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THE CATASTROPHIC EFFECTS OF NATURAL DISASTERS ON INSURANCE MARKETS

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ABSTRACT

Natural catastrophes often have catastrophic risks on insurance companies as well as on the insured. Using a very large dataset on homeowners' insurance coverage by state, by firm, and by year for the 1984 to 2004 period, this paper documents the positive effect on losses and loss ratios of both unexpected catastrophes as well as large events that the authors term "blockbuster catastrophes." Insurers adapt to these catastrophic risks by raising insurance rates, leading to lower loss ratios after the catastrophic event. There is a widespread event of unexpected catastrophes and blockbuster catastrophes that reduces total premiums earned in the state, reduces the total number writing insurance coverage in the state, and leads to the exit of firms from the state. Firms with low levels of homeowners' premiums are most adversely affected by the catastrophes.

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In conventional insurance markets, such as for automobile insurance, the insurer faces a large number of independent risks that tend to follow a fairly predictable pattern across time. By charging premiums that the firm can invest and earn a return on before paying off the losses, the firm will be able to run a profitable insurance business.

Catastrophic losses caused by natural disasters are much more problematic from an insurance standpoint. Rather than a large number of risks that on average follow a quite predictable year-to-year pattern, catastrophic losses tend to be lumpy. In fact, the situation parallels that in an automobile insurance case in which there is not a large number of independent trials but rather a single draw for highly correlated risks so that either every auto or no autos are involved in an accident that year.

Catastrophic risks consequently pose a variety of problems for insurers. First, because the losses arise from a small number of lumpy events, the insurer may not have sufficient resources to cover the losses. Less dramatically, the firm may suffer losses well in excess of the value of the premiums that it charged for the coverage. In the absence of adequate reinsurance, the firm may go bankrupt or may choose to exit a state in which there is a substantial exposure to such catastrophic risks. In response to losses incurred following Hurricane Katrina, which accounted for over $38 billion in insured losses last year, one major insurer, Allstate, has exited several coastal states while another, State Farm, has chosen not to renew some policies in these areas.[1] The fourth-largest personal insurer in Florida, Poe Financial, went bankrupt.[2]

The second ramification of catastrophic losses is that they will influence the rate structure even for firms that remain quite viable in the presence of natural disasters. Suppose that an insurer is writing coverage in a very high-risk state that experiences a major disaster once every

[1] "The Price of Sunshine," *The Economist*, June 8, 2006, p. 76.
[2] *Ibid*. More specifically, the article concluded: "In April Poe Financial, Florida's fourth-largest personal insurer, collapsed, leaving 316,000 policyholders in need of coverage."

decade. In that disaster year, the firm will suffer losses well in excess of premiums. For it to be profitable for the insurer to write coverage in the state, it will consequently have to charge more for insurance in the other years in which there are no catastrophes than it would if there were not the threat of catastrophic risks. Thus, one would expect to observe very high loss ratios in the catastrophic risk states in years in which a catastrophe has occurred and expect especially low loss ratios in the non-catastrophe years as compared to the loss ratios in states not subject to such catastrophic risks.

A third phenomenon linked to natural disasters is that of learning about the risks over time. The distribution of losses due to catastrophes may change over time for a variety of reasons. Locational patterns may have shifted over time, as reflected in increased construction in high-risk beach front locales. There also may be shifts in weather patterns, as evidenced in the recent speculation that catastrophic losses from Hurricane Katrina are likely to increase in the presence of global warming. The hurricane season in the period 1995-2005 averaged 15 named storms per year, up from an average of 8.5 named storms from 1971-1994.[3] To the extent that insurers are rational Bayesian decision makers, one would expect them to update their risk beliefs over time when writing insurance coverage.

Somewhat surprisingly, there is no econometric analysis whatsoever that addresses these and other fundamental aspects of how catastrophic risks affect insurance markets. There have, of course, been extensive discussions of a conceptual nature as well as analyses of the potential role of reinsurance, but there has been no empirical examination of how catastrophic risks affect insurance company behavior.[4]

[3] National Oceanic and Atmospheric Administration (2006).

[4] Examples of previous treatments of the insurance of catastrophic risks include special issues of the *Journal of Risk and Insurance* (December 1996) and the *Geneva Papers on Risk and Insurance* (April 1997). Representative articles are those by Grace, Klein and Kleindorfer (2004), Angbazo and Narayanan (1996), Gollier (1997), Kleffner

This paper will provide a detailed empirical examination of how catastrophic risks affect the performance of the market for homeowners' insurance. The dataset that we use is unprecedented in the homeowners' insurance literature in terms of its level of detail. In particular, we use information on losses and premiums by firm and by state over a 21-year period from 1984 to 2004. This quite-comprehensive dataset enables us to analyze the effect of catastrophic events of differing magnitude and to explore the effects over time in how these catastrophic events affected insurance company behavior in subsequent years.

Section 1 provides some background information regarding catastrophic events arising from natural disasters. That there might be hurricanes in Florida and tornadoes in the Midwest should not take insurance companies entirely by surprise. Thus, we calculate the average number of catastrophic events by state, where the number of such events is typically not great, but they are not extremely rare events either. That section also explores what we term "blockbuster" catastrophes, which are the twenty most costly natural catastrophes that occurred from 1984 to 2004. These blockbuster events may have particularly dire consequences for insurance companies to the extent that these very large losses were not anticipated.

After reviewing the data sources and the variables used in our analysis in Section 2, in Section 3 we estimate the effect of catastrophic risks on loss ratios, the losses incurred by the insurer, and the premiums earned by the insurer. This analysis will indicate that insurers do in fact suffer catastrophic losses in response to catastrophic events, but that they also respond by altering their premium structure in the non-catastrophe years.

In Section 4 of the article, we examine the effects of these catastrophic risks on the size of the market in any given state. Do natural disasters lead firms to exit the market, and what is

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and Doherty (1996), and Zeckhauser (1995). More generally see Viscusi (1993), which focused on liability insurance ratemaking in response to the surge in tort liability.

their effect on the total number of firms writing insurance coverage in the state? Are some firms particularly vulnerable to the risks of catastrophes, and what are the characteristics of these firms that are most at risk? Section 5 concludes the paper.

1. Catastrophic Events

The focus of our empirical analysis is on a series of measures of catastrophic events. We analyze the period from 1984 to 2004, which is the 21-year span covered by our dataset on homeowners' insurance that will be the reference point for our empirical analysis. The catastrophic events were compiled from Swiss Re Sigma Reports dating from 1985 to 2005. These Swiss Re figures were in turn based on data from the Property Claims Service (PCS), which is a division of the Insurance Services Office (ISO). The PCS currently defines catastrophes as "events that cause $25 million or more in direct insured losses to property that affect a significant number of policy holders and insurers."

We restrict the definition of catastrophes to natural catastrophes; that is, events which are caused by natural forces. Thus, for example, the consequences of terrorism attacks are not included. Because our concern is with homeowners' exposure, we exclude those natural catastrophes which are more likely to have an impact on commercial lines. Specifically, we account for floods, storms, fires, and earthquakes, but we do not include drought and cold waves. We also do not include man-made disasters, such as aviation accidents and explosions, because most of these disasters involve commercial exposures or affect only a very limited space. These events also likely involve only a small number of insurance policies as well.

Our accounting for catastrophic events consequently relies on the selection criteria used by Swiss Re. The threshold for losses included in the Sigma Reports is adjusted annually to

account for inflation in the United States so that our annual tally of catastrophic events over the two-decade period is in comparable inflation-adjusted terms.

Figure 1 summarizes the number of catastrophic events by year for the 1984 to 2004 period. Although catastrophes are not as frequent as, for example, automobile accidents, they are not extremely rare events. In 1996, there were over 200 state-level catastrophic events that met the damages threshold.[5] Moreover, in just over half of the years shown in the figure, there were more than 100 catastrophic events throughout the country. Note that there was also an upward trend in the number of catastrophic events over time. This trend suggests that either there is increased vulnerability to catastrophic events, or that the underlying climatic conditions generating these events now pose a greater risk than they did two decades ago.

The frequency of these catastrophic events varies considerably across different states. Table 1 summarizes the average number of catastrophic events per year for each of these states. The 21-year period for the analysis provides a reliable long-term perspective on the frequency of these risks and is much more informative than, for example, focusing on the results of a single year. Even comparatively safe states, such as Alaska and Hawaii, experience 0.14 catastrophic events per year. Put somewhat differently, these states experienced three catastrophic events over the 21-year period shown in the table.

At the high end of the spectrum is the state of Texas, which averages 7.43 catastrophic events annually. This figure translates into a total of 156 natural disasters over the 21-year period, as Texas is very vulnerable to tropical storms as well as tornadoes.

Insurance companies should have a general sense of the average frequency of catastrophic events by state, such as these statistics in Table 1. Thus, the main concern for

[5] Since we focus on insurers' state-level performance, we account for catastrophes at the state level. Thus, a hurricane affecting three states is counted as three catastrophic events, once in each of the three states affected.

insurers as well as for subsequent empirical analysis will be the extent to which there is a departure in the experience of a particular state from this longer-term average. If, for example, Texas continued to have seven or eight catastrophic events every year and there was no variation in this amount, then insurance pricing would be much more stable than if there was a pronounced upward trend in the number of catastrophic events.

The twenty most devastating of these natural catastrophes are those that we term blockbuster catastrophes. Table 2 lists the twenty most costly natural catastrophes over the 1984-2004 period. Although the losses associated with Hurricane Katrina dwarf those for the catastrophic events shown in Table 2, these disasters also were quite costly. The most costly of the catastrophes was the 1992 Hurricane Andrew, which led to an insured loss of $21.5 billion. The 1994 Northridge earthquake was not far behind, with a loss of $17.8 billion. Every one of the twenty blockbuster catastrophes shown in Table 2 created a loss of $1.7 billion or more. While these losses were often spread across several states, it is noteworthy that some states have a prominent role in many of these events. Florida, for example, is represented in eleven of the twenty blockbuster catastrophes.

Our empirical conjecture is that the incidence of these blockbuster catastrophes will not be fully anticipated by the insurers. As a consequence, we expect there to be a major effect of blockbuster effects on insurance pricing as well as exit of insurance companies from the state. Blockbuster events by their very nature should be unexpected in terms of their severity. There consequently should be a twofold effect resulting from both a one-time major financial shock as well as a longer-term effect as insurance companies revise their risk assessments for the coverage that they are writing in these states that are susceptible to blockbuster catastrophes.

2. Data Sources

The core database that we use for our empirical analysis consists of the state-level homeowners' insurance operations for all U.S. insurers from 1984 to 2004. We obtained the direct premiums earned and losses incurred statistics from the State Pages of insurer's annual filings with the National Association of Insurance Commissioners for all insurers with positive premiums in the homeowners' line. This dataset is also the source of our information on total premiums earned in a state, organizational form, and the number of states in which the insurer writes homeowners' coverage.

The number of firm-state units in the dataset declines steadily through the time period analyzed. Whereas there were 9,644 observations in 1984, by 2004 there were only 6,596 firm-state units in the dataset. The number of unique firms in the sample ranges from a high of 1,103 in 1990 to a low of 961 in 2004. These figures suggest that firms offering homeowners' coverage have consolidated their operations, electing to provide coverage in fewer and fewer states over time, but not exiting the U.S. market.

Our analysis links an insurer's state-level homeowners' experience to catastrophic events in the state. The compilation of catastrophic events at the state level revealed that some states are affected by catastrophes on a regular basis. Anticipated catastrophic events would be reflected in premiums if insurers are rational. Likewise, insurer underwriting performance should not be adversely affected by catastrophic events that are anticipated, but would be adversely affected by a greater-than-anticipated number of events, and enhanced by a lower-than-anticipated number of events. To capture this relationship, we create a variable by year and by state called *Unexpected Catastrophes*. This variable is defined as the difference between the

number of actual catastrophic events in a given year and the average number of catastrophic events in that state over the 1984-2004 period.

The second set of catastrophic variables used are what we call *Blockbuster Catastrophes*. This variable is the number of blockbuster catastrophe events from Table 2 that occurred in that state in that particular year. While all catastrophic events were counted equally in the creation of the *Unexpected Catastrophes* variable, we expect that these blockbuster catastrophes may have a differential effect. Because these events have a more profound effect on insurers' performance, this variable equals the number of blockbuster catastrophic events in the state in which the insurer operates for a given year.

The next set of variables pertains to organizational form. We have separate variables to distinguish whether the firm had a *Mutual* insurance structure, a *Lloyds* insurance structure, or was a *Reciprocal* firm. The omitted category is that of stock firms.[6]

We also included four variables that reflect the overall size of the insurance companies' operations. The three national measures are the *Number of States* in which the insurer operates, the *Total Homeowners' Premiums* written by the insurance company throughout the country, and the *Total National Premiums* written by the insurance company in all lines of insurance. We also include *Total Premiums in State* as a measure of the scale of the firm's operations within the state. One would expect smaller firms to be more susceptible to shocks than larger firms. Moreover, one would expect firms with a substantial presence in the state to be more reluctant to leave the state after a catastrophic event because of the losses associated with other lines.

The final variable we include is a 0-1 variable for *Restrictive Rate Regulation*. In these states, the firm must obtain prior approval before changing its homeowners' insurance rates. We

[6] For a review of the effect of organizational form on insurer performance see Born, Gentry, Viscusi, and Zeckhauser (1998).

expect that a more restrictive state regulatory regime would hinder insurer's ability to recover financially following a catastrophic event.[7]

A major concern in the literature on insurance is how premiums are adjusted over time in response to fluctuations in interest rates. This phenomenon, which is known in the literature as the underwriting cycle, is often captured in empirical analyses of insurance markets by including some type of interest rate variable. Our subsequent regression analysis will be more general, in that we include time-specific indicator variables for each year in the sample, thus sweeping out all time-dependent influences such as interest rate fluctuations and temporal trends in the number of firms writing homeowners insurance, as well as any other temporal effects.

3. Insurance Market Consequences of Catastrophes: Loss Ratios, Premiums, and Losses

To explore the effects of catastrophic risks, we present a series of regression analyses of the effect of these various variables on loss ratios, premiums, and losses. The loss ratio is the first measure that we consider, which is the ratio of losses incurred divided by premiums earned. The inverse of the loss ratio is the most widely accepted measure of insurance company profitability.

Figure 2 presents the loss ratio pattern for all homeowners' insurers over the 1984-2004 period as well as the pattern for states that are particularly vulnerable to catastrophic risks: Florida, California, and Texas. As one might expect, in these high-risk states, there are often spikes in loss ratios that greatly exceed the loss ratios in the homeowners' lines more generally. However, in the years in which there are no big spikes, it is also noteworthy that in these high-risk states, the loss ratios are very low. Indeed, for the states of Florida, California, and Texas, in most years of the last decade, shown in Figure 2, the loss ratios in these states are substantially

[7] For a discussion of the effects of rate regulation on property and casualty insurers, see Born (2001).

below the average loss ratios for homeowners' insurance generally. Our hypothesis is that insurers that experience these catastrophic losses and blockbuster events will adjust their pricing practices so that the insurance they write in the years in which catastrophic events do not occur will be more profitable than insurance written in states not subject to a large number of catastrophes. This additional profitability is needed to compensate for the increased losses that these firms experience during the years in which major catastrophes occur.

Table 3 presents the regression of the natural logarithm of loss ratio on the series of explanatory variables. Specifically, we estimate:

$$\begin{aligned} LossRatio_{ist} = {} & \alpha_1 + \beta_1 UnexpCat_{ist} + \beta_2 UnexpCat_{is,t-1} + \beta_3 UnexpCat_{is,t-2} \\ & + \beta_4 Blockbuster_{ist} + \beta_5 Blockbuster_{is,t-1} + \beta_6 Blockbuster_{is,t-2} \\ & + \beta_7 Mutual_i + \beta_8 Lloyds_i + \beta_9 Reciprocal_i + \beta_{10} LnNumsts_{it} \\ & + \beta_{11} LnHOPrems_{it} + \beta_{12} LnStatePrems_{ist} + \beta_{13} LnNatPrems_{it} \\ & + \beta_{14} RateReg_{ist} + \sum_{j=1}^{20} Y_i + \varepsilon_{1t}. \end{aligned} \quad (1)$$

for firm i in state s at time t, and where Y_j is a dummy variable for each year j=1985-2004. The main hypotheses are that unexpected catastrophes and blockbuster catastrophes should substantially boost the loss ratios that firms experience in the catastrophe years and lower loss ratios in the non-catastrophe years.

This basic set of predictions is in fact borne out in the results in Table 3. There is the expected positive effect of the current value of the catastrophe variable as well as the value lagged one year. Notably, two years after the unexpected catastrophe, there is a negative effect that is roughly the same size as the estimated standard error. Thus, the *Unexpected Catastrophe* variable lagged two years is consistent with our pricing hypothesis, but there is no statistically significant evidence of such an effect.

The subsequent loss ratio offset is more pronounced for blockbuster catastrophes. The effect of blockbuster catastrophes is to boost the loss ratio during the year of the blockbuster catastrophe, but there is an opposite and almost offsetting effect two years later. This result is consistent with our hypothesis that after a blockbuster event, firms will raise their insurance premiums in order to provide sufficient coverage in case of future blockbuster catastrophes. These premium adjustments lead to lower future loss ratios during the years in which a blockbuster catastrophe does not strike. The evidence for such adjustments is much stronger for blockbuster catastrophes than for catastrophes more generally.

Table 4 presents the regression of the log of premiums earned against our set of explanatory variables. Specifically,

$$\begin{aligned} LnHOPrems_{ist} &= \alpha_1 + \beta_1 LnHOPrems_{is,t-1} + \beta_2 Un\,exp\,Cat_{ist} + \beta_3 Un\,exp\,Cat_{is,t-1} \\ &+ \beta_4 Un\,exp\,Cat_{is,t-2} + \beta_5 Blockbuster_{ist} + \beta_6 Blockbuster_{is,t-1} \\ &+ \beta_7 Blockbuster_{is,t-2} + \beta_8 Mutual_i + \beta_9 Lloyds_i + \beta_{10} Re\,ciprocal_i \\ &+ \beta_{11} LnNumsts_{it} + \beta_{12} RateReg_{st} + \beta_{13} LnStatePrems_{ist} + \beta_{14} LnNatPrems_{it} \\ &+ \sum_{j=1}^{20} \delta_j Y_j + \varepsilon_{ist}\,. \end{aligned} \tag{2}$$

Premiums reflect both the price of insurance as well as the quantity of insurance, so in many respects are a less instructive measure than the loss ratio, which serves as an ex-post measure of insurer profitability. We include a measure of the one-period-lagged homeowners' premiums in the analysis as well to capture the fact that there is a strong autoregressive character to insurance underwriting, as firms that write a large number of premiums in the state in a given year will tend to continue to do so in subsequent years. Indeed, the elasticity of premiums earned to homeowners' premiums earned in the previous year is 0.973.

Catastrophic events have a mixed effect on insurance premiums. One would expect these unexpected catastrophes or blockbuster events to raise the rate that firms charge for insurance. Thus, for any given number of policies written, the total premiums will rise. However, these major catastrophes also may reduce the quantity of insurance written, both because of the higher rates and insurance rationing, as well as exiting of firms from the state.

The regression results in Table 4 indicate that the negative quantity effect is dominant. Unexpected catastrophes have a negative effect on premiums earned, both in the year of the catastrophe as well as in the subsequent year. Similarly, the blockbuster catastrophes are influential as well with a significant negative effect both in the current year as well as two years after the catastrophic event.

The most easily predictable results are those pertaining to losses incurred. These major catastrophes should clearly boost the losses incurred by the insurance company, controlling for the scale of the company's operations, which we do by including the lagged value of the homeowners' premiums written by the company in that state. We estimate:

$$\begin{aligned} LnHOLosses_{ist} = {} & \alpha_1 + \beta_1 LnHOPrems_{is,t-1} + \beta_2 UnexpCat_{ist} + \beta_3 UnexpCat_{is,t-1} \\ & + \beta_4 UnexpCat_{is,t-2} + \beta_5 Blockbuster_{ist} + \beta_6 Blockbuster_{is,t-1} \\ & + \beta_7 Blockbuster_{is,t-2} + \beta_8 Mutual_i + \beta_9 Lloyds_i + \beta_{10} Reciprocal_i \\ & + \beta_{11} LnNumsts_{it} + \beta_{12} RateReg_{ist} + \beta_{13} LnStatePrems_{ist} + \beta_{14} LnNatPrems_{it} \\ & + \sum_{j=1}^{20} \delta_j Y_i + \varepsilon_{ist} . \end{aligned} \tag{3}$$

The results, shown in Table 5, suggest that unexpected catastrophes raise the value of losses incurred, both in the year of the catastrophe as well as in the subsequent year. About three-

fourths of the influence occurs in the current year, with the remainder occurring with a one-period lag.

Blockbuster catastrophes raise the value of losses in the year of the catastrophe, but two years later reduce the value of losses. This effect of reducing losses two years after a catastrophe would be expected, to the extent that the blockbuster event leads to either a reduced quantity of insurance written or the exit of the firm from the state insurance market altogether.

4. Effect of Catastrophes on Insurance Firms' Exit from the State

The negative effect of catastrophic events on premiums suggests that firms have adapted to catastrophic events either by reducing the amount of coverage they write or by exiting the state altogether. In this section we will explore the effect of catastrophes on exit in two ways. First, we will examine the effect of catastrophes on the number of firms writing homeowners' insurance coverage in the state. Second, we will explore what determines a firm's exit from the state and how catastrophes affect these exit decisions.

If catastrophes were fully anticipated by companies, then we would not expect there to be a substantial effect on the exit of firms. Catastrophes would not lead firms to revise their assessments of the risks of writing future homeowners' insurance coverage in the state. The catastrophic event would function as a fixed cost, so that if it was optimal to write insurance coverage previously in the state then it will continue to be profitable to do so. Because the risks were fully anticipated, the premiums will have been set in a manner so that in the long run, the insurer will earn sufficient profits to make writing coverage desirable. If, however, the risks were not fully anticipated and catastrophic events lead firms to revise their assessments of the

future hazards, then the expectation is that firms will choose either to raise their rates or to exit the state.[8]

In addition to the effect of catastrophic events on insurance firms' expectations of future losses, there is the additional problem that major catastrophes may generate losses that either bankrupt the firm or lead it to exit the state if the firm did not have adequate reinsurance to cover these risks. In terms of an empirical prediction, these effects of catastrophic losses should be greatest for firms with the fewest available resources.

We estimate two equations to assess the effects of catastrophes on the number of firms in the state, where the dependent variable in the number of firms in the state. First, we estimate:

$$\begin{aligned} NumFirms_{st} &= \alpha_1 + \beta_1 StateLR_{s,t-1} + \beta_2 StateLR_{s,t-2} + \beta_3 UnexpCat_{s,t-1} \\ &+ \beta_4 UnexpCat_{s,t-2} + \beta_5 Blockbuster_{s,t-1} + \beta_6 Blockbuster_{s,t-2} \\ &+ \beta_7 RateReg_{st} + \beta_8 HOPrems_{st} + \sum_{j=1}^{20} \delta_j Y_{jt} + \varepsilon_{st}. \end{aligned} \quad (4)$$

The results of estimating equation 4 are presented in the first column of Table 6. The first set of variables is the state homeowners' loss ratio lagged one year and lagged two years. Neither measure is found to have a significant effect on a number of firms in the state. The profitability of insurance per se consequently is not influential.

The next sets of variables pertained to the influence of unexpected catastrophes and blockbuster catastrophes in the state, in the previous year and two years earlier. Unexpected catastrophes did not have a significant effect on the number of firms writing homeowners' insurance in the state; however, blockbuster catastrophes do have an influence. The significant effect occurs with a one-period lag, as the occurrence of a blockbuster catastrophe event reduces

[8] While insurers may voluntarily leave a state, a catastrophe could also force them to exit the market if they have become insolvent. We did not investigate the reason for exit, but note the collapse of at least one large personal lines insurer in Florida following hurricane Katrina. ("The Price of Sunshine," *The Economist*, June 8, 2006, p. 79).

the number of firms writing homeowners' insurance coverage by 11. Thus, much of the reduction in premiums following blockbuster catastrophes stems from a net decrease in the number of firms writing insurance in that state.

Two state characteristic variables included in the first column in Table 6 are for restrictive rate regulation, which reduces the number of firms writing coverage, and the total level of state homeowners' premiums, which, as one might expect, is positively correlated to the number of homes in the state.

The second column in Table 6 explores the influence of possible interactive effects of the regulatory regime with the effect of the blockbuster catastrophe variables. We estimate equation 4 again, this time including two interaction terms. We find that there is a negative effect on market size of blockbuster catastrophes with both a one-period lag and a two-period lag. Thus, the combined effect is to reduce the number of firms writing homeowners' insurance by 22 firms, where this result pertains to states that do not have restrictive regulation. If, however, there is a restrictive regulatory regime, as is modeled by the two interactions of *Restrictive Regulation* with the two lagged *Blockbuster Catastrophe* variables, then this effect is substantially reduced. The statistically significant interaction for the two-period lag of blockbuster catastrophes with the restrictive rate regulation variable increases the number of firms writing insurance by 19, which offsets most of the influence of the two statistically significant blockbuster catastrophe variables. Although the mechanism for this influence is not clear, what may be at work is that in states with restrictive rate regulation, firms are reluctant to exit the homeowners' insurance market in the state because doing so may jeopardize a firm's ability to write coverage in other insurance lines.

Whereas the estimates in Table 6 focused on the net effect of exit and entry into the homeowners' insurance market, in Table 7 we will restrict the focus to the probability of exit. In particular, we estimate using a probit analysis:

$$\begin{aligned} Pr(\ Exit\ )_{ist} = {} & \alpha_1 + \beta_1\, UnexpCat_{ist} + \beta_2 UnexpCat_{is,t-1} + \beta_3\, UnexpCat_{is,t-2} \\ & + \beta_4\, Blockbuster_{ist} + \beta_5\, Blockbuster_{is,t-1} + \beta_6\, Blockbuster_{is,t-2} \\ & + \beta_7 Mutual_i + \beta_8 Lloyds_i + \beta_9 Reciprocal_i \\ & + \beta_{10} LnNumsts_{it} + + \beta_{11} RateReg_{ist} + \beta_7 LnNatPrems_{it} + \beta_8 LnStatePrems_{ist} \\ & + \sum_{j=1}^{20} Y_i + \varepsilon_{1t}\,. \end{aligned} \tag{5}$$

As with the earlier results, the first column in Table 7 includes a parsimonious set of explanatory variables, and we include a variety of interactive effects in the second column.

The three unexpected catastrophe variables each have a positive and statistically significant effect on the probability of exit. The combined influence of these variables is that an increase in the number of unexpected catastrophes by 1 increases the probability of exit for the average firm in the state by 0.125.

Whether the catastrophe is a blockbuster catastrophe does not appear to be as influential. The negative effect of the contemporaneous blockbuster catastrophe variable is offset by the positive effect after a two-year lag, so that on balance, there is no net effect of the blockbuster catastrophes above and beyond the influence of the unexpected catastrophe variable.

The next three variables all pertain to different measures of the scale of the firm's operations. The first of the scale variables is the total national homeowners' premiums earned. One might expect that large firms would have greater resources, which would diminish their incentive to exit. An effect in the opposite direction is that with substantial homeowners' insurance sales in other states, such large firms can redirect their efforts to more profitable

markets. The net effect is positive, as firms with total national homeowners' premiums earned that are larger are more likely to exit the state.

If, however, the firm has a substantial stake in writing insurance in the state, the level of the state homeowners' insurance premiums earned will be high and the firm will be more reluctant to give up that market, as is indicated by the negative effect of that state total homeowners' premiums earned variable. The number of states in which the insurer operates has a negative effect on exit, so that while writing a large level of homeowners' premiums increases the probability of exit, when these premiums are spread across a large number of markets the incentive to exit is reduced.

The final variables indicate that firms with a mutual, reciprocal, or Lloyd's structure each have a lower probability of exit. Restrictive state rate regulation increases the probability of exit.

Many of these variables are of interest with respect to how they interact with the presence of the catastrophe. Thus, the level of state homeowners' premiums earned or the level of national premiums earned will affect the nature of the firm's response to a catastrophic event.

The second column of Table 7 includes a large number of these interactions. Even in the presence of these interactive effects, both the contemporaneous and the two-period lag unexpected catastrophes variable have a positive and statistically significant effect on the probability of exit.

The final variables included in this equation are a series of six interactions of unexpected catastrophes. Consider first the interactions with total national homeowners' premiums earned. That interaction has a significant negative effect in the year of the catastrophe, a significant positive effect with a one-period lag, and a significant positive effect with a two-period lag. The net effect of these influences is positive. Firms with a high level of total national homeowners'

premiums earned will be more likely to exit the state following a catastrophe. These are the firms with larger potential markets outside the state to which they could direct their efforts.

Consider next the three interactions with the state local homeowners' premiums earned. This interaction is negative in the year of the catastrophe, statistically insignificant with a one-period lag, and negative and significant with a two-period lag. Firms with a large level of state homeowners' premiums earned are less likely to leave the state following a catastrophe. These are the firms that have a substantial investment in insurance operations in the state so that the opportunity cost of leaving is greater.

5. Conclusion

Following natural disasters, there are typically very large losses suffered by individual homeowners. These victims of catastrophes, as well as consumer advocates, frequently assume that the challenge that insurers face in dealing with catastrophes should not be great. That, after all, is the purpose of insurance—to provide coverage after such adverse events. Moreover, if the risks involved are quite large, then one would expect these firms to obtain reinsurance coverage to address these hazards.

The analysis here indicates that catastrophic risks pose considerable problems for the insurance industry, just as they do for individual homeowners. To analyze the effect of catastrophes, we used an extremely large dataset that consisted of every firm by state by year writing homeowners' insurance coverage in the United States from 1984 to 2004. Because this is the first such examination of the effect of catastrophes using micro data on any major insurance market, it provides a unique perspective on how firms respond to these major natural catastrophes.

The evidence is consistent with insurers not fully anticipating catastrophes and being hit particularly hard by the major catastrophes that we term blockbuster catastrophes. Almost every phase of insurance operations is affected by the catastrophic risk. It is not surprising that both the losses incurred and loss ratios each rise in response to catastrophic events. What is interesting is that these natural disasters lead firms to alter their subsequent insurance rates, so that the loss ratios in the non-catastrophe years following a catastrophe are lower than they were before. In effect, the firms have updated the assessed risks of a catastrophe and addressed the rates that they charge to make writing insurance profitable in the presence of increased assessed risks.

The perhaps more troubling effects pertain to the effect on insurance activities more generally. Catastrophic risks reduce the total premiums earned in the state, which is not a reflection of lower rates, but rather a reflection of reduced amounts of insurance coverage that people purchase. One would expect the quantity of coverage to decline as the price of insurance rises, but the results indicate that more than this influence is at work. Catastrophes lead to a reduction in the net number of firms writing insurance coverage in the state as well as an increase in the probability of exit from the state. As one would expect, these effects are greatest for the firms that are least able to withstand the major financial shock of a catastrophic event. Particularly for these firms, the natural disaster is a catastrophic event for the insurer as well as for the homeowner who has suffered the catastrophe.[9]

[9] The result that catastrophic events pose problems to the insurance industry is well known to the industry as well. Many of the concerns have focused on the effect of catastrophic risks on the affordability and availability of insurance in the homeowners' market. See Insurance Services Office (1996). More recently, see the commentary by the Insurance Information Institute (2006), which gives an update of the insurance industry concerns relating to Hurricane Katrina.

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Table 1
Average Annual Catastrophic Events by State, 1984-2004

State	Events		State	Events		State	Events
AK	0.14		LA	3.62		OH	3.76
AL	3.00		MA	1.52		OK	4.33
AR	3.10		MD	1.71		OR	0.62
AZ	0.76		ME	0.52		PA	3.90
CA	2.19		MI	2.29		RI	0.76
CO	2.00		MN	1.52		SC	2.43
CT	1.86		MO	3.76		SD	0.90
DE	0.90		MS	3.48		TN	3.05
FL	2.67		MT	0.33		TX	7.43
GA	3.05		NC	3.10		UT	0.33
HI	0.14		ND	0.43		VA	2.76
IA	2.57		NE	2.33		VT	0.67
ID	0.29		NH	0.62		WA	0.52
IL	4.90		NJ	2.62		WI	2.00
IN	4.14		NM	0.71		WV	1.62
KS	3.81		NV	0.48		WY	0.38
KY	3.00		NY	3.81			

Source: Swiss Re Sigma Reports, 1985-2005.

Table 2
Blockbuster Catastrophes: The Twenty Most Costly Natural Catastrophes
for U.S. Property Insurers, 1984-2004

Date	Peril	Insured Loss ($Billions 2004 Dollars)	States Affected
Aug. 1992	Hurricane Andrew	21.5	FL, LA
Jan. 1994	Northridge Earthquake	17.8	CA
Sep. 2004	Hurricane Ivan	11.0	AL, DE, FL, GA, LA, MD, MS, NC, NJ, NY, OH, PA, TN, VA, WV
Aug. 2004	Hurricane Charley	8.0	FL, NC, SC
Sep. 1989	Hurricane Hugo	6.4	NC, SC
Aug. 2004	Hurricane Frances	5.0	FL, GA, NC, NY, SC
Sep. 1998	Hurricane Georges	4.1	AL, FL, MS, LA
Sep. 2004	Hurricane Jeanne	4.0	DE, FL, GA, MD, NC, NJ, NY, PA, SC, VA
May 2001	Tropical Storm Allison	3.4	FL, LA, GA, MS, NC, NJ, PA, SC, TX
May 2003	Hailstorms/Tornadoes/ Floods	3.3	AL, AR, CO, GA, IA, IL, IN, KS, KY, MO, MS, NC, NE, OK, SC, SD, TN
Sep. 1999	Hurricane Floyd	2.7	CT, FL, DE, GA, MA, MD, ME, NC, NH, NJ, NY, PA, RI, SC, VT, VA
Oct. 1995	Hurricane Opal	2.6	AL, FL, GA, MS, NC, SC, TN
Oct. 1991	Oakland, CA Fires	2.4	CA
Apr. 2001	Hail/Floods/Tornadoes	2.3	AR, KS, MO, MS, OK, TX
Mar. 1993	Winter Storm	2.3	AL, CT, DE, FL, GA, KY, LA, MA, MD, ME, MS, NC, NH, NJ, NY, OH, PA, RI, SC, TN, TX, VA, VT, WV
Sep. 1992	Hurricane Iniki	2.2	HI
Sep. 1996	Hurricane Fran	1.9	MD, NC, OH, PA, SC, VA, WV
Apr. 2002	Spring Storms/Tornadoes	1.8	GA, IL, IN, KS, KY, MD, MO, NY, OH, PA, TN, VA, WV
Sep. 2003	Hurricane Isabel	1.7	DE, MD, NC, NJ, NY, PA, VA, WV
May 1999	Series of Tornadoes in Midwest	1.7	AL, AR, FL, GA, IL, IN, KS, KY, LA, MO, MS, NC, NE, OH, OK, SC, TN, TX

Source: Swiss Re.

Table 3
Insurer Loss Ratio Regressions[a]

Explanatory Variable	Coefficient (Std. Error)
Intercept	-0.910*** (0.043)
Unexpected Catastrophes $_t$	0.060*** (0.002)
Unexpected Catastrophes $_{t-1}$	0.019*** (0.002)
Unexpected Catastrophes $_{t-2}$	-0.002 (0.002)
Blockbuster Catastrophes $_t$	0.120*** (0.008)
Blockbuster Catastrophes $_{t-1}$	0.004 (0.011)
Blockbuster Catastrophes $_{t-2}$	-0.085*** (0.012)
Mutual	0.019** (0.008)
Lloyds	-0.038 (0.043)
Reciprocal	0.115*** (0.019)
Ln(No. of states in which insurer operates)	-0.075*** (0.005)
Ln(Homeowners Premiums)	-0.015*** (0.002)
Ln(Total Premiums in State)	0.051*** (0.003)
Ln(Total National Premiums)	-0.005* (0.003)
Restrictive Rate Regulation	0.034*** (0.007)
Adjusted R^2	0.031

[a] Dependent Variable = Ln(Loss Ratio)
*, **, and *** denote significance at the 90%, 95% and 99% level, two-tailed test.
Regression includes 20 year dummies, which are not shown.

Table 4
Regression Results for Insurer Premiums[a]

Explanatory Variable	Coefficient (Std. Error)
Intercept	-0.976*** (0.035)
Ln(Homeowners Premiums) $_{t-1}$	0.973*** (0.001)
Unexpected Catastrophes $_{t}$	-0.027*** (0.002)
Unexpected Catastrophes $_{t-1}$	-0.022*** (0.002)
Unexpected Catastrophes $_{t-2}$	-0.023*** (0.002)
Blockbuster Catastrophes $_{t}$	-0.033*** (0.007)
Blockbuster Catastrophes $_{t-1}$	0.013 (0.009)
Blockbuster Catastrophes $_{t-2}$	-0.029*** (0.010)
Mutual	0.156*** (0.007)
Lloyds	0.241*** (0.037)
Reciprocal	0.225*** (0.017)
Ln(No. of states in which insurer operates)	0.088*** (0.004)
Restrictive Rate Regulation	-0.015*** (0.006)
Ln(Total Premiums in State)	0.109*** (0.002)
Ln(Total National Premiums)	-0.041*** (0.003)
Adjusted R^2	0.896

[a] Dependent Variable = Ln(Premiums Earned)
*, **, and *** denote significance at the 90%, 95% and 99% level, two-tailed test.
Regression includes 20 year dummies, which are not shown.

Table 5
Regression Results: Effect of Unexpected Catastrophic Events on Insurer Losses[a]

Explanatory Variable	Coefficient (Std. Error)
Intercept	-0.910*** (0.043)
Ln(Homeowners Premiums) $_{t-1}$	0.985*** (0.002)
Unexpected Catastrophes $_{t}$	0.060*** (0.002)
Unexpected Catastrophes $_{t-1}$	0.019*** (0.002)
Unexpected Catastrophes $_{t-2}$	-0.002 (0.002)
Blockbuster Catastrophes $_{t}$	0.120*** (0.008)
Blockbuster Catastrophes $_{t-1}$	0.004 (0.011)
Blockbuster Catastrophes $_{t-2}$	-0.085*** (0.012)
Mutual	0.019** (0.008)
Lloyds	-0.038 (0.043)
Reciprocal	0.115*** (0.019)
Ln(No. of states in which insurer operates)	-0.075*** (0.005)
Restrictive Rate Regulation	0.034*** (0.007)
Ln(Total Premiums in State)	0.051*** (0.003)
Ln(Total National Premiums)	-0.005* (0.003)
Adjusted R^2	0.850

[a] Dependent Variable = Ln(Losses Incurred)
*, **, and *** denote significance at the 90%, 95% and 99% level, two-tailed test.
Regression includes 20 year dummies, which are not shown.

Table 6
Regression Estimates of Number of Firms in the State Writing Homeowners' Insurance Coverage[a]

Explanatory Variable	Coefficient (Std. Error)	Coefficient (Std. Error)
Intercept	184.415 (6.545)	185.133*** (6.510)
State Homeowners Loss Ratio $_{t-1}$	0.607 (2.863)	-0.198 (2.864)
State Homeowners Loss Ratio $_{t-2}$	-0.172 (2.379)	-0.271 (2.365)
Unexpected Catastrophes $_{t-1}$	-0.195 (0.845)	-0.221 (0.840)
Unexpected Catastrophes $_{t-2}$	1.095 (0.847)	1.083 (0.842)
Blockbuster Catastrophes in State $_{t-1}$	-11.367*** (3.550)	-9.582** (4.708)
Blockbuster Catastrophes in State $_{t-2}$	-3.390 (3.373)	-12.596*** (4.225)
Restrictive Rate Regulation	-8.615*** (2.678)	-8.758*** (2.671)
Restrictive Rate Regulation * Blockbuster Catastrophes $_{t-1}$	--	2.242 (5.670)
Restrictive Rate Regulation * Blockbuster Catastrophes $_{t-2}$	--	19.387*** (5.382)
Total State Homeowners Premiums ($Millions)	0.037*** (0.002)	0.037 (0.002)
Adjusted R^2	0.370	0.370

[a] Dependent Variable = Number of Firms in State. Regression includes year dummy variables, which are not shown.
*, **, and *** denote significance at the 90%, 95% and 99% level, two-tailed test.

Table 7
Probit Analysis: Effect of Catastrophic Events on Likelihood of Exit

Explanatory Variable	Coefficient (Std. Error)	Coefficient (Std. Error)
Intercept	1.150*** (0.066)	3.298*** (0.063)
Unexpected Catastrophes $_{t}$	0.052*** (0.003)	0.180*** (0.029)
Unexpected Catastrophes $_{t-1}$	0.034*** (0.003)	-0.031 (0.031)
Unexpected Catastrophes $_{t-2}$	0.039*** (0.003)	0.053* (0.029)
Blockbuster Catastrophes $_{t}$	-0.059*** (0.013)	-0.011 (0.019)
Blockbuster Catastrophes $_{t-1}$	0.013 (0.016)	-0.027 (0.020)
Blockbuster Catastrophes $_{t-2}$	0.048*** (0.017)	0.019 (0.022)
Total national homeowners premiums earned ($Billions)	0.012*** (0.005)	--
State total homeowners premiums earned ($Millions)	-0.162*** (0.003)	--
Number of states in which insurer operates	-0.159*** (0.008)	--
Mutual	-0.423*** (0.017)	-0.353*** (0.018)
Lloyds	-0.698*** (0.059)	-0.129 (0.087)
Reciprocal	-0.243*** (0.078)	-0.643*** (0.066)
Ln(Number of states in which insurer operates)	--	0.073*** (0.007)
Restrictive Rate Regulation	0.056*** (0.012)	0.062*** (0.013)
Ln(Total national homeowners premiums)	--	-0.191*** (0.003)
Ln(State total homeowners premiums earned)	--	-0.124*** (0.003)
(Ln(Total national homeowners premiums earned) * Unexpected Catastrophes) $_{t}$	--	-0.003** (0.001)
(State total homeowners premiums earned * Unexpected Catastrophes) $_{t}$	--	-0.004*** (0.001)
(Total national homeowners premiums earned * Unexpected Catastrophes) $_{t-1}$	--	0.004*** (0.002)

Explanatory Variable	Coefficient (Std. Error)	Coefficient (Std. Error)
(State total homeowners premiums earned * Unexpected Catastrophes) $_{t-1}$	--	0.001 (0.002)
(Total national homeowners premiums earned * Unexpected Catastrophes) $_{t-2}$	--	0.005*** (0.002)
(State total homeowners premiums earned * Unexpected Catastrophes) $_{t-2}$	--	-0.005*** (0.002)
Pseudo R^2	0.100	0.168

Figure 1
State-level Catastrophic Events, 1984-2004

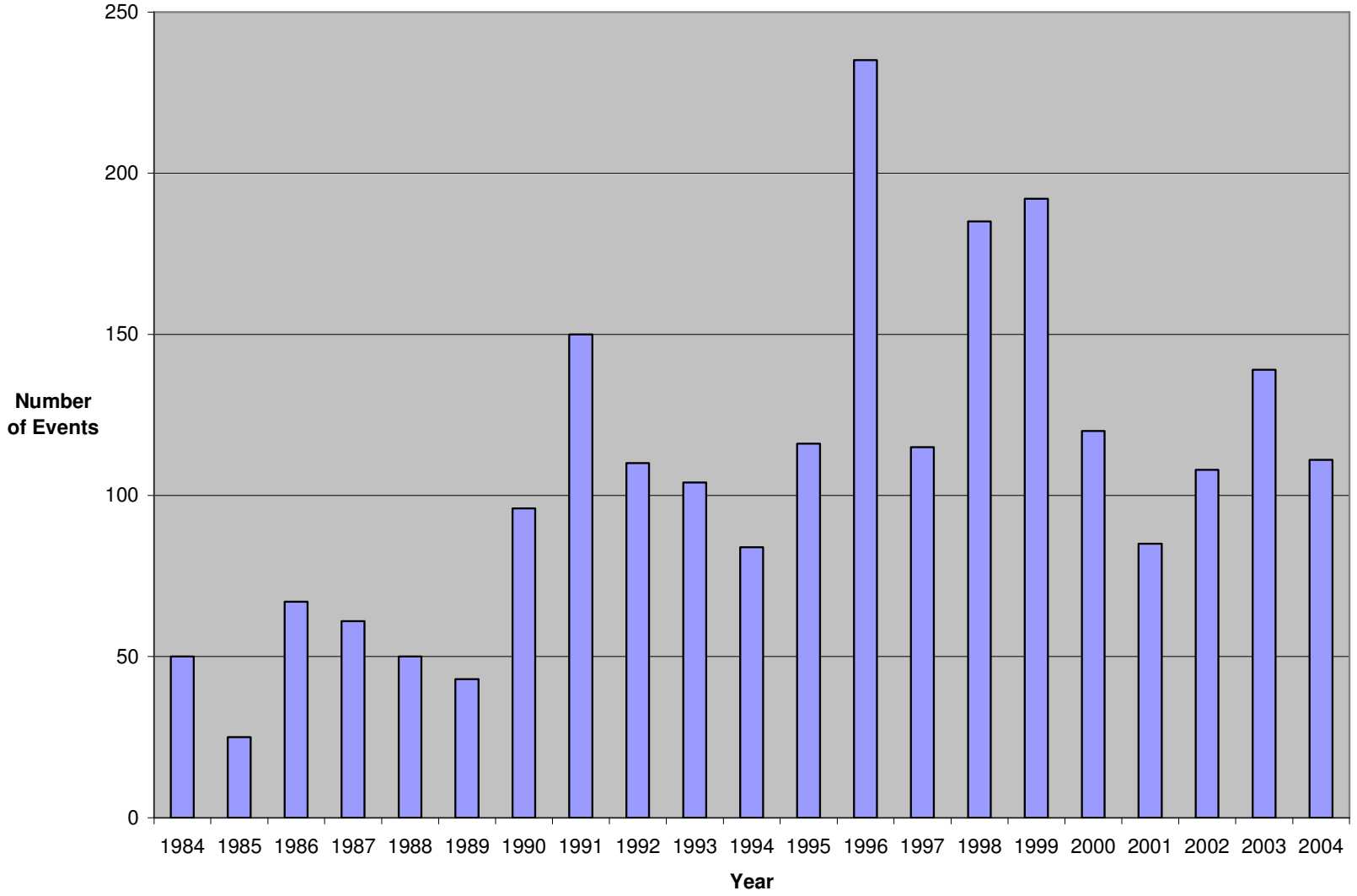

Figure 2
Average "Firm-State" Loss Ratios in Homeowners' Insurance, 1984-2004