	0.9690
2019	1,584	0.2043	0.5231	-0.9672	0.9739
2020	1,570	0.1941	0.4931	-0.9699	0.9829

Note: Summary statistics: Detrended Correlation coefficient between group and unaffiliated company *i*'s losses and the industry losses by year (1999–2020).

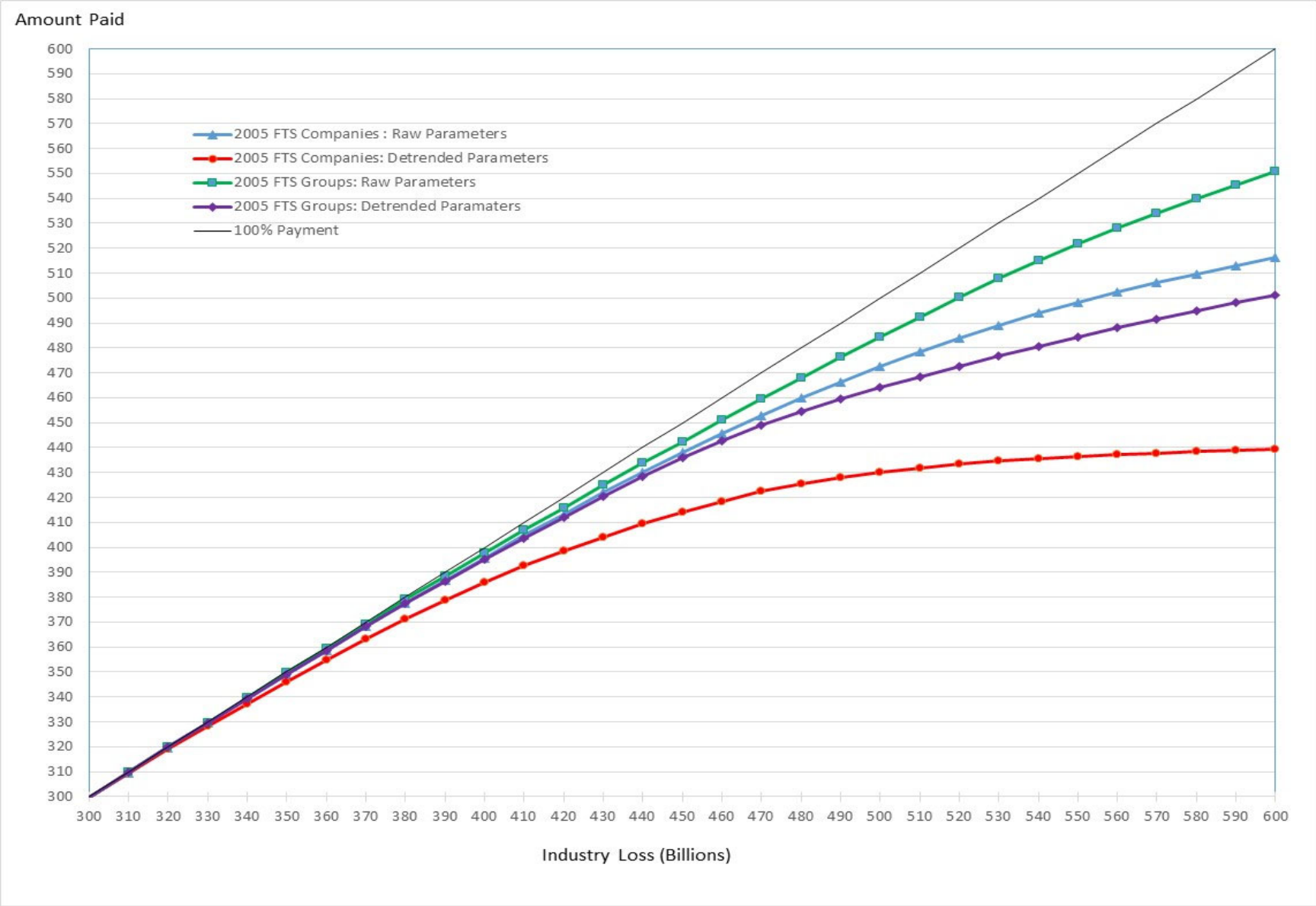

Figure OA2.1: Response functions national net loss, 2005 (FTS Sample 2)

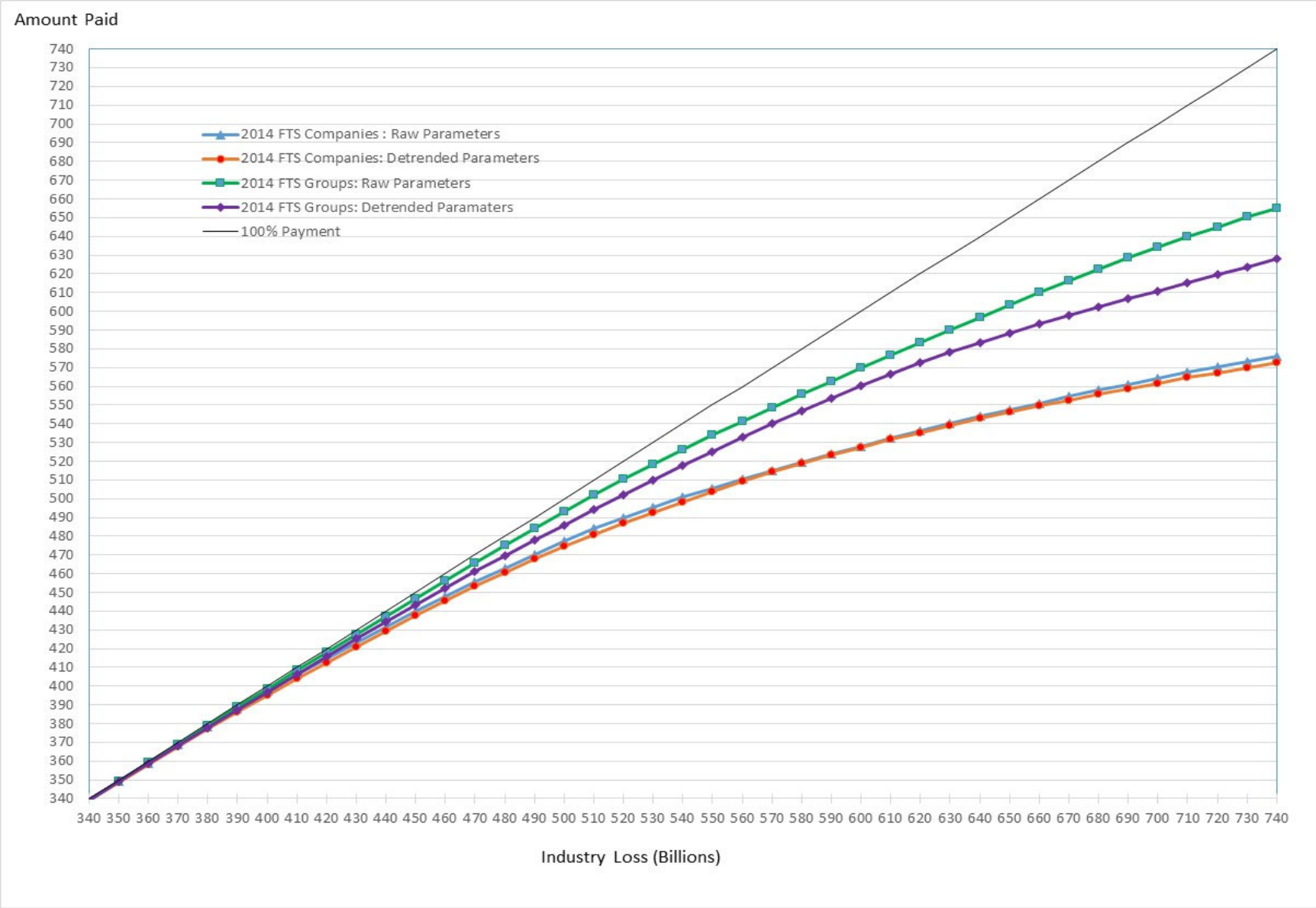

Figure OA2.2: Response functions national net loss, 2014 (FTS Sample 2)

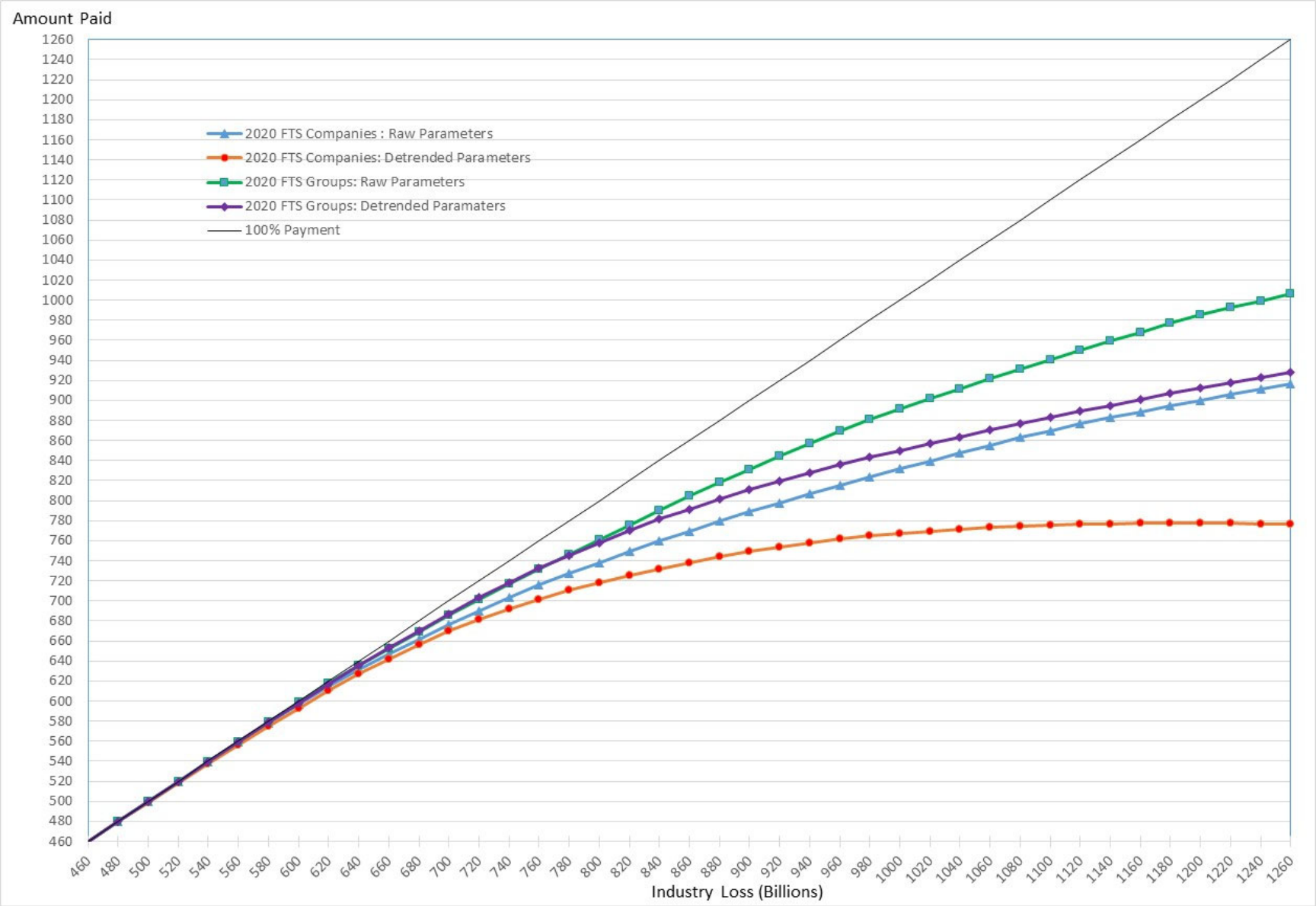

Figure OA2.3: Response functions national net loss, 2020 (FTS Sample 2)

Regression models for parameters estimations

Table OA2.14b: Sample 2
Tobit censored (lb=0) model
Standard deviations: Net losses incurred 2005

Variable	Companies Raw	Companies Detrended	Group Raw	Group Detrended
Intercept	0.2099 10.21	-0.3193 -15.45	0.3720 6.11	0.1717 6.21
Ln(equity capital)	0.0385 13.07	0.0202 13.94	0.0636 7.78	0.0296 7.98
Ln(net losses incurred)	0.0042 1.90	0.0007 0.61	0.0050 0.75	0.0010 0.35
Short / Asset	0.1041 5.07	0.0454 4.49	0.2094 4.01	0.0889 3.75
Liquid asset / Asset	-0.0503 -2.04	-0.0319 -2.63	-0.1338 -1.83	-0.0649 -1.96
Sigma	0.1308 56.99	0.0645 56.98	0.2614 41.62	0.1187 41.61
Log likelihood	999	2,148	-67	617
AIC	-1,986	-4,284	145	-1,221
No. of observation	1,624	1,624	866	866

Note: Short = Cash + cash equivalent + short-term investment; Liquid asset = bond + stock + short. Lb is for lower bond. The dependent variable is the standard deviation of net losses incurred. For each variable, we report the regression coefficient and the *t*-ratio.

Table OA2.14c: Sample 2
Tobit censored (lb=0) model
Standard deviations: Net losses incurred 2014

Variable	Companies Raw	Companies Detrended	Group Raw	Group Detrended
Intercept	0.1749	-0.4333	0.2763	0.1693
	8.72	-13.87	5.62	5.79
Ln(equity capital)	0.0344	0.0246	0.0537	0.0323
	11.53	10.96	7.68	7.76
Ln(net losses incurred)	0.0054	0.0029	0.0049	0.0031
	2.25	1.63	0.80	0.85
Short / Asset	0.1192	0.0824	0.1821	0.1027
	5.24	4.82	3.95	3.75
Liquid asset / Asset	-0.0336	-0.0185	-0.0747	-0.0442
	-1.38	-1.01	-1.25	-1.24
Sigma	0.1346	0.1013	0.2241	0.1334
	56.65	56.65	41.64	41.64
Log likelihood	941	1,398	66	517
AIC	-1,870	-2,784	-121	-1,021
No. of observation	1,605	1,605	867	867

Note: Short = Cash + cash equivalent + short-term investment; Liquid asset = bond + stock + short. Lb is for lower bond. The dependent variable is the standard deviation of net losses incurred. For each variable, we report the regression coefficient and the *t*-ratio.

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Table OA2.14d: Sample 2
Tobit censored (lb=0) model
Standard deviations: Net losses incurred 2020

Variable	Companies Raw	Companies Detrended	Group Raw	Group Detrended
Intercept	0.2585 7.85	-0.5220 -14.83	0.4102 5.22	0.1917 6.39
Ln(equity capital)	0.0561 10.43	0.0305 11.86	0.0913 7.38	0.0404 8.55
Ln(net losses incurred)	0.0038 0.93	0.0017 0.89	0.0034 0.34	0.0023 0.60
Short / Asset	0.1486 3.83	0.0803 4.33	0.2937 3.52	0.1208 3.78
Liquid asset / Asset	-0.0716 -1.79	-0.0320 -1.67	-0.1251 -1.31	-0.0575 -1.57
Sigma	0.2331 56.03	0.1115 56.03	0.3887 41.88	0.1485 41.88
Log likelihood	59	1,217	-416	428
AIC	-105	-2,421	843	-844
No. of observation	1,570	1,570	877	877

Note: Short = Cash + cash equivalent + short-term investment; Liquid asset = bond + stock + short. Lb is for lower bond. The dependent variable is the standard deviation of net losses incurred. For each variable, we report the regression coefficient and the *t*-ratio.

Table OA2.15b: Sample 2
Tobit censored (lb=-1 ub=1) model
Correlation coefficient: Net losses incurred 2005

Variable	Companies Raw	Companies Detrended	Group Raw	Group Detrended
Intercept	0.4089	-0.1515	0.7585	0.3115
	3.58	-0.97	4.88	2.46
Ln(equity capital)	-0.1336	-0.0058	-0.1317	-0.0252
	-10.52	-0.57	-7.88	-1.83
Ln(net losses incurred)	0.1863	0.0315	0.1830	0.0542
	16.88	3.51	11.84	4.26
Short / Asset	0.0036	0.0346	-0.1417	0.0685
	0.04	0.53	-1.49	0.87
Total liability / Asset	0.0968	0.1542	-0.0678	0.0130
	1.08	2.11	-0.57	0.13
Liquid asset / Asset	0.3973	0.0597	0.1571	0.0198
	4.02	0.74	1.15	0.18
Sigma	0.5092	0.4142	0.4754	0.3916
	56.99	56.99	41.62	41.62
Log likelihood	-1,208	-873	-858	-417
AIC	2,431	1,760	1,184	848
No. of observation	1,624	1,624	866	866

Note: Short = Cash + cash equivalent + short-term investment. Liquid asset = bond + stock + short. Lb and Ub are for lower bond and upper bond. The dependent variable is the correlation coefficient of net losses incurred. For each variable, we report the regression coefficient and the *t*-ratio.

Table OA2.15c: Sample 2
Tobit censored (lb=-1 ub=1) model
Correlation coefficient: Net losses incurred 2014

Variable	Companies Raw	Companies Detrended	Group Raw	Group Detrended
Intercept	0.3881	-0.4621	0.8262	0.4284
	3.18	-3.67	4.89	4.03
Ln(equity capital)	-0.1221	0.0231	-0.1318	0.0063
	-9.87	2.89	-7.36	0.56
Ln(net losses incurred)	0.1435	0.0123	0.1612	0.0258
	12.77	1.69	9.42	2.40
Short / Asset	-0.2770	-0.0756	-0.2037	-0.0018
	-3.32	-1.40	-2.05	-0.03
Total liability / Asset	-0.0763	-0.0554	-0.3668	-0.3054
	-0.78	-0.87	-2.69	-3.56
Liquid asset / Asset	0.2057	0.1122	-0.0877	-0.0441
	2.09	1.76	-0.63	-0.50
Sigma	0.4937	0.3200	0.4834	0.3036
	56.66	56.66	41.64	41.64
Log likelihood	-1,145	-449	-600	-197
AIC	2,303	911	1,214	408
No. of observation	1,605	1,605	867	867

Note: Short = Cash + cash equivalent + short-term investment. Liquid asset = bond + stock + short. Lb and Ub are for lower bond and upper bond. The dependent variable is the correlation coefficient of net losses incurred. For each variable, we report the regression coefficient and the *t*-ratio.

Table OA2.15d: Sample 2
Tobit censored (lb=-1 ub=1) model
Correlation coefficient: Net losses incurred 2020

Variable	Companies Raw	Companies Detrended	Group Raw	Group Detrended
Intercept	0.5834	-0.3984	0.7702	0.3949
	4.68	-2.06	4.60	2.71
Ln(equity capital)	-0.0751	0.0099	-0.1091	0.0061
	-5.34	0.78	-5.67	0.36
Ln(net losses incurred)	0.1323	0.0366	0.1708	0.0422
	10.86	3.33	9.84	2.80
Short / Asset	0.0432	-0.0583	0.0349	0.0972
	0.49	-0.73	0.31	0.98
Total liability / Asset	0.2411	-0.0015	-0.0091	-0.1132
	2.36	-0.02	-0.07	-0.96
Liquid asset / Asset	-0.0517	0.0706	-0.0562	-0.0137
	-0.52	0.78	-0.40	-0.11
Sigma	0.5316	0.4797	0.5285	0.4600
	56.02	56.02	41.88	41.88
Log likelihood	-1,235	-1,074	-685	-563
AIC	2,484	2,162	1,384	1,141
No. of observation	1,570	1,570	877	877

Note: Short = Cash + cash equivalent + short-term investment. Liquid asset = bond + stock + short. Lb and Ub are for lower bond and upper bond. The dependent variable is the correlation coefficient of net losses incurred. For each variable, we report the regression coefficient and the *t*-ratio.

Table OA2.16: ($\hat{\sigma}_i$) NFTS Sample 2
($000 omitted)

Year	N	Mean	Std	Min	Max
1999	2,210	29,506.48	76,887.20	2.9154759	1,887,885.58
2000	2,165	29,397.51	79,836.69	3.5213634	1,855,958.00
2001	2,137	31,696.41	90,428.06	4.9665548	2,066,663.63
2002	2,103	33,629.08	98,680.05	5.0563491	2,560,266.88
2003	2,099	36,285.77	107,472.07	3.9721251	2,806,037.96
2004	2,142	38,910.48	116,296.65	1.8737959	2,995,902.86
2005	2,152	43,085.32	132,200.84	0.6992059	3,4229,09.26
2006	2,193	42,747.27	130,946.48	0.8432740	3,244,337.70
2007	2,223	43,208.34	127,692.89	0.9486833	2,888,558.78
2008	2,246	46,586.26	136,223.28	3.3730962	2,503,745.18
2009	2,207	45,200.06	129,888.20	0.9486833	1,864,819.90
2010	2,163	42,926.18	124,808.42	0.9486833	2,031,191.09
2011	2,119	42,625.19	126,767.07	0.9486833	2,540,712.37
2012	2,070	42,123.77	125,538.76	0.9486833	2,507,130.26
2013	2,015	42,024.62	126,983.77	0.9486833	2,305,921.62
2014	1,922	42,303.06	140,027.85	2.6161889	3,237,178.54
2015	1,952	44,756.80	163,155.91	2.1602469	4,527,884.46
2016	1,911	45,320.68	181,844.03	2.1832697	5,430,884.19
2017	1,867	50,803.46	211,890.08	2.2110832	6,471,322.48
2018	1,825	55,409.37	231,633.67	0.6324555	7,152,922.33
2019	1,805	59,029.28	244,075.17	0.3162278	7,557,199.84
2020	1,787	59,267.73	242,734.58	0.3162278	7,458,306.70

Note: Summary statistics: Raw Standard deviation of the net losses and loss expense incurred for a company by year (1999–2020).

Table OA2.17: ($\hat{\rho}_i$) NFTS Sample 2

Year	N	Mean	Std	Min	Max
1999	2,210	0.3835	0.5051	-0.9704	0.9715
2000	2,165	0.3549	0.5302	-0.9324	0.9808
2001	2,137	0.3591	0.5179	-0.9315	0.9924
2002	2,103	0.3772	0.5273	-0.9556	0.9923
2003	2,099	0.3920	0.5270	-0.9607	0.9960
2004	2,142	0.4174	0.5255	-0.9691	0.9958
2005	2,152	0.4334	0.5295	-0.9494	0.9970
2006	2,193	0.4290	0.5236	-0.9534	0.9922
2007	2,223	0.4162	0.5152	-0.9715	0.9914
2008	2,246	0.4061	0.5048	-0.9611	0.9924
2009	2,207	0.3714	0.5066	-0.9408	0.9792
2010	2,163	0.3429	0.5006	-0.9254	0.9766
2011	2,119	0.3271	0.5009	-0.9218	0.9750
2012	2,070	0.2896	0.5141	-0.9060	0.9663
2013	2,015	0.2557	0.5026	-0.8908	0.9602
2014	1,922	0.2651	0.4966	-0.9139	0.9645
2015	1,952	0.2726	0.5099	-0.9181	0.9763
2016	1,911	0.2823	0.5282	-0.9166	0.9884
2017	1,867	0.3297	0.5402	-0.9506	0.9909
2018	1,825	0.3702	0.5560	-0.9704	0.9933
2019	1,805	0.3788	0.5573	-0.9683	0.9939
2020	1,787	0.3675	0.5632	-0.9893	0.9932

Note: Summary statistics: Raw Correlation coefficient between company *i*'s losses and the industry losses by year (1999–2020).

Table OA2.18: ($det\ \hat{\sigma}_i$) NFTS Sample 2
($000 omitted)

Year	N	Mean	Std	Min	Max
1999	2,210	11,037.27	51,501.66	1.6873092E-8	1,272,861.08
2000	2,165	11,480.86	49,994.20	1.2808325E-9	1,107,651.96
2001	2,137	13,038.17	54,261.66	1.487163E-11	1,200,026.42
2002	2,103	13,179.49	54,128.87	8.450219E-11	1,484,939.05
2003	2,099	14,488.93	58,886.86	1.09997E-11	1,552,538.52
2004	2,142	15,018.83	59,329.96	9.538021E-13	1,331,008.48
2005	2,152	16,121.82	65,263.00	7.677228E-13	1,155,583.79
2006	2,193	16,319.67	72,364.00	4.756371E-10	1,751,475.90
2007	2,223	17,803.20	78,012.67	1.83634E-10	1,989,581.17
2008	2,246	19,690.73	85,446.69	2.21409E-10	1,916,812.61
2009	2,207	20,666.74	83,523.15	6.075651E-11	1,571,607.28
2010	2,163	20,761.81	83,154.18	8.846025E-15	1,349,008.72
2011	2,119	20,568.16	80,599.99	1.23586E-10	1,417,577.44
2012	2,070	20,939.64	81,449.57	4.219499E-12	1,574,857.32
2013	2,015	21,895.37	88,817.72	8.1952557E-8	1,611,686.73
2014	1,922	2,3103.77	103,502.50	1.676807E-8	2,429,124.08
2015	1,952	22,927.71	106,809.40	0.000014226	2,6515,84.09
2016	1,911	21,524.21	100,625.57	3.4815672E-7	2,701,452.59
2017	1,867	23,124.76	108,076.18	8.1102733E-7	2,759,258.24
2018	1,825	23,867.98	104,277.78	3.552285E-10	2,351,454.89
2019	1,805	25,307.55	106,466.13	3.9606036E-9	2,052,079.98
2020	1,787	26,397.51	118,769.56	5.189889E-8	2,665,761.81

Note: Summary statistics: Detrented Standard deviation of the net losses and loss expense incurred by year (1999–2020).

Table OA2.19: ($det\ \hat{\rho}_i$) NFTS Sample 2

Year	N	Mean	Std	Min	Max
1999	2,210	0.0561308	0.2419988	-0.9113002	0.8791261
2000	2,165	0.0829784	0.3306470	-0.8848727	0.9062199
2001	2,137	0.1492890	0.4486326	-0.9165006	0.9579918
2002	2,103	0.1769855	0.4321266	-0.9362879	0.9480210
2003	2,099	0.1841322	0.4309459	-0.9213306	0.9719303
2004	2,142	0.1734907	0.3879521	-0.9028957	0.9617352
2005	2,152	0.1664388	0.3705514	-0.9139766	0.9613169
2006	2,193	0.0698362	0.3249339	-0.8896857	0.9628554
2007	2,223	0.0624265	0.3671784	-0.8996794	0.9724440
2008	2,246	0.0726045	0.3082824	-0.9130245	0.9224714
2009	2,207	0.1107048	0.2938225	-0.8825206	0.9014672
2010	2,163	0.1072923	0.3417404	-0.8879953	0.8960446
2011	2,119	0.1178442	0.3153727	-0.8845190	0.9175202
2012	2,070	0.1048357	0.2941345	-0.6725480	0.9169408
2013	2,015	0.1000450	0.3196648	-0.7315389	0.9034360
2014	1,922	0.1042828	0.3038340	-0.7816404	0.8886744
2015	1,952	0.1030059	0.3390722	-0.7870556	0.9251872
2016	1,911	0.1393747	0.3332437	-0.8494264	0.9573621
2017	1,867	0.1947610	0.4415163	-0.9046197	0.9709898
2018	1,825	0.1713428	0.4947873	-0.9576501	0.9689824
2019	1,805	0.1817952	0.4937008	-0.9672119	0.9739209
2020	1,787	0.1734089	0.4655057	-0.9698640	0.9829143

Note: Summary statistics: Detrented Correlation coefficient between company *i*'s losses and the industry losses by year (1999–2020).

Table OA2.20: FTS Groups and unaffiliated companies Sample 2
Summary statistics: Net losses and loss expense incurred by year (1999–2020)
($000 omitted)

Year	N	Sum	Mean	Std	Min	Max
1999	842	212,438,498	252,302.25	1,343,736.71	1	27,172,137
2000	849	225,907,905	266,087.05	1,440,232.62	1	29,576,579
2001	868	253,852,110	292,456.35	1,636,866.86	1	35,272,293
2002	857	251,871,393	293,898.94	1,693,498.46	1	36,550,548
2003	854	263,898,977	309,015.20	1,742,723.97	1	36,142,636
2004	863	277,595,068	321,662.88	1,785,084.77	1	34,527,770
2005	866	301,056,223	347,639.98	1,993,280.34	2	38,802,151
2006	867	285,021,697	328,744.75	1,835,138.59	2	34,552,444
2007	901	305,571,487	339,147.04	1,933,145.88	1	37,115,057
2008	887	349,086,306	393,558.41	2,270,790.97	1	43,841,026
2009	872	317,512,832	364,120.22	2,110,662.50	1	43,148,612
2010	864	317,669,976	367,673.58	2,123,863.00	2	44,304,427
2011	852	352,088,151	413,249.00	2,352,879.13	1	47,704,237
2012	868	341,834,579	393,818.64	2,257,076.56	2	45,231,091
2013	885	328,008,464	370,631.03	2,143,519.05	1	44,975,965
2014	867	341,865,660	394,308.72	2,283,272.68	1	47,090,286
2015	887	355,257,530	400,515.82	2,354,187.96	1	47,884,283
2016	893	379,480,446	424,950.11	2,581,203.02	2	53,294,126
2017	885	416,136,535	470,210.77	2,852,907.50	1	57,033,235
2018	880	435,339,900	494,704.43	2,849,788.90	1	52,921,588
2019	872	446,855,787	512,449.30	2,943,917.11	1	52,235,775
2020	877	455,145,860	518,980.46	2,939,039.93	1	52,557,754

Table OA2.21: ($\hat{\sigma}_i$) FTS Groups and unaffiliated companies Sample 2
($000 omitted)

Year	N	Mean	Std	Min	Max
1999	842	35,445.74	144,592.80	2.92	2,433,491.10
2000	849	37,221.16	146,263.11	3.52	2,048,966.23
2001	868	41,196.30	175,758.39	4.97	2,664,535.89
2002	857	44,220.03	200,303.20	5.06	3,473,703.88
2003	854	48,305.80	218,868.02	3.97	3,527,033.66
2004	863	54,889.60	255,223.62	1.87	3,982,968.44
2005	866	62,114.42	295,908.63	0.70	5,041,392.33
2006	867	62,943.70	305,475.53	0.84	5,670,628.35
2007	901	62,777.68	308,142.98	0.95	6,376,623.55
2008	887	70,003.48	336,430.31	3.37	6,914,804.88
2009	872	66,676.43	306,677.79	0.95	6,180,918.76
2010	864	61,850.94	270,039.27	0.95	4,832,031.99
2011	852	63,053.60	271,422.13	0.95	3,913,752.26
2012	868	59,124.25	255,582.50	0.95	4,054,974.74
2013	885	58,275.49	256,126.89	0.95	3,986,484.49
2014	867	57,926.90	255,284.55	4.64	3,876,707.40
2015	887	60,008.28	280,002.45	2.41	4,470,181.66
2016	893	58,290.38	286,576.14	2.49	5,076,876.38
2017	885	67,540.26	348,077.41	2.72	6,503,066.81
2018	880	75,833.13	396,058.31	0.63	7,383,658.90
2019	872	82,265.77	432,867.04	0.32	8,1434,04.02
2020	877	82,170.44	434,594.04	0.32	8,251,043.15

Note: Summary statistics: Raw Standard deviation of the net losses and loss expense incurred for group and unaffiliated company by year (1999–2020).

Table OA2.22: ($\hat{\rho}_i$) FTS Groups and unaffiliated companies Sample 2

Year	N	Mean	Std	Min	Max
1999	842	0.4582021	0.5397633	-0.9703992	0.9714910
2000	849	0.4256767	0.5621793	-0.9323654	0.9807786
2001	868	0.4207913	0.5513787	-0.9192239	0.9868139
2002	857	0.4447435	0.5630046	-0.9555623	0.9897574
2003	854	0.4599169	0.5611528	-0.9607217	0.9956393
2004	863	0.4782765	0.5557820	-0.9691315	0.9959253
2005	866	0.4953638	0.5583144	-0.9493773	0.9943744
2006	867	0.4865091	0.5606947	-0.9533898	0.9950528
2007	901	0.4751910	0.5588997	-0.9593293	0.9851949
2008	887	0.4600376	0.5625427	-0.9216893	0.9877887
2009	872	0.4241771	0.5584742	-0.9014436	0.9843718
2010	864	0.3754707	0.5582730	-0.9084753	0.9850996
2011	852	0.3549288	0.5499201	-0.9176632	0.9851497
2012	868	0.3149773	0.5438706	-0.9001097	0.9797809
2013	885	0.2726843	0.5281308	-0.8962236	0.9685895
2014	867	0.2760357	0.5258044	-0.9139016	0.9552408
2015	887	0.2753037	0.5390516	-0.9180757	0.9646192
2016	893	0.2695586	0.5587759	-0.8979984	0.9884284
2017	885	0.3210043	0.5602746	-0.9641799	0.9884347
2018	880	0.3586351	0.5818723	-0.9774711	0.9929838
2019	872	0.3747197	0.5911957	-0.9806438	0.9938098
2020	877	0.3482611	0.6020103	-0.9869020	0.9931503

Note: Summary statistics: Raw Correlation coefficient between groups and unaffiliated company *i*'s losses and the industry losses by year (1999–2020).

Table OA2.23: ($det\ \hat{\sigma}_i$) FTS Groups and unaffiliated companies Sample 2 ($000 omitted)

Year	N	Mean	Std	Min	Max
1999	842	19,020.50	88,296.15	2.4151598	1,825,332.40
2000	849	20,016.86	89,401.74	3.4836801	1,620,662.00
2001	868	21,742.95	98,791.32	4.4517617	1,855,937.03
2002	857	22,631.63	100,952.76	4.2767872	1,999,336.88
2003	854	25,770.04	117,038.69	2.7915216	2,010,766.79
2004	863	27,470.07	127,957.68	1.4889040	2,420,617.83
2005	866	29,277.77	133,992.35	0.6904837	2,506,470.52
2006	867	29,434.85	138,184.14	0.7905162	2,124,213.03
2007	901	30,812.45	139,737.91	0.7302967	2,339,614.99
2008	887	34,947.51	149,017.01	3.1620647	2,477,974.45
2009	872	37,667.34	162,064.09	0.8090398	2,581,477.57
2010	864	38,383.42	174,528.64	0.8668997	3,260,453.37
2011	852	38,394.00	175,765.77	0.9078780	3,139,550.30
2012	868	36,426.63	161,431.88	0.9341987	2,518,030.14
2013	885	37,815.94	163,440.79	0.9470848	2,232,425.46
2014	867	37,168.95	152,497.37	4.6310328	2,213,480.30
2015	887	36,482.97	148,366.09	1.9691219	2,067,127.39
2016	893	33,005.58	133,797.96	1.9498770	2,051,858.56
2017	885	37,232.92	165,654.40	2.6598397	2,381,809.06
2018	880	37,599.64	163,018.78	0.5779332	2,297,066.22
2019	872	40,150.12	172,294.01	0.3113996	2,466,507.10
2020	877	40,152.19	172,814.13	0.3026260	2,632,140.22

Note: Summary statistics: Detrented Standard deviation of the net losses and loss expense incurred for group and unaffiliated company by year (1999–2020).

Table OA2.24: ($det\ \hat{\rho}_i$) FTS Groups and unaffiliated companies Sample 2

Year	N	Mean	Std	Min	Max
1999	842	0.0737906	0.2976860	-0.9113002	0.8809932
2000	849	0.0880346	0.3777057	-0.8848727	0.9062199
2001	868	0.1744023	0.4880856	-0.9165006	0.9584600
2002	857	0.2138801	0.4684246	-0.9355147	0.9344357
2003	854	0.2406392	0.4665278	-0.9147893	0.9570180
2004	863	0.2193823	0.4155582	-0.9028957	0.9617352
2005	866	0.2041872	0.4046419	-0.9139766	0.9275936
2006	867	0.0685664	0.3684314	-0.8896857	0.9554446
2007	901	0.0630561	0.4170703	-0.8996794	0.8945646
2008	887	0.0664739	0.3495255	-0.9130245	0.8875683
2009	872	0.1319914	0.3119212	-0.8294105	0.8955433
2010	864	0.1287995	0.3765150	-0.7584445	0.9147744
2011	852	0.1430629	0.3413696	-0.8047673	0.9100181
2012	868	0.1257701	0.3126331	-0.6604502	0.9035408
2013	885	0.1140450	0.3301017	-0.7208757	0.8915942
2014	867	0.1097407	0.3128532	-0.7816404	0.8635014
2015	887	0.1062847	0.3486837	-0.7870556	0.9130083
2016	893	0.1271336	0.3599488	-0.8494264	0.9489242
2017	885	0.1946553	0.4674133	-0.9073442	0.9672222
2018	880	0.1626788	0.5066650	-0.9266609	0.9606080
2019	872	0.1778420	0.5035217	-0.9615062	0.9796879
2020	877	0.1553911	0.4739425	-0.9698640	0.9666069

Note: Summary statistics: Detrented Correlation coefficient between groups and unaffiliated company i's losses and the industry losses by year (1999–2020).

Table OA2.25: ($\hat{\sigma}_i$) NFTS Groups and unaffiliated companies Sample 2 ($000 omitted)

Year	N	Mean	Std	Min	Max
1999	1,152	38,900.38	124,582.14	2.9154759	2,433,491.10
2000	1,108	39,807.47	128,962.07	3.5213634	2,048,966.23
2001	1,118	45,268.13	155,839.06	4.9665548	2,664,535.89
2002	1,091	49,651.31	178,598.03	5.0563491	3,473,703.88
2003	1,114	54,186.42	192,872.24	3.9721251	3,527,033.66
2004	1,178	62,202.87	219,764.34	1.8737959	3,982,968.44
2005	1,201	70,478.44	252,625.42	0.6992059	5,041,392.33
2006	1,225	72,531.37	258,482.10	0.8432740	5,670,628.35
2007	1,272	72,603.05	260,832.26	0.9486833	6,376,623.55
2008	1,269	81,090.81	282,839.06	3.3730962	6,914,804.88
2009	1,232	75,442.76	259,288.88	0.9486833	6,180,918.76
2010	1,203	68,157.48	229,846.95	0.9486833	4,832,031.99
2011	1,171	68,140.55	232,509.90	0.9486833	3,913,752.26
2012	1,132	64,133.30	224,799.15	0.9486833	4,054,974.74
2013	1,116	63,644.70	229,133.63	0.9486833	3,986,484.49
2014	1,064	63,177.52	231,520.02	4.6427961	3,876,707.40
2015	1,070	66,635.88	256,155.81	2.4129281	4,470,181.66
2016	1,054	65,298.45	265,069.91	2.4855136	5,076,876.38
2017	1,022	75,398.49	325,293.20	2.7162065	6,503,066.81
2018	1,010	84,736.63	371,349.75	0.6324555	7,383,658.90
2019	995	92,141.77	406,967.84	0.3162278	8,143,404.02
2020	992	89,728.53	409,764.70	0.3162278	8,251,043.15

Note: Summary statistics: Raw Standard deviation of the net losses and loss expense incurred for group and unaffiliated company by year (1999–2020).

Table OA2.26: ($\hat{\rho}_i$) NFTS Groups and unaffiliated companies Sample 2

Year	N	Mean	Std	Min	Max
1999	1,152	0.4533342	0.4698575	-0.9703992	0.9738872
2000	1,108	0.4276573	0.4991161	-0.9323654	0.9807786
2001	1,118	0.4149191	0.4936483	-0.9192239	0.9868139
2002	1,091	0.4395369	0.5062441	-0.9555623	0.9928669
2003	1,114	0.4527352	0.5007823	-0.9607217	0.9956393
2004	1,178	0.4693005	0.4848601	-0.9691315	0.9959253
2005	1,201	0.4812208	0.4839047	-0.9493773	0.9943744
2006	1,225	0.4703294	0.4822171	-0.9533898	0.9950528
2007	1,272	0.4637776	0.4775477	-0.9593293	0.9851949
2008	1,269	0.4469821	0.4782414	-0.9216893	0.9877887
2009	1,232	0.4120101	0.4760261	-0.9014436	0.9843718
2010	1,203	0.3698930	0.4769318	-0.9084753	0.9850996
2011	1,171	0.3417709	0.4736752	-0.9176632	0.9851497
2012	1,132	0.3091556	0.4795520	-0.9001097	0.9797809
2013	1,116	0.2733970	0.4727783	-0.8962236	0.9685895
2014	1,064	0.2787078	0.4775763	-0.9139016	0.9552408
2015	1,070	0.2801329	0.4939387	-0.9180757	0.9646192
2016	1,054	0.2765563	0.5177067	-0.8979984	0.9884284
2017	1,022	0.3214266	0.5250343	-0.9641799	0.9884347
2018	1,010	0.3576589	0.5470414	-0.9774711	0.9929838
2019	995	0.3698607	0.5573500	-0.9806438	0.9938098
2020	992	0.3495761	0.5685190	-0.9869020	0.9931503

Note: Summary statistics: Raw Correlation coefficient between groups and unaffiliated company *i*'s losses and the industry losses by year (1999–2020).

Table OA2.27: ($det\ \hat{\sigma}_i$) NFTS Groups and unaffiliated companies Sample 2 ($000 omitted)

Year	N	Mean	Std	Min	Max
1999	1,152	22,011.39	76,034.52	2.4151598	1,825,332.40
2000	1,108	22,417.68	78,790.40	3.4836801	1,620,662.00
2001	1,118	24,493.40	87,596.89	4.4517617	1,855,937.03
2002	1,091	25,391.91	90,023.16	4.2767872	1,999,336.88
2003	1,114	29,054.00	103,142.80	2.7915216	2,010,766.79
2004	1178	31,386.90	110,170.51	1.4889040	2,420,617.83
2005	1,201	32,898.45	114,376.62	0.6904837	2,506,470.52
2006	1,226	33,591.02	116,907.65	0.7905162	2,124,213.03
2007	1,272	34,315.82	118,279.02	0.7302967	2,339,614.99
2008	1,269	38,544.66	125,317.90	3.1620647	2,477,974.45
2009	1,232	41,377.35	137,021.21	0.8090398	2,581,477.57
2010	1,203	43,105.23	148,563.25	0.8668997	3,260,453.37
2011	1,171	42,908.09	150,577.41	0.9078780	3,139,550.30
2012	1,132	40,109.63	141,970.02	0.9341987	2,518,030.14
2013	1,116	41,330.59	146,216.50	0.9470848	2,232,425.46
2014	1,064	39,863.88	138,274.99	4.6310328	2,213,480.30
2015	1,070	39,195.50	135,701.59	1.9691219	2,067,127.39
2016	1,054	35,285.53	123,761.11	1.9498770	2,051,858.56
2017	1,024	40,094.02	154,633.42	2.6598397	2,381,809.06
2018	1,010	40,523.59	152,872.97	0.5779332	2,297,066.22
2019	995	43,391.11	162,023.92	0.3113996	2,466,507.10
2020	992	42,080.48	162,898.62	0.3026260	2,632,140.22

Note: Summary statistics: Detrented Standard deviation of the net losses and loss expense incurred for group and unaffiliated company by year (1999–2020).

Table OA2.28: ($det\ \hat{\rho}_i$) NFTS Groups and unaffiliated companies Sample 2

Year	N	Mean	Std	Min	Max
1999	1,152	0.0931507	0.2567889	-0.9113002	0.8809932
2000	1,108	0.1084120	0.3329742	-0.8848727	0.9062199
2001	1,118	0.1888922	0.4323385	-0.9165006	0.9584600
2002	1,091	0.2246220	0.4167042	-0.9355147	0.9344357
2003	1,114	0.2483449	0.4099204	-0.9147893	0.9570180
2004	1,178	0.2258472	0.3569273	-0.9028957	0.9617352
2005	1,201	0.2167726	0.3452684	-0.9139766	0.9275936
2006	1,226	0.0916111	0.3124010	-0.8896857	0.9554446
2007	1,272	0.0896285	0.3540254	-0.8996794	0.8945646
2008	1,269	0.0902788	0.2947609	-0.9130245	0.8875683
2009	1,232	0.1378985	0.2631364	-0.8294105	0.8955433
2010	1,203	0.1396687	0.3201347	-0.7584445	0.9147744
2011	1,171	0.1488828	0.2918409	-0.8047673	0.9100181
2012	1,132	0.1313155	0.2742947	-0.6604502	0.9035408
2013	1,116	0.1220889	0.2947764	-0.7208757	0.8915942
2014	1,064	0.1157216	0.2830714	-0.7816404	0.8635014
2015	1,070	0.1147983	0.3183565	-0.7870556	0.9130083
2016	1,054	0.1344597	0.3322788	-0.8494264	0.9489242
2017	1,024	0.2017260	0.4357763	-0.9073442	0.9672222
2018	1,010	0.1722915	0.4740943	-0.9266609	0.9606080
2019	995	0.1859773	0.4723639	-0.9615062	0.9796879
2020	992	0.1635044	0.4464262	-0.9698640	0.9666069

Note: Summary statistics: Detrended Correlation coefficient between group and unaffiliated company *i*'s losses and the industry losses by year (1999–2020).

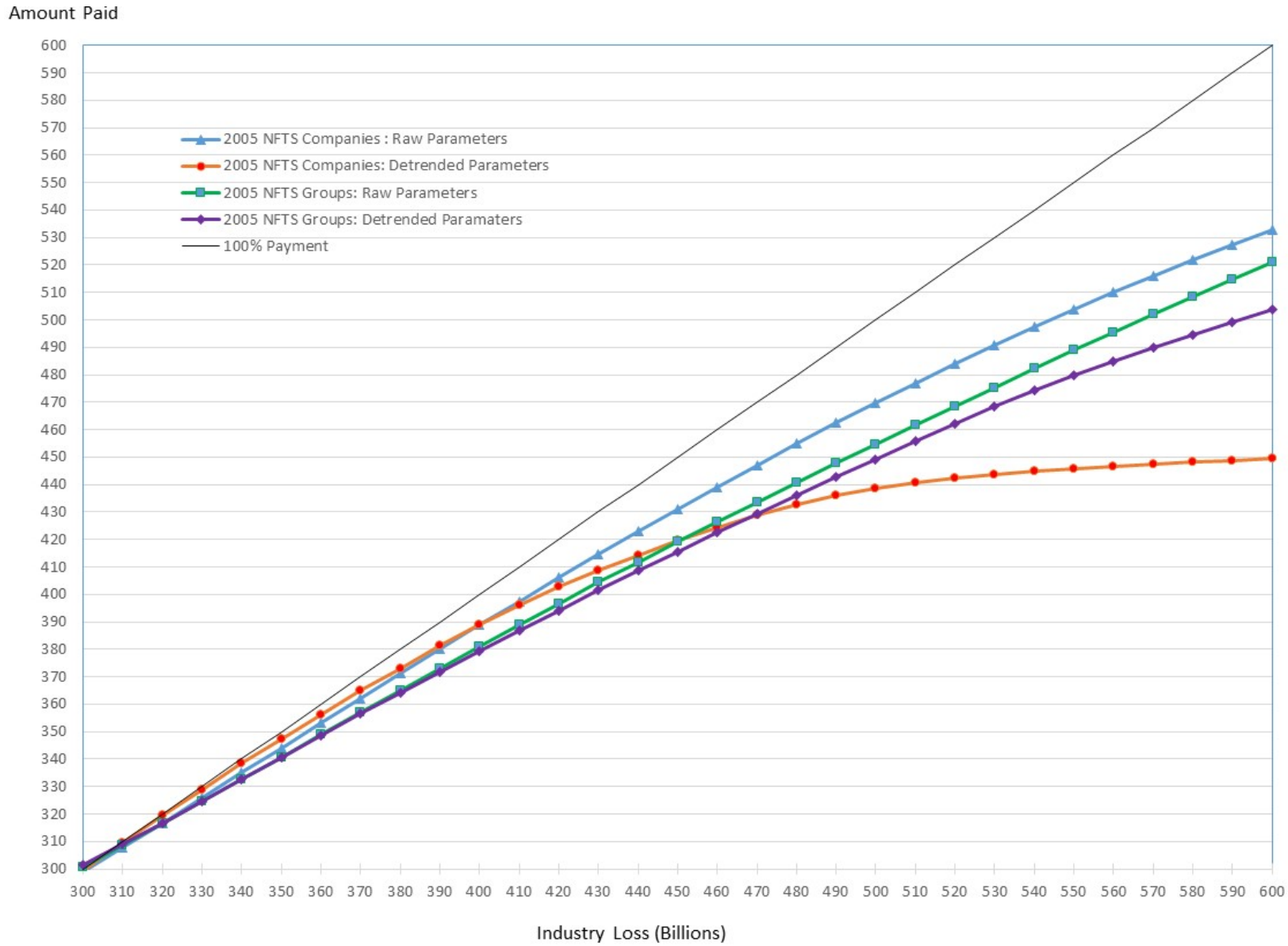

Figure OA2.4: Response functions national net loss, 2005 (NFTS)

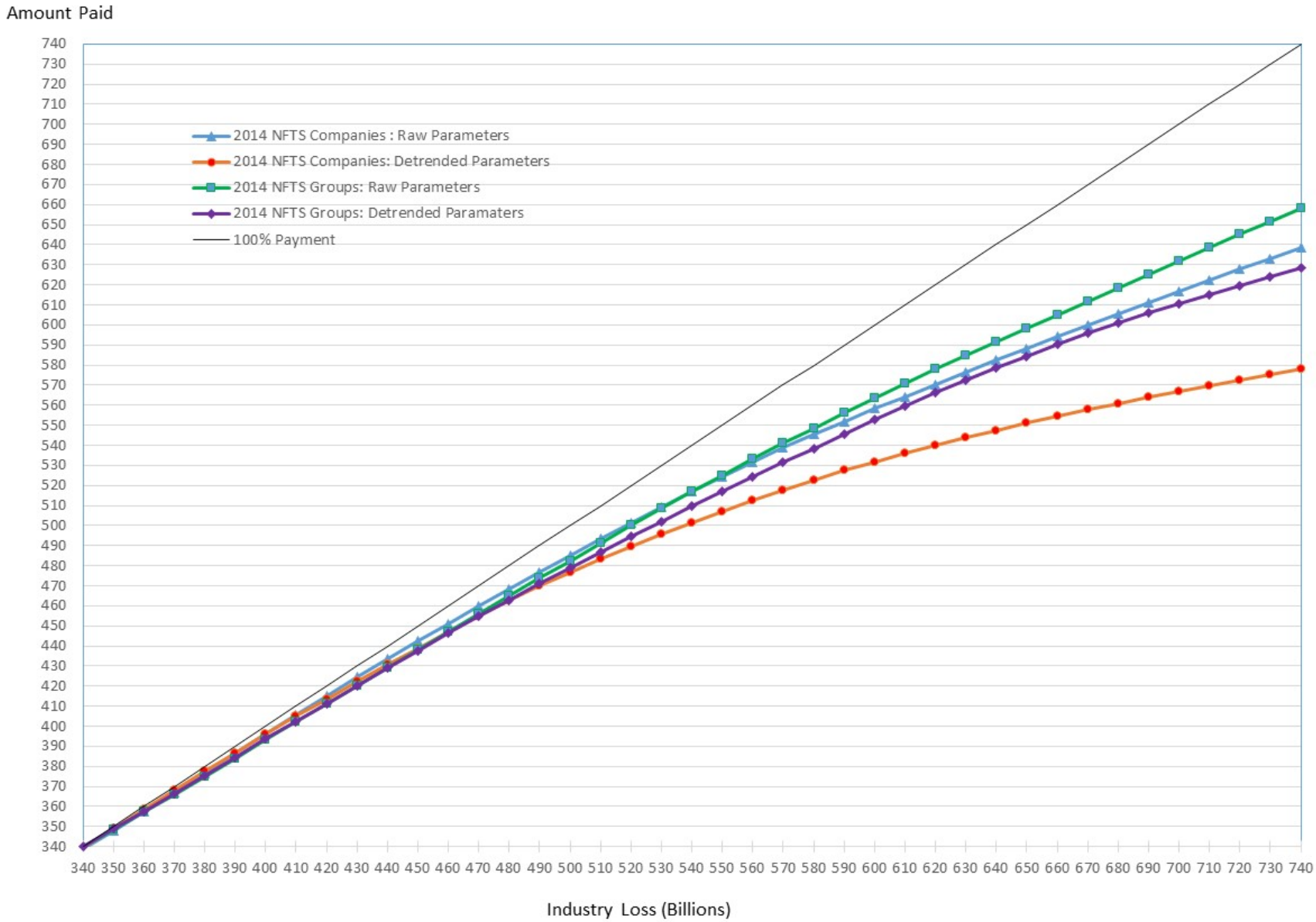

Figure OA2.5: Response functions national net loss, 2014 (NFTS)

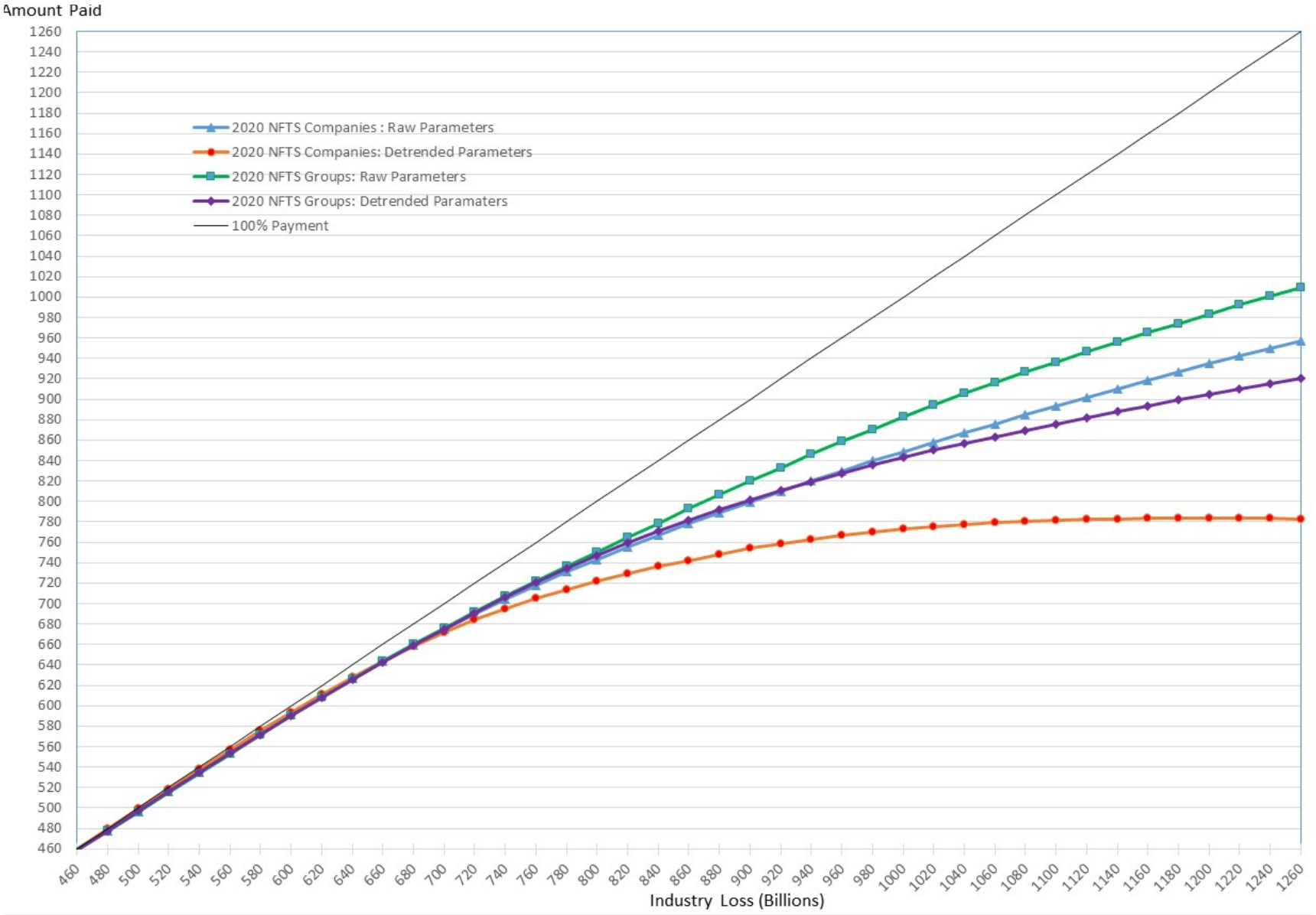

Figure OA2.6: Response functions national net loss, 2020 (NFTS)

Online appendix OA3 – Sample 3

Table OA3.1 and Table OA3.2 report net losses and equity capital for FTS and NFTS data for different years for all companies and groups and unaffiliated companies. We observe, in Table OA3.2, that the ratio of net losses over capital has decreased over the years. The net losses in 2005 are equal to $312 billion for 2,152 insurance companies. It increased to $461 billion for 1,787 insurers in 2020 while capital increased more rapidly during the same period. For example, in Table OA3.1 (Table OA3.2), the ratio was 60% (60%) in 2005 and 42% (42%) in 2020.

In 2005, the FTS Sample 3 decreases by 264 companies compared to Sample 1 and by 189 and 102 companies in 2014 and in 2020 respectively. For group and unaffiliated companies, the decrease in comparison to Sample 1 are respectively 106, 118 and 57.

In 2005, the FTS Sample 3 decreased by 310 companies compared to Sample 2 and by 220 and 163 companies in 2014 and in 2020 respectively. For group and unaffiliated companies, the decrease in comparison to Sample 2 are respectively 119, 141 and 93.

Table OA3.1: FTS Sample 3
Summary statistics: Losses and equity capital
($000 omitted)

	Insurance industry FTS		Number of firms
Sample	Net losses incurred	Equity capital	
2005			
Groups & unaffiliated companies	287,487,717	472,358,567	747
All companies	287,487,717	472,358,567	1,314
2014			
Groups & unaffiliated companies	335,638,810	768,051,416	726
All companies	335,638,810	768,051,416	1,385
2020			
Groups & unaffiliated companies	448,309,430	1,069,230,397	784
All companies	448,309,430	1,069,230,397	1,407

Table OA3.2: NFTS Sample 3
Summary statistics: Losses and equity capital
($000 omitted)

Sample	Insurance industry FTS		Number of firms
	Net losses incurred	Equity capital	
2005			
Groups & unaffiliated companies	311,568,085	520,451,388	1,201
All companies	311,568,085	520,451,388	2,152
2014			
Groups & unaffiliated companies	349,123,503	803,479,225	1,064
All companies	349,123,503	803,479,225	1,922
2020			
Groups & unaffiliated companies	461,350,387	1,109,446,600	992
All companies	461,350,387	1,109,446,600	1,787

To estimate the industry observed response function, we need, for each company *i*, to calculate the standard deviation of the net losses ($\hat{\sigma}_i$) and the correlation coefficient between company *i*'s losses and the industry losses ($\hat{\rho}_i$). On average, the detrended standard deviation is higher in 2014 than 2005 and is higher in 2020 than 2014, regardless the sample. This is not the same pattern for the detrended correlation coefficient. It is lower in 2014 than 2005 and 2020 for Sample 3.

The average value of the raw and detrended parameter estimates for all companies and groups and unaffiliated companies are presented in Table OA3.3 for FTS and NFTS samples from Sample 3. The detrended standard deviations and correlations are higher in 2020.

By inserting the financial characteristics of the NFTS firms into the estimated equations, we obtain fitted parameters of the standard deviation and correlation coefficient and used these values for company not in the FTS sample, called NFTS estimates. On average, the detrented standard deviation for all companies are lower than those from FTS sample, as so for Sample 1.

As expected, detrending reduces the magnitudes of loss standard deviations and the correlations between companies and industry losses. Because detrending leads to larger

reductions in correlations than the standard deviations, we expect the estimated loss payments to be lower for the detrended parameter estimates than for the raw estimates.

Table OA3.3: Detrended and raw parameter estimates:
Property-liability insurance industry with values from Sample 3

	Average				
Case	Detrended sigma × 10^8	Detrended correlation	Raw Sigma × 10^8	Raw Correlation	Number of firms
2005					
Insurance industry (FTS)					
Groups & unaffiliated companies	0.3573	0.2186	0.7330	0.5283	747
All companies	0.2765	0.2013	0.5103	0.4599	1,314
Insurance industry (NFTS)					
Groups & unaffiliated companies	0.4173	0.2412	0.8479	0.5042	1,201
All companies	0.1689	0.1594	0.5637	0.4555	2,152
2014					
Insurance industry (FTS)					
Groups & unaffiliated companies	0.5018	0.1411	0.8730	0.4476	867
All companies	0.3663	0.1481	0.5761	0.3991	1,605
Insurance industry (NFTS)					
Groups & unaffiliated companies	0.5454	0.1597	0.9520	0.4233	1,064
All companies	0.2638	0.1078	0.5970	0.3931	1,922
2020					
Insurance industry (FTS)					
Groups & unaffiliated companies	0.5223	0.1883	1.0606	0.3762	784
All companies	0.3862	0.2023	0.6929	0.3833	1,407
Insurance industry (NFTS)					
Groups & unaffiliated companies	0.5523	0.2011	1.2135	0.3738	992
All companies	0.3041	0.1621	0.7731	0.3802	1,787

Note: FTS: Full Time Sample. NFTS: Non Full Time Sample.

The response functions are calculated for various values of *L*, the total industry net loss. The response functions for the insurance industry Sample 3 are shown in figures OA3.1 to OA3.3 respectively for 2005, 2014 and 2020. This sample is composed of firms that have full time series (FTS). The horizontal axis measures possible values for aggregate insurance industry net losses. The vertical axis measures the expected payout of all firms considered.

The figures show the estimated amounts that would be paid for the industry losses, spanning from the actual expected losses adding unexpected losses for a given year: spanning from $300 billion to $600 billion in 2005; from $340 billion to $740 billion in 2014; and from $460 billion to $1,260 billion in 2020. These limits were chosen because total losses and loss expenses for the US property-liability insurance industry and the total equity capital. Four response curves are shown in the figure based on raw and detrended parameters for group and company sample. Our main interpretation will be for detrented parameters for all companies.

Figure OA3.1 shows that in 2005 the response curve with detrented FTS data from Sample 3 begins to diverge from the 45° line approximatively at $350 billion and that the 2020 response curve begins to diverge from the 45° line approximatively at $620 billion (same amount as in Sample 1).

The corresponding numbers for realized capacity are presented in Table OA3.4. Realized capacity is obtained as the ratio, at the chosen loss level, of the value of the response curve E(L)Z to the value of the maximum curve E(L)C. We observe that all companies in the FTS Sample 3 were able to pay 96.4% of a $100 billion loss in 2005, but only 85.2% for a $200 billion loss. In 2020, the percentage are 99.3% and 96.2%. We observe that, in 2020, the industry seems to be able to cover 84.2% (85.2% NFTS) of a $400 billion event during a year.

Table OA3.4: Capacity from Sample 3 with detrented values

	%			
2005	100 billion	200 billion	300 billion	400 billion
Insurance industry (FTS)				
Groups & unaffiliated companies	98.3	91.5	82.2	73.3
All companies	96.4	85.2	72.6	61.2
Insurance industry (NFTS)				
Groups & unaffiliated companies	94.6	88.1	83.8	78.1
All companies	98.0	88.3	76.6	65.0

	%			
2014	100 billion	200 billion	300 billion	400 billion
Insurance industry (FTS)				
Groups & unaffiliated companies	98.1	92.5	85.6	79.1
All companies	96.6	89.4	81.0	72.3
Insurance industry (NFTS)				

Groups & unaffiliated companies	95.6	90.9	84.7	79.1
All companies	97.4	90.7	82.6	73.9

	%					
2020	100 billion	200 billion	300 billion	400 billion	500 billion	600 billion
Insurance industry (FTS)						
Groups & unaffiliated companies	99.7	97.8	97.1	89.6	85.2	80.8
All companies	99.3	96.2	90.4	84.2	78.6	73.4
Insurance industry (NFTS)						
Groups & unaffiliated companies	98.3	96.4	93.1	89.6	85.3	81.6
All companies	99.5	96.9	91.4	85.2	79.6	74.4

Tables OA3.5 to OA3.8 report net losses and capital for all years of our data (2004-2020). We can see from Table OA3.5 and Table OA3.7 that the number of companies significantly decreases after 2015. Also, the mean of the net losses increases by year, with few exceptions. Summary statistics on equity capital, the other determinant for computing industry capacity, are presented in tables OA3.6 and OA3.8 for the same period.

Table OA3.5: NFTS Sample 3
Summary statistics: Net losses and loss expense incurred by year (2004–2020)
($000 omitted)

Year	N	Sum	Mean	Std	Min	Max
2004	2,140	289,559,364	135,308.11	807,869.43	1	27,059,473
2005	2,152	311,568,085	144,780.71	907,532.39	1	29,846,734
2006	2,192	293,805,410	134,035.31	792,521.56	1	25,459,006
2007	2,222	310,035,489	139,529.92	820,493.63	1	26,371,754
2008	2,246	356,466,021	158,711.50	912,082.83	1	28,142,990
2009	2,206	324,990,899	147,321.35	883,556.86	1	28,701,847
2010	2,163	323,710,757	149,658.23	910,450.20	1	29,717,899
2011	2,119	358,938,218	169,390.38	988,525.45	1	30,474,865
2012	2,069	347,995,242	168,194.90	971,027.18	1	30,204,525
2013	2,015	334,896,552	166,201.76	983,058.36	1	31,447,613
2014	1,922	349,121,622	181,644.96	107,9198.03	1	32,970,073
2015	1,952	363,650,313	186,296.27	111,6173.01	1	34,203,391
2016	1,911	388,339,598	203,212.77	124,7026.09	1	38,768,776
2017	1867	425,020,601	227,648.96	132,6338.40	1	38,816,047
2018	1,825	443,081,776	242,784.53	131,9597.25	1	36,187,577
2019	1,805	454,609,413	251,861.17	136,1103.60	1	36,311,052
2020	1,787	461,350,387	258,170.33	131,9821.69	1	31,865,776

Note: NFTS : Non Full Time Sample.

Table OA3.6: NFTS Sample 3
Summary statistics: Equity capital by year (2004–2020)
($000 omitted)

Year	N	Sum	Mean	Std	Min	Max
2004	2,140	476,599,199	222,709.91	1,388,976.31	0.77	46,144,211
2005	2,152	520,451,388	241,845.44	1,489,481.92	107.24	50,187,253
2006	2,192	590,349,854	269,320.19	1,736,181.36	246.48	58,034,268
2007	2,222	635,219,555	285,877.39	1,849,937.08	147.83	63,577,269
2008	2,246	573,351,953	255,276.92	1,553,939.71	18.16	53,273,952
2009	2,206	637,140,200	288,821.49	1,792,377.79	161.83	58,180,271
2010	2,163	681,298,430	314,978.47	2,233,559.24	7.94	68,437,054
2011	2,119	677,006,054	319,493.18	2,268,255.59	45.51	70,155,428
2012	2,069	717,863,794	346,961.72	2,521,356.59	15.41	78,861,515
2013	2,015	788,520,341	391,325.23	3,008,637.56	2.81	97,226,052
2014	1,922	803,479,224	418,043.30	3,107,233.08	1.62	93,997,652
2015	1,952	817,507,742	418,805.20	3,059,085.59	5.07	89,828,619
2016	1,911	855,520,039	447,681.86	3,355,687.24	77.63	101,285,906
2017	1867	913,923,769	489,514.61	4,000,798.79	77.10	128,562,566
2018	1,825	902,810,027	494,690.43	3,991,042.47	106.64	122,471,087
2019	1,805	1,034,756,942	573,272.54	5,092,094.30	256.15	167,718,679
2020	1,787	1,109,446,572	620,843.07	5,648,877.36	167.44	187,762,294

Note: NFTS: Non Full Time Sample.

Table OA2.7: FTS Sample 3
Summary statistics: Net losses and loss expense incurred by year (2004–2020)
($000 omitted)

Year	N	Sum	Mean	Std	Min	Max
2004	1,237	264,503,191	213,826	1,052,472	1	27,059,473
2005	1,314	287,487,717	218,788	1,152,654	1	29,846,734
2006	1,367	274,902,657	201,099	995,308	1	25,459,006
2007	1,382	289,964,171	209,815	1,032,292	1	26,371,754
2008	1,426	335,444,768	235,235	1,135,859	1	28,142,990
2009	1,439	306,754,410	213,172	1,086,599	1	28,701,847
2010	1,443	307,905,021	213,378	1,107,813	1	29,717,899
2011	1,438	342,188,269	237,961	1,192,243	1	30,474,865
2012	1,440	335,233,522	232,801	1,157,314	1	30,204,525
2013	1,415	321,412,915	227,147	1,166,891	1	31,447,613
2014	1,385	335,638,810	242,338	1,264,738	1	32,970,073
2015	1,411	349,653,387	247,805	1,306,360	1	34,203,391
2016	1,399	374,753,733	267,873	1,451,008	1	38,768,776
2017	1,401	410,793,280	293,214	1,524,343	1	38,816,047
2018	1,408	429,370,329	304,951	1,495,464	1	36,187,577
2019	1,406	441,127,949	313,747	1,535,221	1	36,311,052
2020	1,407	448,309,430	318,628	1,480,309	1	31,865,776

Note: FTS :Full Time Sample.

Table OA3.8: FTS Sample 3
Summary statistics: Equity capital by year (2004–2020)
($000 omitted)

Year	N	Sum	Mean	Std	Min	Max
2004	1,237	424,505,481	343,173	1,806,940	1	46,144,211
2005	1,314	472,358,567	359,481	1,888,726	107	50,187,253
2006	1,367	547,659,699	400,629	2,182,941	246	58,034,268
2007	1,382	589,061,477	426,238	2,329,006	346	63,577,269
2008	1,426	534,548,107	374,858	1,935,882	66	53,273,952
2009	1,439	597,343,315	415,110	2,204,569	168	58,180,271
2010	1,443	647,522,802	448,734	2,722,582	266	68,437,054
2011	1,438	636,826,755	442,856	2,738,029	68	70,155,428
2012	1,440	68,2782,249	474,154	3,007,913	37	78,861,515
2013	1,415	746,776,490	527,757	3,574,915	3	97,226,052
2014	1,385	768,051,416	554,550	3,645,278	2	93,997,652
2015	1,411	778,215,499	551,535	3,582,339	5	89,828,619
2016	1,399	813,843,448	581,732	3,906,138	401	101,285,906
2017	1,401	870,517,591	621,354	4,604,487	413	128,562,566
2018	1,408	863,508,966	613,288	4,531,000	348	122,471,087
2019	1,406	994,499,796	707,326	5,757,755	256	167,718,679
2020	1,407	1,069,230,397	759,936	6,355,109	167	187,762,294

Note: FTS: Full Time Sample.

Table OA3.9: FTS Sample 3
($000 omitted)

Year	L_{t-14}	L_{t-13}	L_{t-12}	…	L_{t-2}	L_{t-1}	L_t	$\bar{L}$	$\hat{\sigma}$
2004	148,999,366	154,443,808	167,877,353	…	237,886,545	253,204,795	264,503,191	222,366,403	35,073,580.34
2005	153,889,337	166,332,196	158,834,720	…	254,938,814	266,709,049	287,487,717	233,253,214	40,542,289.84
2006	165,372,484	158,494,474	174,285,852	…	267,852,091	289,331,774	274,902,657	241,321,486	40,446,703.10
2007	157,975,308	173,886,885	172,189,022	…	291,072,432	276,921,632	289,964,171	255,198,659	39,923,130.87
2008	175,188,896	173,470,666	183,846,948	…	279,359,332	294,283,112	335,444,768	270,846,560	43,859,714.49
2009	173,484,842	183,888,602	181,454,633	…	293,507,470	335,502,036	306,754,410	281,705,995	38,617,557.67
2010	180,224,307	178,439,625	187,494,458	…	336,332,946	308,471,486	307,905,021	290,007,323	33,708,500.25
2011	176,626,139	185,788,643	193,898,815	…	306,936,444	307,397,321	342,188,269	299,841,348	34,405,314.98
2012	184,928,009	194,582,973	209,392,567	…	309,386,531	343,771,374	335,233,522	308,125,942	29,817,333.68
2013	189,973,582	204,840,387	231,333,881	…	337,611,159	329,020,262	321,412,915	309,431,752	25,470,658.89
2014	203,221,052	229,481,349	231,217,844	…	326,453,493	320,060,325	335,638,810	312,610,604	23,467,858.46
2015	229,701,945	231,521,439	248,460,174		322,047,383	338,663,859	349,653,387	321,220,378	25,025,958.16
2016	229,039,328	247,511,596	262,497,337		335,523,538	347,973,049	374,753,733	326,154,782	27,685,472.28
2017	245,717,383	260,574,010	281,903,102		347,276,505	373,677,808	410,793,280	338,579,195	35,813,920.94
2018	256,588,234	278,276,664	265,704,223		372,002,895	409,340,179	429,370,329	348,724,284	46,787,638.49
2019	277,151,229	264,786,847	276,614,729		408,051,610	427,812,742	441,127,949	362,843,563	51,625,156.21
2020	263,247,674	274,680,698	307,462,312		426,522,710	440,303,925	448,309,430	377,105,854	54,409,930.12

Note: Sum of the observed losses of company *i* were incurred in year *t-9 up to t* ($L_{t-9,}$ … L_t). Mean of $\bar{L}$ and $\hat{\sigma}$ of losses for the industry by year (2004–2020).

Table OA3.10: ($\hat{\sigma}_i$) FTS Sample 3
($000 omitted)

Year	N	Mean	Std	Min	Max
2004	1,237	49,780.35	170,609.61	5.73	3,618,578.85
2005	1,314	51,030.08	179,498.04	6.11	3,845,429.32
2006	1,367	50,683.90	174,596.61	6.30	3,526,813.30
2007	1,382	52,374.29	175,355.10	6.27	3,290,493.04
2008	1,426	56,933.81	186,650.03	6.19	3,158,760.30
2009	1,439	57,331.26	188,734.21	5.92	3,222,894.32
2010	1,443	57,162.85	188,345.83	5.80	3,264,642.47
2011	1,438	58,612.28	194,561.10	5.14	3,272,819.44
2012	1,440	58,739.45	190,982.45	4.32	3,040,593.75
2013	1,415	58,033.82	187,577.01	0.77	2,798,325.46
2014	1,385	57,608.06	193,004.85	3.95	3,054,550.34
2015	1,411	57,612.30	205,161.11	3.98	4,107,800.61
2016	1,399	57,268.90	223,205.33	2.85	5,013,368.92
2017	1,401	61,055.71	253,356.54	2.85	6,108,732.75
2018	1,408	63,677.70	272,299.87	2.46	6,909,486.53
2019	1,406	66,961.47	289,748.09	2.40	7,621,411.37
2020	1,407	69,294.22	304,492.55	2.20	8,190,674.39

Note: Summary statistics: Standard deviation of the net losses and loss expense incurred for a company by year (2004–2020).

Table OA3.11: ($\hat{\rho}_i$) FTS Sample 3

Year	N	Mean	Std	Min	Max
2004	1,237	0.4637	0.5651	-0.9653	0.9932
2005	1,314	0.4599	0.5678	-0.9501	0.9959
2006	1,367	0.4504	0.5734	-0.9498	0.9949
2007	1,382	0.4481	0.5726	-0.9551	0.9921
2008	1,426	0.4454	0.5694	-0.9513	0.9935
2009	1,439	0.4478	0.5669	-0.9596	0.9865
2010	1,443	0.4530	0.5593	-0.9498	0.9867
2011	1,438	0.4614	0.5402	-0.9494	0.9889
2012	1,440	0.4517	0.5354	-0.9452	0.9858
2013	1,415	0.4184	0.5419	-0.9357	0.9848
2014	1,385	0.3991	0.5424	-0.9507	0.9808
2015	1,411	0.3661	0.5543	-0.9381	0.9886
2016	1,399	0.3546	0.5548	-0.9366	0.9856
2017	1,401	0.3476	0.5657	-0.9491	0.9869
2018	1,408	0.3659	0.5634	-0.9467	0.9886
2019	1,406	0.3767	0.5774	-0.9603	0.9900
2020	1,407	0.3833	0.5834	-0.9668	0.9928

Note: Summary statistics: Correlation coefficient between company *i*'s losses and the industry losses by year (2004–2020).

Table OA3.12: ($det\ \hat{\sigma}_i$) FTS Sample 3
($000 omitted)

Year	N	Mean	Std	Min	Max
2004	1,237	27,296.67	84,659.14	4.58	125,6612.94
2005	1,314	27,654.68	88,411.14	4.11	131,4722.85
2006	1,367	27,464.23	91,451.69	4.03	159,3122.96
2007	1,382	28,065.64	91,156.46	4.64	171,0220.57
2008	1,426	31,270.40	103,169.81	5.75	171,5076.42
2009	1,439	31,569.23	102,086.40	5.39	167,7031.61
2010	1,443	32,293.24	104,187.90	5.66	166,6887.22
2011	1,438	33,054.99	105,981.68	4.98	166,6155.71
2012	1,440	34,110.42	107,462.51	4.29	164,3885.09
2013	1,415	35,339.67	112,125.56	0.76	155,0253.11
2014	1,385	36,632.79	122,138.51	3.95	203,4562.94
2015	1,411	37,484.41	135,247.07	3.97	258,7674.99
2016	1,399	35,671.85	136,162.30	2.72	288,7470.78
2017	1,401	37,390.42	146,980.15	2.74	3,245,279.14
2018	1,408	38,405.34	148,507.40	2.44	3,257,791.60
2019	1,406	39,387.62	148,807.16	2.30	3,147,193.52
2020	1,407	38,625.19	142,499.26	2.13	2,672,567.99

Note: Summary statistics: Detrended Standard deviation of the net losses and loss expense incurred group and unaffiliated company by year (2004–2020).

Table OA3.13: ($det\ \hat{\rho}_i$) FTS Sample 3

Year	N	Mean	Std	Min	Max
2004	1,237	0.1956	0.5021	-0.9158	0.9402
2005	1,314	0.2013	0.5116	-0.9232	0.9599
2006	1,367	0.1774	0.4474	-0.8212	0.9339
2007	1,382	0.1653	0.4032	-0.8120	0.9478
2008	1,426	0.1668	0.3640	-0.7770	0.9312
2009	1,439	0.1512	0.2845	-0.7525	0.8486
2010	1,443	0.1450	0.3399	-0.7774	0.8317
2011	1,438	0.1303	0.3356	-0.7512	0.8034
2012	1,440	0.1419	0.3667	-0.7382	0.8238
2013	1,415	0.1581	0.3926	-0.7553	0.8611
2014	1,385	0.1481	0.3813	-0.7278	0.8547
2015	1,411	0.1209	0.3558	-0.6587	0.9072
2016	1,399	0.1343	0.2890	-0.6867	0.8263
2017	1,401	0.1635	0.3332	-0.8204	0.8794
2018	1,408	0.1962	0.4020	-0.8897	0.9306
2019	1,406	0.2125	0.4344	-0.8940	0.9497
2020	1,407	0.2023	0.4456	-0.8961	0.9598

Note: Summary statistics: Detrended Correlation coefficient between group and unaffiliated company *i*'s losses and the industry losses by year (2004–2020).

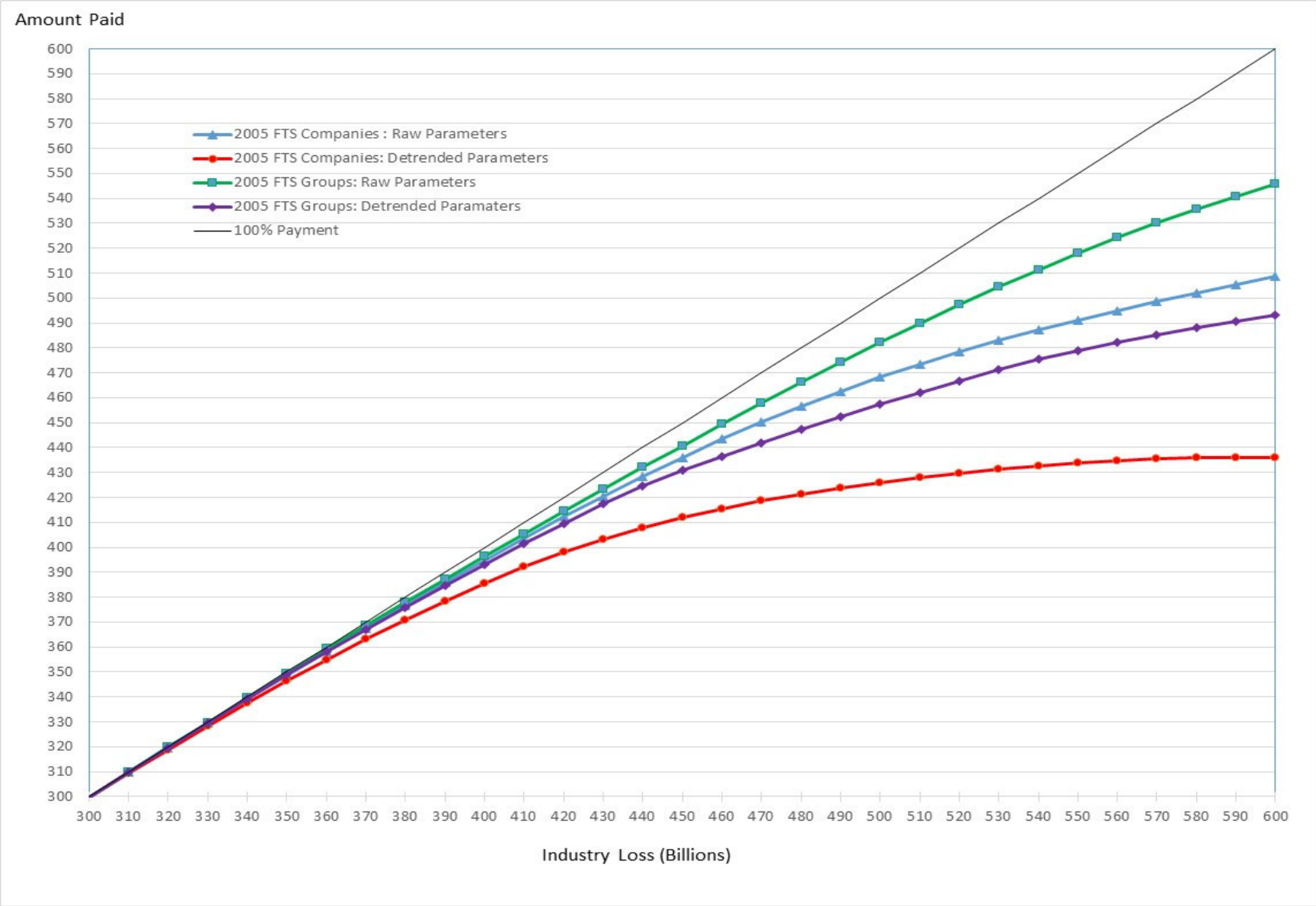

Figure OA3.1: Response functions national net loss, 2005 (FTS Sample 3)

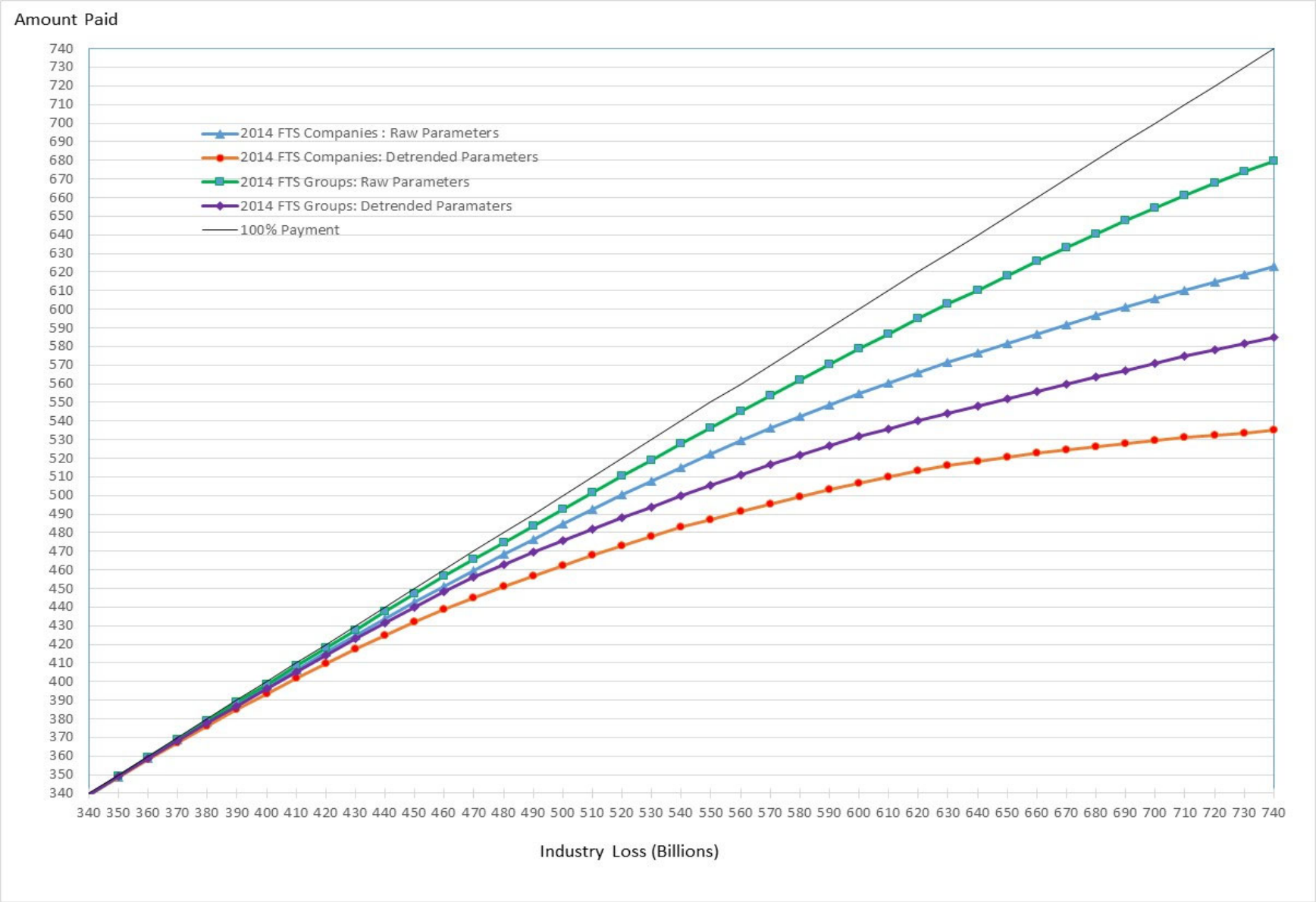

Figure OA3.2: Response functions national net loss, 2014 (FTS Sample 3)

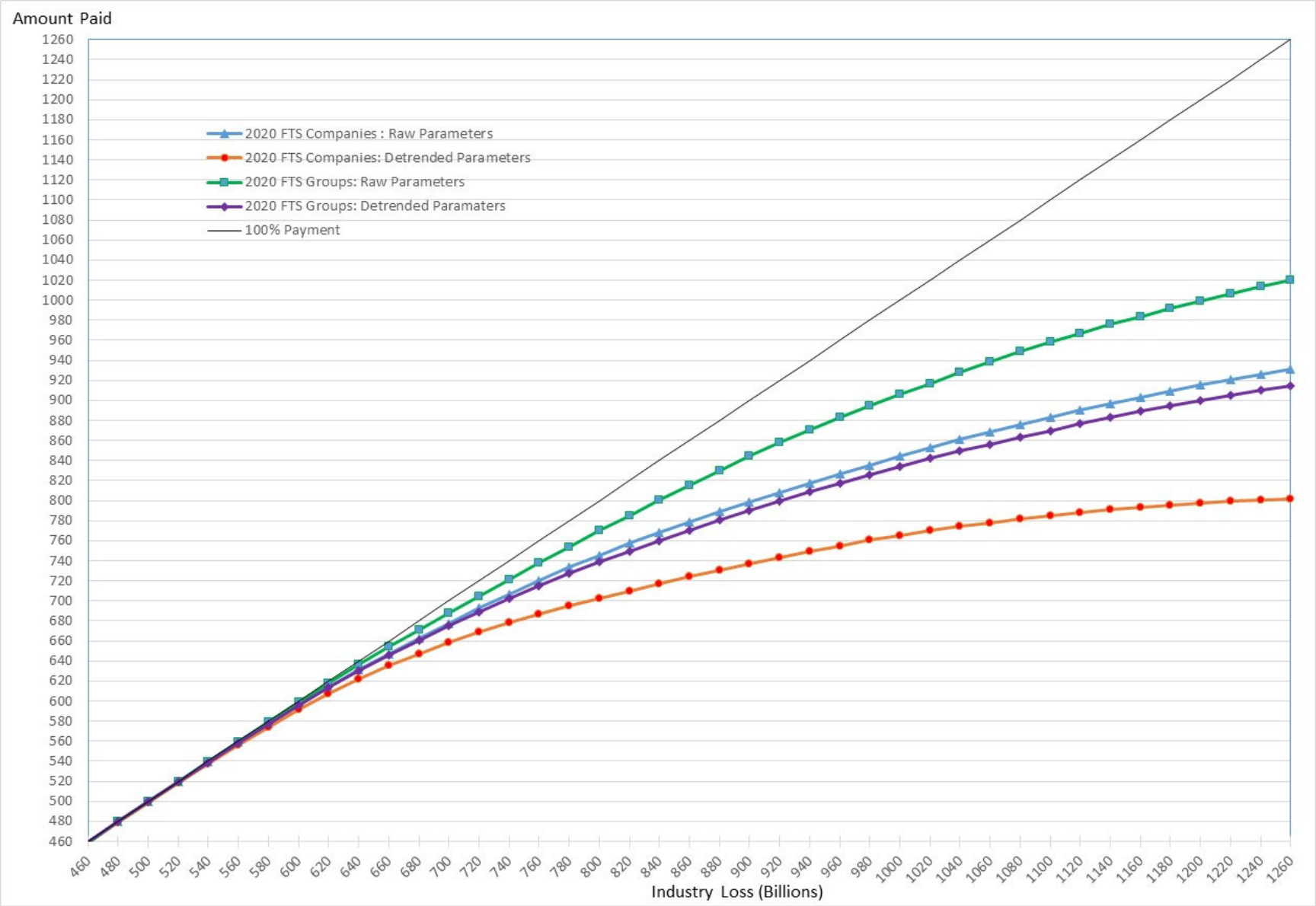

Figure OA3.3: Response functions national net loss, 2020 (FTS Sample 3)

Regression models for parameters estimations

Table OA3.14b: Sample 3
Tobit censored (lb=0) model
Standard deviations: Net losses incurred 2005

Variable	Companies Raw	Companies Detrended	Group Raw	Group Detrended
Intercept	0.2355 8.61	-0.4021 -14.75	0.3842 5.40	0.1919 5.43
Ln(equity capital)	0.0463 11.69	0.0260 13.50	0.0745 7.79	0.0359 7.55
Ln(net losses incurred)	0.0042 1.38	-0.0002 -0.12	0.0035 0.45	0.0004 0.11
Short / Asset	0.1298 4.66	0.0599 4.43	0.2617 4.13	0.1147 3.64
Liquid asset / Asset	-0.0505 -1.53	-0.0420 -2.61	-0.1206 -1.40	-0.0701 -1.64
Sigma	0.1308 51.26	0.0749 51.26	0.2795 38.65	0.1389 38.65
Log likelihood	591	1,540	-108	414
AIC	-1,170	-3,068	228	-817
No. of observation	1,314	1,314	747	747

Note: Short = Cash + cash equivalent + short-term investment; Liquid asset = bond + stock + short. Lb is for lower bond. The dependent variable is the standard deviation of net losses incurred. For each variable, we report the regression coefficient and the *t*-ratio.

Table OA3.14c: Sample 3
Tobit censored (lb=0) model
Standard deviations: Net losses incurred 2014

Variable	Companies Raw	Companies Detrended	Group Raw	Group Detrended
Intercept	0.2301	-0.5540	0.3725	0.2047
	8.51	-15.64	4.87	4.79
Ln(equity capital)	0.0504	0.0327	0.0749	0.0412
	12.77	12.93	7.16	7.06
Ln(net losses incurred)	0.0050	0.0014	0.0080	0.0030
	1.56	0.70	0.88	0.59
Short / Asset	0.1650	0.1005	0.2784	0.1403
	5.27	5.02	3.81	3.44
Liquid asset / Asset	-0.0426	-0.0278	-0.1046	-0.0590
	-1.29	-1.31	-1.11	-1.12
Sigma	0.1653	0.1057	0.3092	0.1726
	52.63	52.63	38.10	38.10
Log likelihood	528	1,147	-178	245
AIC	-1,044	-2,283	368	-478
No. of observation	1,385	1,385	726	726

Short = Cash, cash equivalent and short-term investment; Liquid asset = bond + stock + short. Lb is for lower bond. The dependent variable is the standard deviation of net losses incurred. For each variable, we report the regression coefficient and the *t*-ratio.

Table OA3.14d: Sample 3
Tobit censored (lb=0) model
Standard deviations: Net losses incurred 2020

Variable	Companies Raw	Companies Detrended	Group Raw	Group Detrended
Intercept	0.2999 7.17	-0.6587 -15.62	0.4508 4.13	0.2097 5.32
Ln(equity capital)	0.0724 10.77	0.0399 13.05	0.1223 7.53	0.0548 9.35
Ln(net losses incurred)	0.0009 0.18	-0.0013 -0.54	-0.0025 -0.19	-0.0020 -0.42
Short / Asset	0.1776 3.49	0.1035 4.48	0.3894 3.32	0.1597 3.77
Liquid asset / Asset	-0.0802 -1.57	-0.0338 -1.46	-0.1045 -0.78	-0.0520 -1.07
Sigma	0.2733 53.05	0.1241 53.04	0.4785 39.60	0.1727 39.60
Log likelihood	-171	939	-535	264
AIC	355	-1,866	1,081	-517
No. of observation	1,407	1,407	784	784

Note: Short = Cash + cash equivalent + short-term investment; Liquid asset = bond + stock + short. Lb is for lower bond. The dependent variable is the standard deviation of net losses incurred. For each variable, we report the regression coefficient and the *t*-ratio.

Table OA3.15b: Sample 3
Tobit censored (lb=-1 ub=1) model
Correlation coefficient: Net losses incurred 2005

Variable	Companies Raw	Companies Detrended	Group Raw	Group Detrended
Intercept	0.4947	-0.1803	0.7865	0.4492
	4.06	-0.87	4.95	2.74
Ln(equity capital)	-0.1392	-0.0369	-0.1449	-0.0611
	-10.15	-2.68	-8.51	-3.47
Ln(net losses incurred)	0.1937	0.0844	0.1929	0.0998
	16.17	7.01	12.29	6.15
Short / Asset	0.0978	0.1113	-0.1823	0.0708
	1.11	1.26	-1.80	0.68
Total liability / Asset	-0.0638	0.0276	-0.2067	-0.0607
	-0.67	0.29	-1.70	-0.48
Liquid asset / Asset	0.4157	0.2158	0.2457	0.0047
	3.90	2.01	1.73	0.03
Sigma	0.4844	0.4868	0.4468	0.4617
	51.26	51.26	38.65	38.65
Log likelihood	-912	-919	-458	-483
AIC	1,838	1,851	930	979
No. of observation	1,314	1,314	747	747

Note: Short = Cash + cash equivalent + short-term investment. Liquid asset = bond + stock + short. Lb and Ub are for lower bond and upper bond. The dependent variable is the correlation coefficient of net losses incurred. For each variable, we report the regression coefficient and the *t*-ratio.

Table OA3.15c: Sample 3
Tobit censored (lb=-1 ub=1) model
Correlation coefficient: Net losses incurred 2014

Variable	Companies Raw	Companies Detrended	Group Raw	Group Detrended
Intercept	0.3820	-0.7114	0.8849	0.1093
	2.93	-4.56	4.92	0.76
Ln(equity capital)	-0.0773	0.0436	-0.1043	0.0377
	-5.96	4.39	-5.77	2.60
Ln(net losses incurred)	0.1255	-0.0069	0.1541	-0.0067
	10.59	-0.76	8.77	-0.47
Short / Asset	-0.1961	-0.0112	-0.2646	-0.0529
	-2.12	-0.16	-2.44	-0.61
Total liability / Asset	0.1646	0.0531	-0.3080	-0.0714
	1.57	0.66	-2.13	-0.62
Liquid asset / Asset	0.2734	0.1422	0.0656	0.1859
	2.55	1.73	0.43	1.53
Sigma	0.4881	0.3738	0.4600	0.3688
	52.63	52.63	38.10	38.10
Log likelihood	-972	-602	-466	-306
AIC	1,958	1,218	947	626
No. of observation	1,385	1,385	726	726

Note: Short = Cash + cash equivalent + short-term investment. Liquid asset = bond + stock + short. Lb and Ub are for lower bond and upper bond. The dependent variable is the correlation coefficient of net losses incurred. For each variable, we report the regression coefficient and the *t*-ratio.

Table OA3.15d: Sample 3
Tobit censored (lb=-1 ub=1) model
Correlation coefficient: Net losses incurred 2020

Variable	Companies Raw	Companies Detrended	Group Raw	Group Detrended
Intercept	0.6771	-0.4917	0.8928	0.2661
	5.24	-2.69	5.02	1.75
Ln(equity capital)	-0.0923	0.0106	-0.1185	0.0019
	-6.48	0.88	-6.23	0.12
Ln(net losses incurred)	0.1553	0.0406	0.1832	0.0457
	12.54	3.92	10.71	3.13
Short / Asset	-0.0252	0.1524	-0.0228	0.2054
	-0.27	1.92	-0.19	1.96
Total liability / Asset	0.0783	0.1204	-0.1862	0.1058
	0.75	1.37	-1.35	0.90
Liquid asset / Asset	0.0081	0.0107	-0.0372	0.0251
	0.08	0.12	-0.24	0.19
Sigma	0.5098	0.4272	0.5004	0.4270
	53.03	53.03	39.60	39.60
Log likelihood	-1,048	-799	-570	-445
AIC	2,109	1,612	1,153	904
No. of observation	1,407	1,407	784	784

Note: Short = Cash + cash equivalent + short-term investment. Liquid asset = bond + stock + short. Lb and Ub are for lower bond and upper bond. The dependent variable is the correlation coefficient of net losses incurred. For each variable, we report the regression coefficient and the *t*-ratio.

Table OA3.16: ($\hat{\sigma}_i$) NFTS Sample 3
($000 omitted)

Year	N	Mean	Std	Min	Max
2004	2,140	54,912.05	131,965.81	5.7346067	3,618,578.85
2005	2,152	56,370.15	1424,87.67	6.1116594	3,845,429.32
2006	2,192	54,239.36	139,774.67	6.2958792	3,526,813.30
2007	2,222	55,252.02	140,329.75	6.2663120	3,290,493.04
2008	2,246	58,897.49	150,684.23	6.1898534	3,158,760.30
2009	2,206	59,805.05	154,348.11	5.9217115	3,222,894.32
2010	2,163	58,371.60	155,517.20	5.8047600	3,264,642.47
2011	2,119	60,107.11	162,032.63	5.1390197	3,272,819.44
2012	2,069	60,201.05	161,012.97	4.3171860	3,040,593.75
2013	2,015	60,065.13	158,956.42	0.7745967	2,798,325.46
2014	1,922	59,699.83	165,311.88	3.9460649	3,054,550.34
2015	1,952	61,147.39	175,949.10	3.9797104	4,107,800.61
2016	1,911	62,239.48	192,536.31	2.8452132	5,013,368.92
2017	1,867	67,773.17	221,215.81	2.8452132	6,108,732.75
2018	1,825	71,645.89	240,948.91	2.4553149	6,909,486.53
2019	1,805	75,514.55	257,547.21	2.4043611	7,621,411.37
2020	1,787	77,310.78	271,966.11	2.1995671	8,190,674.39

Note: Summary statistics: Raw Standard deviation of the net losses and loss expense incurred for a company by year (2004–2020).

Table OA1.17: ($\hat{\rho}_i$) NFTS Sample 3

Year	N	Mean	Std	Min	Max
2004	2,140	0.4546902	0.4483530	-0.9653261	0.9931815
2005	2,152	0.4554556	0.4599050	-0.9501159	0.9959215
2006	2,192	0.4404254	0.4674160	-0.9497824	0.9949277
2007	2,222	0.4413788	0.4645582	-0.9550969	0.9921070
2008	2,246	0.4369082	0.4659165	-0.9512583	0.9935037
2009	2,206	0.4340436	0.4691747	-0.9596023	0.9865277
2010	2,163	0.4414353	0.4657871	-0.9497653	0.9866759
2011	2,119	0.4417431	0.4553533	-0.9493755	0.9889317
2012	2,069	0.4309645	0.4566733	-0.9451991	0.9857888
2013	2,015	0.4070722	0.4622474	-0.9357250	0.9848420
2014	1,922	0.3930505	0.4677156	-0.9506626	0.9808095
2015	1,952	0.3632888	0.4781657	-0.9381279	0.9886014
2016	1,911	0.3558370	0.4816997	-0.9366294	0.9856268
2017	1,867	0.3495733	0.4973389	-0.9490993	0.9868746
2018	1,825	0.3662300	0.5013329	-0.9467046	0.9885501
2019	1,805	0.3729897	0.5157657	-0.9603331	0.9899884
2020	1,787	0.3802477	0.5239949	-0.9668353	0.9927877

Note: Summary statistics: Raw Correlation coefficient between company *i*'s losses and the industry losses by year (2004–2020).

Table OA3.18: ($det\ \hat{\sigma}_i$) NFTS Sample 3
($000 omitted)

Year	N	Mean	Std	Min	Max
2004	2,142	15,756.40	65,708.42	1.752335E-14	1,256,612.94
2005	2,152	16,885.80	70,379.28	4.873742E-15	1,314,722.85
2006	2,193	17,119.75	73,410.12	4.72956E-13	1,593,122.96
2007	2,223	17,440.07	73,126.78	1.520423E-19	1,710,220.57
2008	2,246	19,853.78	83,564.25	5.53935E-16	1,715,076.42
2009	2,207	20,583.66	83,783.39	8.468785E-13	1,677,031.61
2010	2,163	21,543.75	86,439.49	1.999368E-17	1,666,887.22
2011	2,119	22,431.84	88,651.37	5.315075E-13	1,666,155.71
2012	2,070	23,740.45	91,005.58	9.021962E-17	1,643,885.09
2013	2,015	24,804.38	95,308.91	1.520287E-15	1,550,253.11
2014	1,922	26,383.99	104,941.00	6.058584E-19	2,034,562.94
2015	1,952	27,081.67	116,166.58	2.282383E-16	2,587,674.99
2016	1,911	26,114.56	117,558.31	1.901331E-11	2,887,470.78
2017	1,867	28,057.84	128,336.10	2.603822E-10	3,245,279.14
2018	1,825	29,629.99	131,425.07	2.658046E-10	3,257,791.60
2019	1,805	30,680.88	132,337.61	4.761655E-10	3,147,193.52
2020	1,787	30,411.66	127,418.73	1.909038E-10	2,672,567.99

Note: Summary statistics: Detrented Standard deviation of the net losses and loss expense incurred by year (2004–2020).

Table OA3.19: ($det\ \hat{\rho}_i$) NFTS Sample 3

Year	N	Mean	Std	Min	Max
2004	2,142	0.1425072	0.3869326	-0.9158120	0.9402143
2005	2,152	0.1593908	0.4038973	-0.9232071	0.9599483
2006	2,193	0.1204652	0.3608090	-0.8211668	0.9338548
2007	2,223	0.1128676	0.3249031	-0.8120274	0.9478374
2008	2,246	0.1323754	0.2938887	-0.7770202	0.9311778
2009	2,207	0.0995025	0.2403785	-0.7524584	0.8486031
2010	2,163	0.0968379	0.2858369	-0.7774213	0.8317238
2011	2,119	0.0885429	0.2829762	-0.7512425	0.8033726
2012	2,070	0.0996039	0.3125511	-0.7382291	0.8238025
2013	2,015	0.1132078	0.3360464	-0.7552936	0.8610978
2014	1,922	0.1077814	0.3299337	-0.7278313	0.8547064
2015	1,952	0.0890173	0.3067299	-0.6587340	0.9072374
2016	1,911	0.0990703	0.2540422	-0.6866608	0.8262655
2017	1,867	0.1263858	0.2956990	-0.8204181	0.8794083
2018	1,825	0.1531442	0.3618562	-0.8896513	0.9305552
2019	1,805	0.1669542	0.3927812	-0.8939908	0.9497062
2020	1,787	0.1621351	0.4028787	-0.8961040	0.9597800

Note: Summary statistics: Detrented Correlation coefficient between company *i*'s losses and the industry losses by year (2004–2020).

Table OA3.20: FTS Groups and unaffiliated companies Sample 3
Summary statistics: Net losses and loss expense incurred by year (2004–2020)
($000 omitted)

Year	N	Sum	Mean	Std	Min	Max
2004	707	264,503,191	374,120	1,909,696	1	33,389,144
2005	747	287,487,717	384,856	2,073,403	2	37,365,769
2006	748	274,902,657	367,517	1,944,225	2	34,552,444
2007	774	289,964,171	374,631	2,006,970	1	35,738,878
2008	775	335,444,768	432,832	2,330,970	1	41,893,664
2009	758	306,754,410	404,689	2,180,565	1	41,358,771
2010	762	307,905,021	404,075	2,182,795	2	42,547,231
2011	747	342,188,269	458,083	2,439,435	1	45,996,798
2012	754	335,233,522	444,607	2,403,693	2	44,829,975
2013	746	321,412,915	430,848	2,324,994	1	44,975,965
2014	726	335,638,810	462,312	2,484,678	1	47,090,286
2015	735	349,653,387	475,719	2,574,159	1	47,884,283
2016	738	374,753,733	507,796	2,827,072	2	53,294,126
2017	752	410,793,280	546,268	3,079,383	1	57,033,235
2018	768	429,370,329	559,076	3,036,684	1	52,921,588
2019	772	441,127,949	571,409	3,113,601	1	52,235,775
2020	784	448,309,430	571,823	3,098,951	1	52,557,754

Table OA3.21: ($\hat{\sigma}_i$) FTS Groups and unaffiliated companies Sample 3
($000 omitted)

Year	N	Mean	Std	Min	Max
2004	707	69,998.14	293,593.17	5.7346067	3,984,748.92
2005	747	73,301.55	321,473.54	6.1116594	4,554,633.14
2006	748	75,099.50	335,768.67	6.2958792	5,201,357.60
2007	774	76,861.29	350,787.45	6.2663120	5,801,584.49
2008	775	86,351.93	385,248.37	6.1898534	6,508,073.36
2009	758	89,096.17	394,146.75	5.9217115	6,484,363.18
2010	762	88,049.76	379,733.48	5.8047600	5,744,263.05
2011	747	92,531.39	395,867.20	5.1390197	5,591,051.80
2012	754	90,705.83	390,405.55	4.3171860	5,5082,46.07
2013	746	89,413.17	375,186.63	0.7745967	5,136,123.44
2014	726	87,296.96	355,163.19	3.9460649	4,594,951.45
2015	735	86,365.90	356,699.91	3.9797104	4,663,551.84
2016	738	85,036.35	373,753.29	4.0473389	5,525,926.90
2017	752	90,682.46	428,435.31	4.0473389	6,905,884.21
2018	768	95,590.82	468,865.89	4.0473389	7,843,598.55
2019	772	102,878.06	506,952.58	3.8815804	8,764,195.99
2020	784	106,062.26	537,481.74	2.5317037	9,644,261.96

Note: Summary statistics: Raw Standard deviation of the net losses and loss expense incurred for group and unaffiliated company by year (2004–2020).

Table OA3.22: ($\hat{\rho}_i$) FTS Groups and unaffiliated companies Sample 3

Year	N	Mean	Std	Min	Max
2004	707	0.5325560	0.5303933	-0.9144850	0.9931815
2005	747	0.5282986	0.5303474	-0.9252321	0.9919107
2006	748	0.5114766	0.5411513	-0.9447594	0.9925776
2007	774	0.5007070	0.5466377	-0.9465556	0.9922203
2008	775	0.4879513	0.5562132	-0.9410837	0.9885393
2009	758	0.5033153	0.5444802	-0.9403212	0.9861364
2010	762	0.4992231	0.5388207	-0.9099596	0.9866757
2011	747	0.5132308	0.5182778	-0.9090587	0.9853968
2012	754	0.4930469	0.5183105	-0.9133251	0.9857888
2013	746	0.4610009	0.5208911	-0.8917605	0.9836246
2014	726	0.4475972	0.5165039	-0.9033075	0.9794053
2015	735	0.4167320	0.5248604	-0.9324193	0.9771787
2016	738	0.3813812	0.5392871	-0.9169411	0.9788871
2017	752	0.3666968	0.5481428	-0.9281775	0.9856858
2018	768	0.3671902	0.5518608	-0.9467046	0.9885501
2019	772	0.3733982	0.5680036	-0.9603331	0.9899884
2020	784	0.3762418	0.5775739	-0.9793097	0.9927877

Note: Summary statistics: Raw Correlation coefficient between groups and unaffiliated company *i*'s losses and the industry losses by year (2004–2020).

Table OA3.23: ($det\ \hat{\sigma}_i$) FTS Groups and unaffiliated companies Sample 3 ($000 omitted)

Year	N	Mean	Std	Min	Max
2004	1,178	80,785.48	230,334.34	5.7346067	3,984,748.92
2005	1,201	84,437.36	256,080.06	6.1116594	4,554,633.14
2006	1,226	87,911.60	265,181.03	6.2958792	5,201,357.60
2007	1,272	91,109.30	276,589.09	6.2663120	5,801,584.49
2008	1,269	100,611.51	303,916.61	6.1898534	6,508,073.36
2009	1,232	103,549.06	311,977.92	5.9217115	6,484,363.18
2010	1,203	99,374.67	304,519.75	5.8047600	5,744,263.05
2011	1,171	103,468.47	318,703.46	5.1390197	5,591,051.80
2012	1,132	101,510.47	321,032.60	4.3171860	5,508,246.07
2013	1,116	98,949.63	308,891.48	0.7745967	5,136,123.44
2014	1,064	95,201.55	295,502.38	3.9460649	4,594,951.45
2015	1,070	95,091.71	297,555.03	3.9797104	4,663,551.84
2016	1,054	95,403.33	314,915.57	4.0473389	5,525,926.90
2017	1,024	102,897.35	369,601.23	4.0473389	6,905,884.21
2018	1,010	111,064.76	411,457.09	4.0473389	7,843,598.55
2019	995	119,604.24	449,196.00	3.8815804	8,764,195.99
2020	992	121,351.31	480,432.90	2.5317037	9,644,261.96

Note: Summary statistics: Detrented Standard deviation of the net losses and loss expense incurred for group and unaffiliated company by year (2004–2020).

Table OA3.24: ($det\ \hat{\rho}_i$) FTS Groups and unaffiliated companies Sample 3

Year	N	Mean	Std	Min	Max
2004	1,178	0.5043031	0.4312634	-0.9144850	0.9941051
2005	1,201	0.5042536	0.4350460	-0.9252321	0.9919107
2006	1,226	0.4834190	0.4414171	-0.9447594	0.9925776
2007	1,272	0.4800209	0.4405383	-0.9465556	0.9922203
2008	1,269	0.4667171	0.4491396	-0.9410837	0.9885393
2009	1,232	0.4705963	0.4415355	-0.9403212	0.9861364
2010	1,203	0.4699574	0.4399464	-0.9099596	0.9866757
2011	1,171	0.4715669	0.4279179	-0.9090587	0.9853968
2012	1,132	0.4570446	0.4344772	-0.9133251	0.9857888
2013	1,116	0.4321402	0.4348066	-0.8917605	0.9836246
2014	1,064	0.4233035	0.4354410	-0.9033075	0.9794053
2015	1,070	0.3979941	0.4429702	-0.9324193	0.9771787
2016	1,054	0.3722486	0.4581339	-0.9169411	0.9788871
2017	1,024	0.3593699	0.4769245	-0.9281775	0.9856858
2018	1,010	0.3667521	0.4878540	-0.9467046	0.9885501
2019	995	0.3690360	0.5060789	-0.9603331	0.9899884
2020	992	0.3737589	0.5185133	-0.9793097	0.9927877

Note: Summary statistics: Detrented Correlation coefficient between groups and unaffiliated company i's losses and the industry losses by year (2004–2020).

Table OA3.25: ($\hat{\sigma}_i$) NFTS Groups and unaffiliated companies Sample 3 ($000 omitted)

Year	N	Mean	Std	Min	Max
2004	707	34,675.51	147,056.20	4.5807940	2,317,992.45
2005	747	35,729.83	157,542.94	4.1135767	2,695,393.98
2006	748	35,884.31	160,294.35	4.0270873	2,741,404.69
2007	774	35,496.47	154,082.83	4.6354153	2,692,700.60
2008	775	41,000.29	169,289.03	5.7455469	2,6864,66.82
2009	758	42,658.78	168,556.75	5.3852911	2,579,350.62
2010	762	43,760.94	173,757.42	5.6623833	2,799,556.58
2011	747	45,862.35	182,253.61	4.9776371	2,981,793.30
2012	754	46,649.35	188,435.58	4.2922668	3,206,557.14
2013	746	50,656.56	209,392.20	0.7611417	3,751,001.82
2014	726	50,184.62	196,312.07	3.9457740	3,378,223.68
2015	735	50,850.98	198,953.24	3.9704371	3,210,357.32
2016	738	46,983.07	175,827.87	4.0062876	2,140,919.54
2017	752	49,939.00	194,261.36	3.9283225	2,460,985.08
2018	768	51,540.77	202,862.62	3.8071272	2,593,569.46
2019	772	54,772.26	216,178.78	3.7488887	2,684,411.72
2020	784	52,227.73	203,814.41	2.2039698	2,500,709.88

Note: Summary statistics: Raw Standard deviation of the net losses and loss expense incurred for group and unaffiliated company by year (2004–2020).

Table OA3.26: ($\hat{\rho}_i$) NFTS Groups and unaffiliated companies Sample 3

Year	N	Mean	Std	Min	Max
2004	707	0.2098112	0.4749432	-0.8861377	0.9402143
2005	747	0.2186490	0.4892162	-0.8865774	0.9350721
2006	748	0.1922154	0.4304525	-0.8211668	0.9044509
2007	774	0.1831258	0.3925028	-0.8120274	0.8505072
2008	775	0.1876948	0.3505970	-0.7770202	0.8502230
2009	758	0.1558743	0.2769927	-0.7309067	0.7985907
2010	762	0.1406547	0.3366185	-0.7774213	0.8441944
2011	747	0.1228034	0.3288244	-0.7211016	0.7955030
2012	754	0.1362618	0.3645110	-0.6793852	0.8420546
2013	746	0.1555715	0.3932400	-0.7552936	0.8838279
2014	726	0.1410741	0.3772353	-0.7090649	0.8843901
2015	735	0.1128660	0.3427623	-0.6247970	0.8326764
2016	738	0.1208521	0.2917294	-0.6795642	0.8034595
2017	752	0.1423927	0.3423896	-0.7884246	0.8697421
2018	768	0.1690276	0.4135594	-0.8896513	0.9069556
2019	772	0.1936776	0.4386565	-0.8939908	0.9206346
2020	784	0.1883354	0.4467571	-0.8943447	0.9287161

Note: Summary statistics: Raw Correlation coefficient between groups and unaffiliated company *i*'s losses and the industry losses by year (2004–2020).

Table OA3.27: ($det\ \hat{\sigma}_i$) NFTS Groups and unaffiliated companies Sample 3 ($000 omitted)

Year	N	Mean	Std	Min	Max
2004	1,178	40,671.69	115,310.64	4.5807940	2,317,992.45
2005	1,201	41,733.62	125,440.99	4.1135767	2,695,393.98
2006	1,226	42,435.24	126,546.35	4.0270873	2,741,404.69
2007	1,272	41,121.70	121,499.12	4.6354153	2,692,700.60
2008	1,269	46,489.28	133,653.82	5.7455469	2,686,466.82
2009	1,232	47,226.60	133,433.93	5.3852911	2,579,350.62
2010	1,203	47,886.05	139,366.20	5.6623833	2,799,556.58
2011	1,171	50,177.51	146,756.40	4.9776371	2,981,793.30
2012	1,132	51,439.14	154,932.88	4.2922668	3,206,557.14
2013	1,116	56,526.23	172,367.70	0.7611417	3,751,001.82
2014	1,064	54,540.53	163,269.97	3.9457740	3,378,223.68
2015	1,070	55,362.01	165,937.70	3.9704371	3,210,357.32
2016	1,054	49,587.67	148,223.32	4.0062876	2,140,919.54
2017	1,024	52,733.47	167,460.45	3.9283225	2,460,985.08
2018	1,010	55,904.44	178,107.03	3.8071272	2,593,569.46
2019	995	59,917.30	191,681.71	3.7488887	2,684,411.72
2020	992	55,230.41	182,208.56	2.2039698	2,500,709.88

Note: Summary statistics: Detrented Standard deviation of the net losses and loss expense incurred for group and unaffiliated company by year (2004–2020).

Table OA3.28: ($det\ \hat{\rho}_i$) NFTS Groups and unaffiliated companies Sample 3

Year	N	Mean	Std	Min	Max
2004	1,178	0.2240838	0.3720539	-0.8861377	0.9402143
2005	1,201	0.2411647	0.3898572	-0.8865774	0.9350721
2006	1,226	0.2088115	0.3391858	-0.8211668	0.9044509
2007	1,272	0.1995182	0.3080185	-0.8120274	0.8505072
2008	1,269	0.1983514	0.2758620	-0.7770202	0.8502230
2009	1,232	0.1564213	0.2183175	-0.7309067	0.7985907
2010	1,203	0.1468312	0.2691551	-0.7774213	0.8441944
2011	1,171	0.1327555	0.2639515	-0.7211016	0.7955030
2012	1,132	0.1501382	0.2990693	-0.6793852	0.8420546
2013	1,116	0.1687363	0.3231594	-0.7552936	0.8838279
2014	1,064	0.1546782	0.3131414	-0.7090649	0.8843901
2015	1,070	0.1266885	0.2857418	-0.6247970	0.8326764
2016	1,054	0.1276205	0.2451718	-0.6795642	0.8034595
2017	1,024	0.1523983	0.2952560	-0.7884246	0.8697421
2018	1,010	0.1842045	0.3636537	-0.8896513	0.9069556
2019	995	0.2041673	0.3884053	-0.8939908	0.9206346
2020	992	0.2010538	0.3990923	-0.8943447	0.9287161

Note: Summary statistics: Detrended Correlation coefficient between group and unaffiliated company *i*'s losses and the industry losses by year (2004–2020).

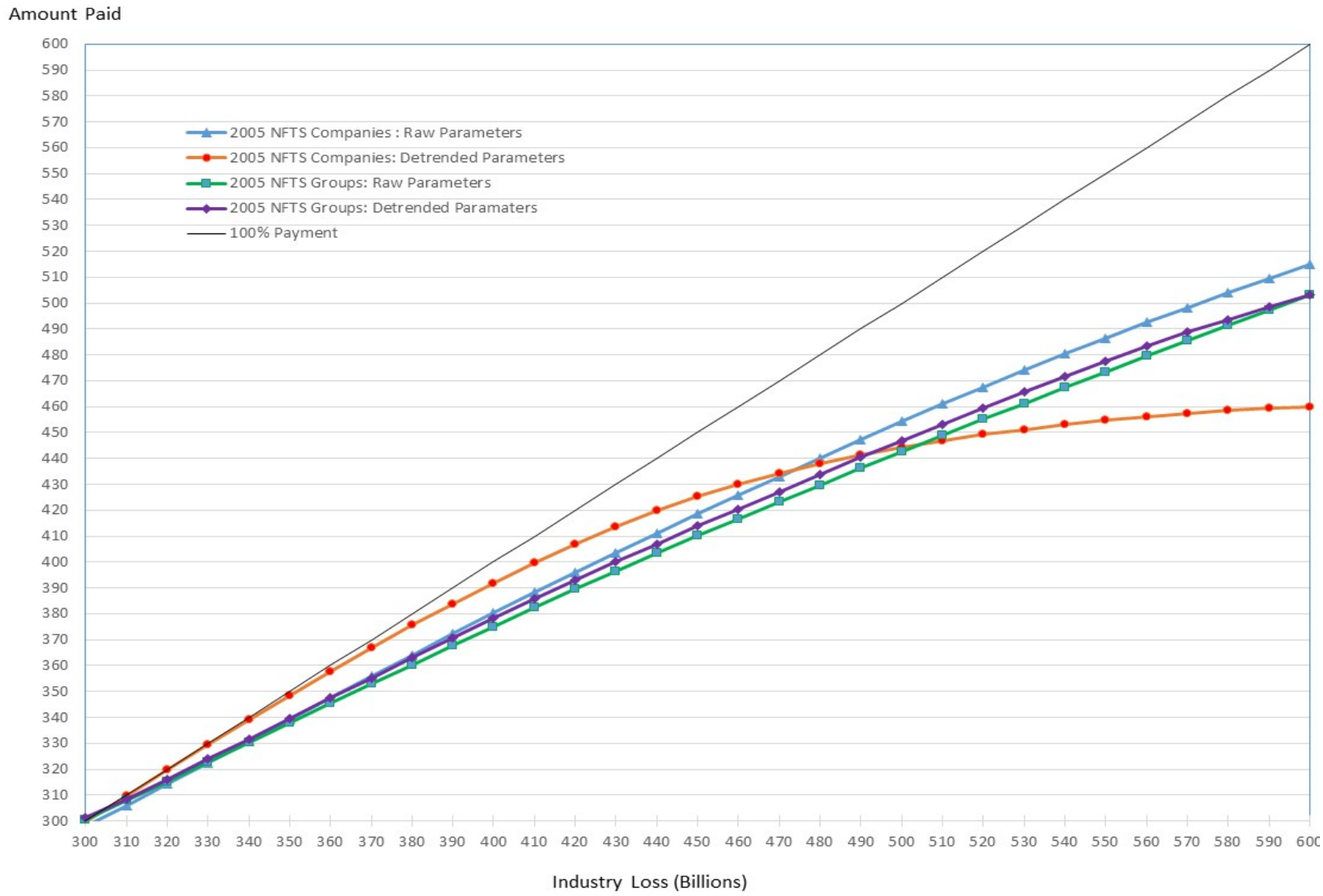

Figure OA3.4: Response functions national net loss, 2005 (NFTS Sample 3)

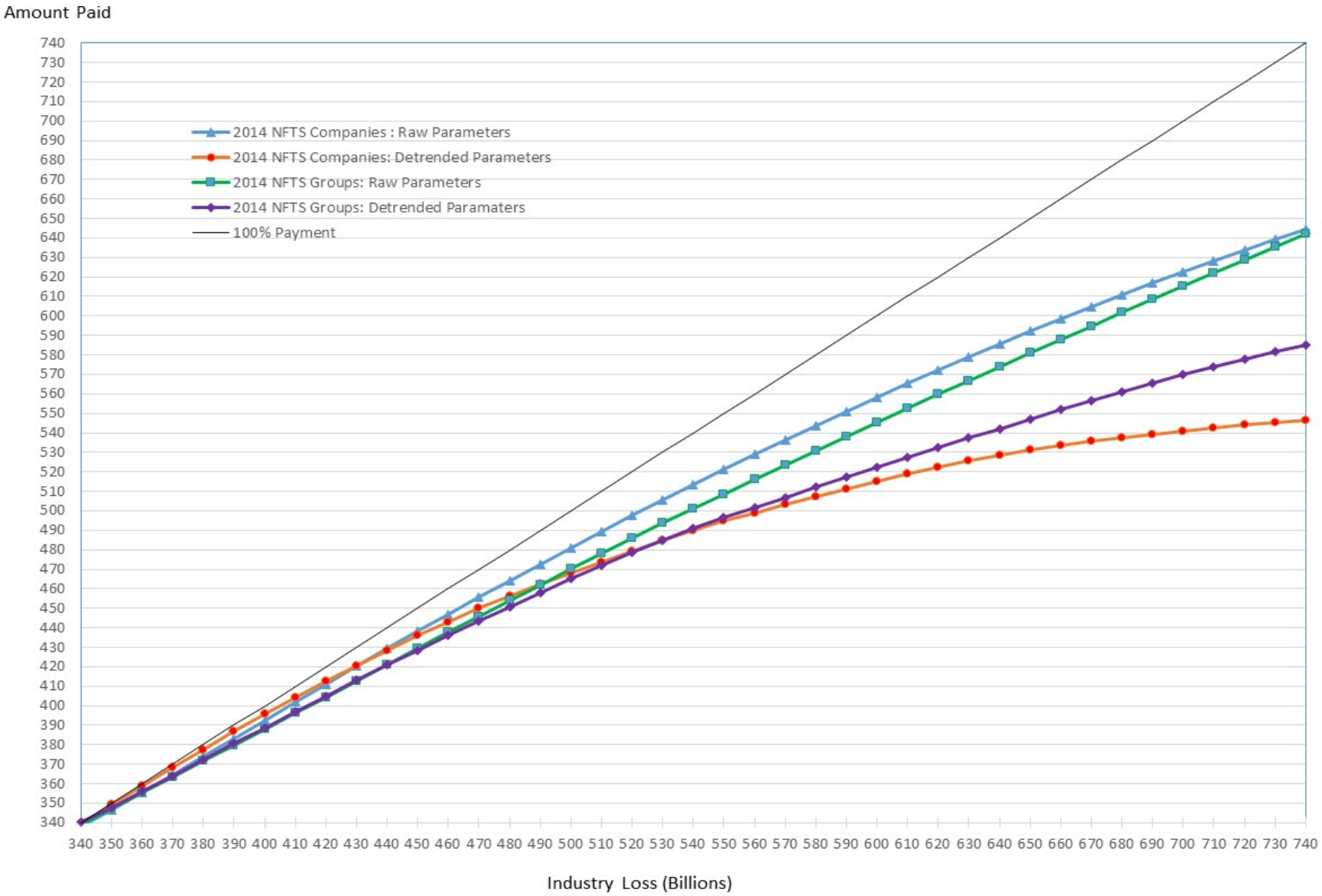

Figure OA3.5: Response functions national net loss, 2014 (NFTS Sample 3)

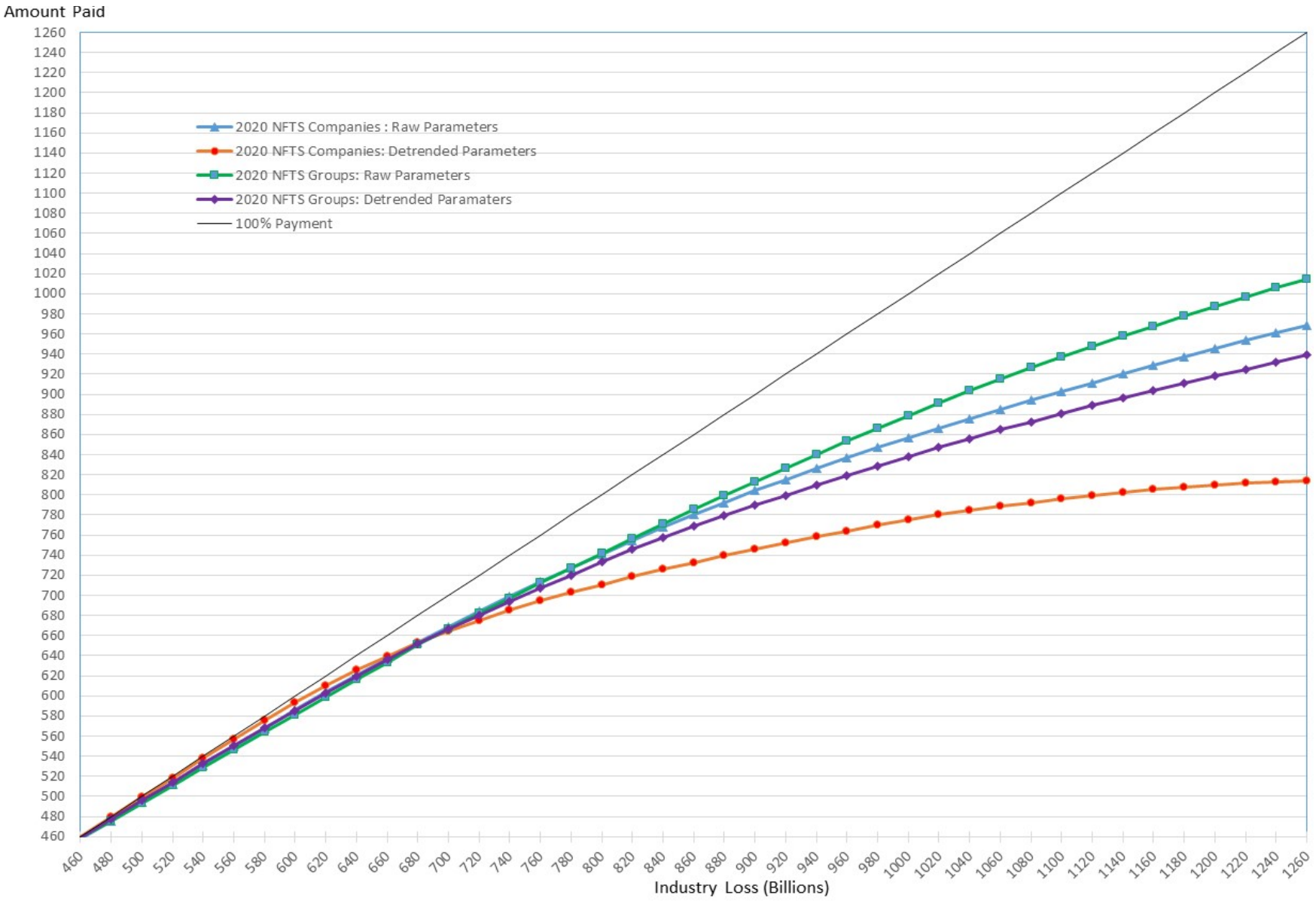

Figure OA3.6: Response functions national net loss, 2020 (NFTS Sample 3)