An Examination of the Geographic Aggregation of Catastrophic Risk

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I. Description of Purpose and Importance of Research

The debate in the United States about establishing a mechanism for insuring catastrophic wind risk at the national level has been ongoing and pre-dates the substantial losses from the 2004 and 2005 hurricane seasons. This debate at times has been contentious and there are a number of factors that impact on the debate that include but are not limited to concerns about cross-state subsidies, the state regulation of insurance, the impact that state political boundaries have on insurance markets within those boundaries, and opposition to public pooling of risk from certain segments of the insurance marketplace.

What is absent from the important public policy debate about aggregating wind risk at the national level is meaningful empirical research that investigates this question. In an effort to better inform the public policy decisions surrounding the debate, this paper examines the behavior of residential property portfolios ranging from single structures to an amalgamation of every residential exposure within the state of Florida and for a larger risk pool that includes multiple combinations of coastal states in the southeastern United States. This is the first academic paper that utilizes a catastrophe modeling methodology to evaluate the broader question of the impact of aggregating catastrophic risk across a larger region on a multiple peril basis. The impact of geographic diversification is evaluated both in terms of risk as well as uncertainty.

II. Research Methodology

Using actual exposures derived from the 2010 American Community Survey (ACS) at the block group level, this paper uses catastrophe models to evaluate whether benefits do accrue by aggregating catastrophic risk across increasingly wide geographic areas and if so, in what fashion. The modeling approach used in this paper captures not only wind risk but also the related risk from tropical cyclones including rain, storm surge, and waves. The baseline analytic tool used to evaluate each portfolio is a plot of the ratio of probable maximum loss (PML) to Average Annual Loss (AAL) against return period. The ratio provides a performance metric that is independent of exposure, allowing the direct comparison of portfolios with radically different composition. A decrease in the ratio of the PML to AAL is the key indicator of superior performance of one portfolio over another.

III. Summary of Results

For less severe but more likely losses reflected in return periods of less than 20 to 25 years, there appears to be no benefit to geographic diversification. For higher return periods (i.e., beyond 25

years), there are clear diversification benefits and these benefits increase as the return period increases. Benefits accrue not only in the form of risk reduction but also in terms of reduction in uncertainty.

If treated in isolation, the sum of the claims paying capacity required for a 100-year event for the eight coastal states evaluated would be just over $130 Billion. In the aggregate, 100-year event for the entire region is just over $71 Billion. As such, it takes 54.7% of the reserves to cover each 100-year loss for the entire region as opposed to treating each state in isolation.

IV. Implications of Research

The most often expressed argument against establishing any larger risk pool is that it potentially provides a subsidy for the higher risk members of that particular pool. In considering catastrophic wind risk, a related question is "Why should someone in the state of Alabama subsidize Florida or Texas wind risk?" As our results indicate, those arguments are invalid as each state in the pool benefits from geographic diversification if each exposure is assessed independently according to its own risk.

With respect to improving the current hurricane wind insurance system, these results have important implications for market design and suggest a two-tiered approach to managing catastrophic wind risk. The first tier would include losses associated up to the 20 to 25 year event. Here there would be no external pooling of wind risk and wind risk would be managed based on the company's appetite for this risk. The second tier would be a wind risk pool that captures multiple states and it would respond for losses above the 25 year return period. Ideally, the pool would include all states with a coastal wind risk exposure; however, our results also indicate clear advantages for a wind pool comprised of a smaller number of states over individual states. Potential players in this second tier could include 1) existing or new multi-state compacts, 2) the reinsurance community, 3) a federal level organization, or 4) a private/public partnership. Proponents of the federal regulation of insurance would view this as a natural part of the progression from state to federal regulation. A national catastrophe plan, incorporating all catastrophic natural hazards risk, could be seen as a logical conclusion of the process begun with the creation of the National Flood Insurance Program. As with the issues involving trigger definitions (i.e., the separation between tier 1 and tier 2), the question of the aggregate pool design requires significant discussion and research.

Introduction

The debate in the United States about establishing a mechanism for insuring catastrophic wind risk at the national level has been ongoing and pre-dates the substantial losses from the 2004 and 2005 hurricane seasons. This debate at times has been contentious and there are a number of factors that impact on the debate. One relates to concerns about cross state subsidies. Individuals who live in what they perceive to be "low-risk" states are strongly opposed to the notion of subsidizing individuals who live in "high-risk" states. This debate also occurs within specific states where there are significant differences in risk by location. For example, the ongoing debate in Florida relates to the potential subsidization that inland exposures provide to the coastal exposures. Other factors include the state regulation of insurance, the impact that state political boundaries have on insurance markets within those boundaries and opposition to public pooling of risk from certain segments of the insurance marketplace.

Some groups have supported the need for a federal level catastrophic wind plan (e.g., Long Term Solutions for Florida's Hurricane Insurance Market, 2006), there has been limited discussion of federal or regional approaches to addressing catastrophic wind exposure. What is absent from the important public policy debate about aggregating wind risk at the national level is any meaningful empirical research that investigates this question. In an effort to better inform the public policy decisions surrounding the debate, this paper examines the behavior of residential property portfolios ranging from single structures to an amalgamation of every residential exposure within the state of Florida and for a larger risk pool that includes multiple combinations of coastal states in the southeastern United States.

This paper uses catastrophe models to evaluate whether benefits do accrue by aggregating catastrophic risk across increasingly wide geographic areas and if so, in what fashion. It is important to note that the modeling approach used here captures not only wind risk but also the related risk from tropical cyclones including rain, storm surge, and waves. As such, this is the first academic paper that utilizes a catastrophe modeling methodology to evaluate the broader question of the impact of aggregating catastrophic risk across a larger region on a multiple peril basis. The impact of geographic diversification is evaluated both in terms of risk as well as uncertainty. Given that the physical basis for the models come from the open scientific literature and that the modeling approach uses publicly available housing data that is representative of the

existing housing stock, the paper also contributes by providing a greater level of transparency than is typically found in the modeling related literature.

In a preview of our results, we find that geographic aggregation matters where it is most important—for the less frequent and more severe catastrophic wind events and that geographic diversification also provides additional benefits in terms of reduced uncertainty. This finding holds true for all state combinations evaluated in this study and each state in the pool receives these diversification benefits.

The paper continues with a review of the literature related to the geographic diversification of risk and pooling of catastrophic risk. This is followed by a description of the data and methodology used in this study. We then provide the results of the two modeling-based experiments and the paper concludes with a summary of our main findings and a discussion of implications of those results.

Literature

As the pooling of risk is fundamental to any risk-bearing system, there is a substantial theoretical and empirical literature related to risk pooling and equilibria (e.g., Rothschild and Stiglitz, 1974) and to the accompanying adverse selection and moral hazard problems. The literature related to catastrophic risk focuses across a number of related topics including market performance in the face of catastrophes, geographic diversification of catastrophic risk, hedging tools that allow for broader shifting of catastrophic risk to the capital markets, the appropriate function of government in supporting markets with catastrophic risk exposure, catastrophe models, and public policy issues related to availability and affordability of coverage.

This research spans several of the aforementioned categories. While our research question relates primarily to the geographic diversification of risk, we use a catastrophe model as the basis of our empirical analysis and our results suggest the need for a larger regional risk sharing pool that may be public or private-public in nature. This regional risk pool also could provide an opportunity to securitize catastrophic risk on a larger and more efficient basis. Selected literature from these categories is described below.

In a paper that addresses the potential for nonperformance in the catastrophic risk market, Ibragimov, Jaffee and Russell (2009) investigate the question of limited existence of markets for catastrophic insurance in large insurance markets even with the presence of independence across

risk types and geography and limited informational asymmetries. They suggest that one explanation is the existence a "non-negligible probability for extremely negative outcomes." (page 982). They describe the nondiversification trap as a situation where there are two possible equilibria: a diversification equilibrium where insurance is offered and there is full risk sharing through reinsurance, and a nondiversification equilibrium where the reinsurance market is not used and no catastrophe insurance is offered. The authors note that attempts to geographically diversify risks –specifically those with heavy-tailed distributions – can result in a coordination failure between insurers located in separate geographic locations. This indicates the need for more governmental control and oversight. As the welfare loss of a diversification trap is high, governments intervene to support catastrophic insurance markets to ensure that diversification is reached.

In identifying innovations in managing catastrophic risk, Doherty (1997) discusses the preconditions that set the stage for significant innovation in the tools available to manage catastrophic risk. These included 1) a more intellectual approach to managing risk, 2) explosive growth in the derivatives market, 3) high transactions costs and 4) improved quality of information regarding catastrophic risk given the growth of catastrophe modeling industry.

Cummins and Trainar (2009) examine the use of securitization, insurance, and reinsurance in the face of potential catastrophic loss. They note that while risk warehousing via reinsurance creates important market efficiencies, there are inefficiencies in the reinsurance market that create the need for capital market solutions. Securitization of catastrophic risk addresses these inefficiencies by transferring risk to the capital market. Jaffe and Russell (1997) examine the question of whether catastrophic risk is insurable in the private market and argue that given its characteristics (infrequent, local, and unlikely to be correlated losses globally), it is diversifiable and should be insurable. As they note, the solution is not simply a "point in time" spreading of risk but rather an intertemporal solution that involves the capital markets.

In a paper that describes the Caribbean Catastrophic Risk Insurance Facility, Grove (2012) describes how risk pooling of catastrophic risk at a regional level allows individual regions better access to the global financial markets via reinsurance contracts. In this case, pooling catastrophe coverage for the broader region provides a more attractive pooling option for reinsurers and this in turn benefits the individual members of the facility. Woo (2001) reviews the territorial development of catastrophe bonds, specifically concerning earthquakes and

explores the geographical horizon for new issues and suggests that pooling of territories allows transaction costs to be shared over a broader premium base. Nyce and Maroney (2012) examine the standard process of rating exposures at the territory level in areas that are exposed to catastrophic wind risk. Given that catastrophe models allow for more granular pricing of risk, the authors find that the use of distance to the coast provides a property-specific rating variable that more closely aligns premiums and average annual loss (AAL) than standard territory rating.

Cummins (2006) examines the question of whether it is appropriate for the government to intervene in catastrophe insurance markets and he focuses in particular on mega-catastrophes. He concludes that given the resources available in and to the primary and reinsurance markets, there does not appear to be a need for government intervention. Conversely, Paudel (2012) provides a comparative study of indicators and components of fully public, fully private and public-private insurance systems across ten countries. He provides a series of recommendations for either establishing new catastrophic insurance systems or improving existing systems including 1) government assumption of some responsibility for part of the extreme risk (i.e., tail risk) and 2) strict mandatory participation requirements in order to facilitate high market penetration and to reduce the need for ex-post government relief. Engeström (1995) suggests that while governments may not be in a financial position to extend social commitments, they can "provide a more efficient financing mechanism for politically motivated or infrequent cataclysmic losses." (pg. 469)

Data and Methodology

The study was constructed in the form of three major experiments, simulating the effects of all historical tropical cyclones (hurricanes and tropical storms) since 1871 against various aggregations of hypothetical and actual exposure databases. The following numerical modeling steps were performed on each candidate exposure set. This approach is consistent with previous endeavors (Watson and Johnson, 1999, 2002, 2004, 2007, 2010).

1. Simulate all Atlantic storms (1871-2011). Storms prior to 1871 were not considered owing to the likelihood of weaker storms not being recorded. Storm tracks are based on ATCF A decks (Sampson and Schrader, 1997).
2. Execute a full physics tropical cyclone model consisting of an asymmetric SLOSH wind model with a trajectory based boundary layer, the WISWAVE III wave model

(including inshore refraction and breaking), a five layer hydrodynamic model for storm surge and riverine flooding, and a TRMM climatology based rain model. Each component of this approach is traceable to public domain sources.

3. Calculate the damage to the target portfolio using a composite damage function derived from six different public domain damage function families. (Watson and Johnson, 2004)

Note that in some respects this analysis is "worst case", in that it covers losses from *all* tropical cyclone events (hurricanes and lesser tropical storms as well), and *all* perils (wind, rain, storm surge, and waves). Thus, it incorporates all hazards from tropical cyclones rather than allocating them among the public (FEMA Flood Insurance Program, FIP), private insurance, and public sector hybrids (such as Citizens).

The exposure data sets varied depending on the specific experiments being conducted. For hypothetical exposures at each ZIP Code centroid, a standard US single frame structure (wood frame effectively) with an insured value of $100,000 and $60,000 contents coverage was used. Actual exposures for the next set of experiments were derived from the 2010 American Community Survey (ACS) at the block group level. The ACS data includes eight construction types, date of construction, building codes, and other detailed information used to create a realistic exposure set. This paper describes the results of the wider study (Watson, Johnson, and Dumm, 2012) as it pertains to portfolios created from the ACS based exposure data at the state and multi-state level. Figure 1A provides a map of the centroids of each ACS tabulation area, indicating complete coverage. Terrain heights and bathymetry are derived from the late 2011 NASA composites, whereas the land cover data set (which is vital for computing the frictional effects of vegetation and structures on wind speeds) was created from MODIS (Moderate Resolution Imaging Spectroradiometer) data as of spring 2012.

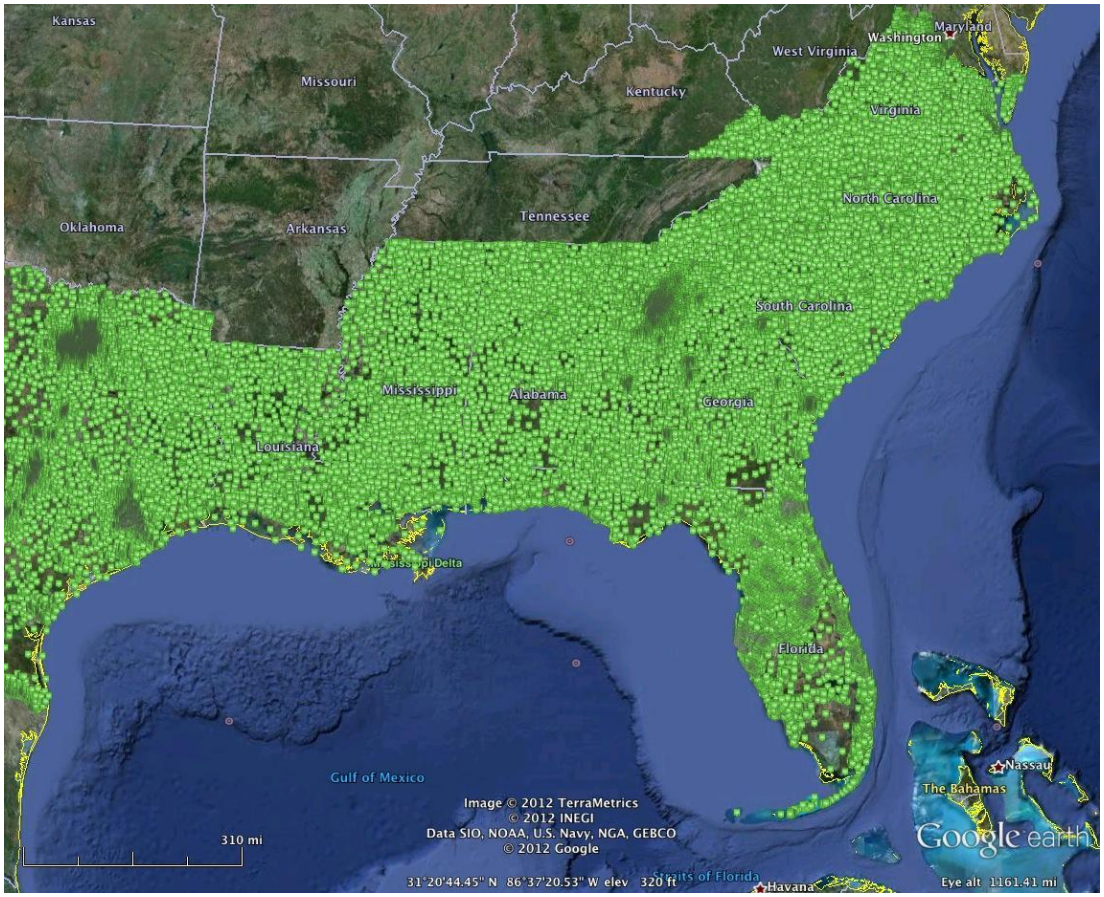

Figure 1A. ACS Exposure points for the multi-state portfolio tests

The baseline analytic tool is a graphic used to evaluate each portfolio is a plot of the ratio of probable maximum loss (PML) to Average Annual Loss (AAL) against return period. The ratio provides a performance metric that is independent of exposure, allowing the direct comparison of portfolios with radically different composition. We consider a decrease in the ratio of the PML to AAL to be the key indicator of superior performance of one portfolio over another, since as noted above a decrease in this ratio demonstrates a decrease in the amount of capital that must be on call to cover extreme event losses beyond that covered by pure premium. Therefore, the smaller the ratio, the better performing is a portfolio. Assuming residential insurance rates are based on the AAL of each individual structure, this baseline provides an indication of the relative magnitude of reserves and reinsurance that a portfolio would require to cover payments for an event corresponding to a given return period.

Experimental Results

Experiment One—Single Exposures

In our initial experiment, we consider fifteen individual structures at ZIP Code centroids located one per county along the east coast of Florida, and one additional site in Georgia (Tybee Island, near Savannah). The specific locations are indicated in Figure 1B. Each exposure consists of a detached, single-family wood frame home valued at $160,000 ($100,000 for structure and $60,000 for contents). The ZIP Code centroids are generally fairly close to the coast (although the corresponding ZIP Codes may not have any direct ocean front exposure). Following the methodology outlined in the previous section, every tropical cyclone (hurricanes and tropical storms) from 1871 through 2011 was simulated and the losses from each event were computed using a composite damage function. No deductibles or exclusions were applied. Annual losses were then computed (for seasons with more than one impacting event, it is assumed that repair has taken place prior to any subsequent within season events), and the set of 140 annual losses were fit with a two-parameter Weibull distribution. Using this fitted distribution the specified metrics were calculated.

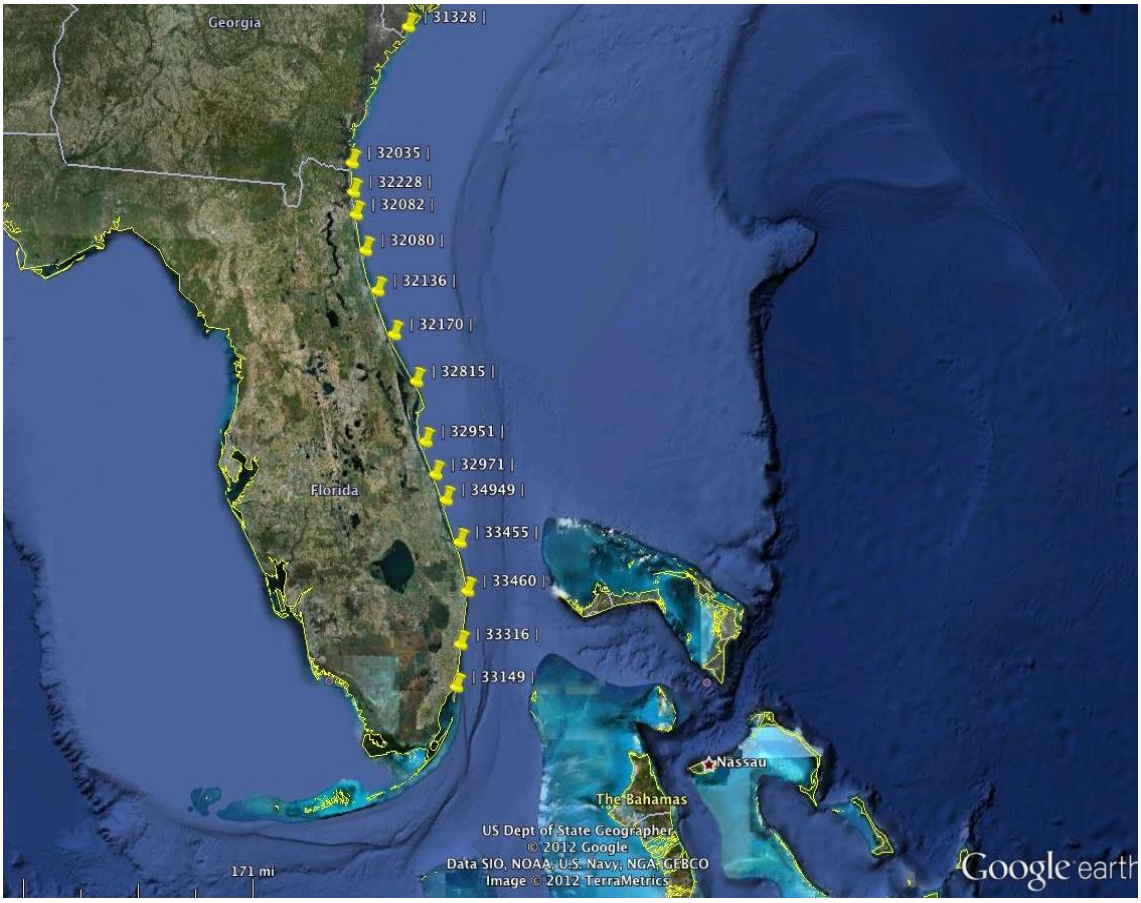

Figure 1B: Single Exposure ZIP Locations

Table 1 includes the individual AAL, the loss cost per $1000 exposure, the return period in years associated with the AAL, the return period associated with a 1% loss of the exposure (i.e., $1600), and the 100 year return period loss in terms of multiples of the AAL.[1] The loss cost ranges from $2.18 in Ponte Verda just south of Jacksonville to $15.98 for Key Biscayne near Miami. The return periods by AAL are fairly consistent (6.5 to 8.7 years) across a broad risk range as gauged by loss cost (2.2 to 16), a factor of approximately 7 to 1. The return period corresponding to 1% of the exposure varies inversely with the hazard risk at the sites and ranges from 6.5 to 16.7 years, while the 100 year return period loss ranges from 16.0 to 21.6 times the average annual loss. Thus, compared to the AAL or loss cost (risk), the ratio of the 100-year loss to the average annual loss is in fact quite stable across radically different levels of risk. This conclusion is further confirmed by the plot of the ratio of loss to AAL versus return period

[1] These entries are abbreviated as aal, losscost, rp_aal, rp_1pct, and ra100, respectively in this and all subsequent tables in this paper.

(Figure 2). The plotted curves are monotonically increasing and show a relatively consistent range of ratios across the spectrum of return periods.

Table 1: Simulation Results for Experiment One Case 1

ZIP Code	site	aal	losscost	rp_aal	rp_1pct	ra100
33149	Key Biscayne	2556.79	15.98	7.8	6.5	20.9
33316	Ft. Lauderdale	1211.84	7.57	8.5	9.6	21.6
33460	Lake Worth	1693.06	10.58	8.7	8.5	19.3
33455	Hobe Sound	1967.76	12.30	8.2	7.4	17.1
34949	Ft. Pierce	1736.72	10.85	8.4	8.1	19.7
32971	Winter Beach	1384.78	8.65	7.3	7.9	19.9
32951	Melbourne Beach	779.88	4.87	6.8	9.9	19.8
32815	KSC/CCAB	367.32	2.30	6.5	16.7	17.9
32170	New Smyrna Beach	508.75	3.18	6.9	14.1	16.6
32136	Flagler Beach	499.39	3.12	6.6	13.1	18.9
32080	St. Augustine	456.71	2.85	6.7	13.9	19.1
32082	Ponte Verda	349.22	2.18	7.2	17.6	20.6
32228	Jacksonville	401.73	2.51	7.2	16.7	18.8
32035	Fernandina Beach	529.69	3.31	7.6	15.3	16.0
31328	Tybee Island	905.52	5.66	6.6	8.9	19.1

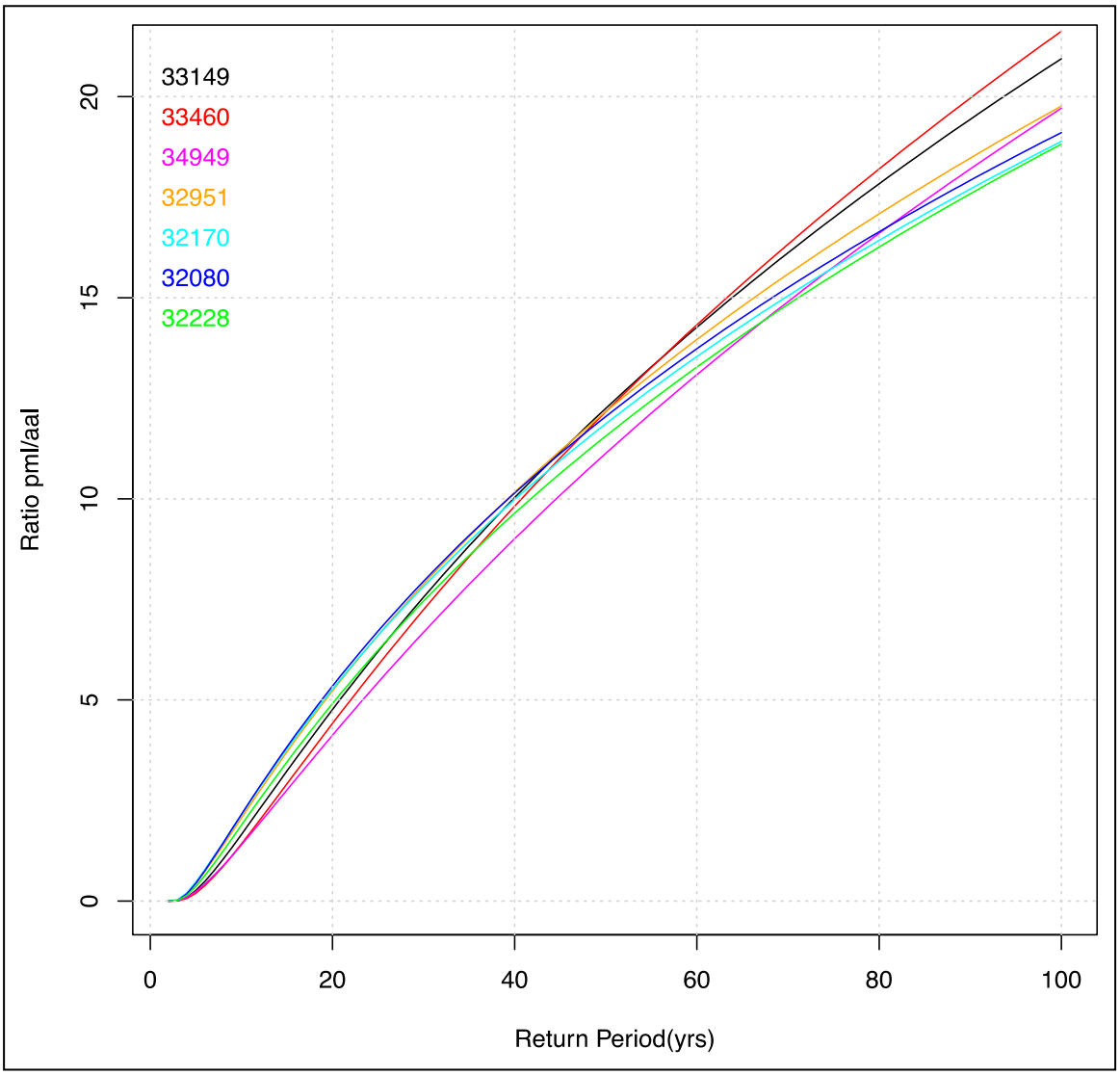

Figure 2: Experiment One Case 1 (Single Structures in Specified ZIP Codes)

The next analysis of Experiment One (Case 2) concerns the impacts to these metrics if the individual exposures are pooled into portfolios consisting of two properties (one per ZIP Code). Table 2 gives a summary of the values for combinations in which ZIP Code 33149 (Key Biscayne) is combined with individual ZIP Codes being considered here.

Table 2. Aggregation of two exposures at the ZIP Code centroid level

ZIP Code Pairs	exposure	aal	losscost	rp_aal	rp_1pct	ra100
33149 plus 33316	320000	3768.63	11.78	7.7	7.1	22.6
33149 plus 33460	320000	4249.84	13.28	7.1	6.3	22.5
33149 plus 33455	320000	4524.54	14.14	6.5	5.6	20.4
33149 plus 34949	320000	4293.51	13.42	6.3	5.5	20.9
33149 plus 32971	320000	3941.56	12.32	6.0	5.4	19.5
33149 plus 32951	320000	3336.66	10.43	5.7	5.5	16.5
33149 plus 32815	320000	2924.11	9.14	6.1	6.5	16.5
33149 plus 32170	320000	3065.54	9.58	6.2	6.3	16.2
33149 plus 32136	320000	3056.18	9.55	6.2	6.4	17.1
33149 plus 32080	320000	3013.50	9.42	6.2	6.4	16.5
33149 plus 32082	320000	2906.01	9.08	6.4	6.7	17.1
33149 plus 32228	320000	2958.52	9.25	6.3	6.6	17.0
33149 plus 32035	320000	3086.47	9.65	6.3	6.4	17.5
33149 plus 31328	320000	3462.31	10.82	5.5	5.3	16.7

As before, a plot of the ratio of PML to AAL across return period is revealing. Figure 3 shows such a plot, using ZIP Code 33149 as the reference base (the black curve). As the second structure moves farther away from the base structure, the corresponding curves remain relatively consistent relative to the baseline. However, by the time we reach ZIP Code 32951, located 140 nautical miles away, the curves begin to bend downward at the high end. In other words, as distance increases, the 100 year event loss decreases relative to the risk (AAL). It is no coincidence that the distance at which the curve changes shape significantly is very close to the typical swath width of a tropical cyclone. Given the nearly identical behavior of the individual curves that was shown in Figure 3, the curve shape changes are clearly due to the distance between ZIP Codes rather than any other factor.

Figure 3 is very helpful in sorting out the performance of the various combined portfolios (the lower curves at fixed return periods reflecting a lesser reserve fund required relative to the AAL to cover losses). Overall the curves in the Figure are relatively close until about 20 years or a 5% probability of occurrence. Beyond 20 years, the curves bifurcate with the upper group corresponding to sites within 120 miles of ZIP Code 33149 and the other group beyond 120

miles. Thus, it is not surprising that pooling exposures that are dispersed (unlikely to be battered by the same tropical cyclone) has significant benefits for the longer return periods.

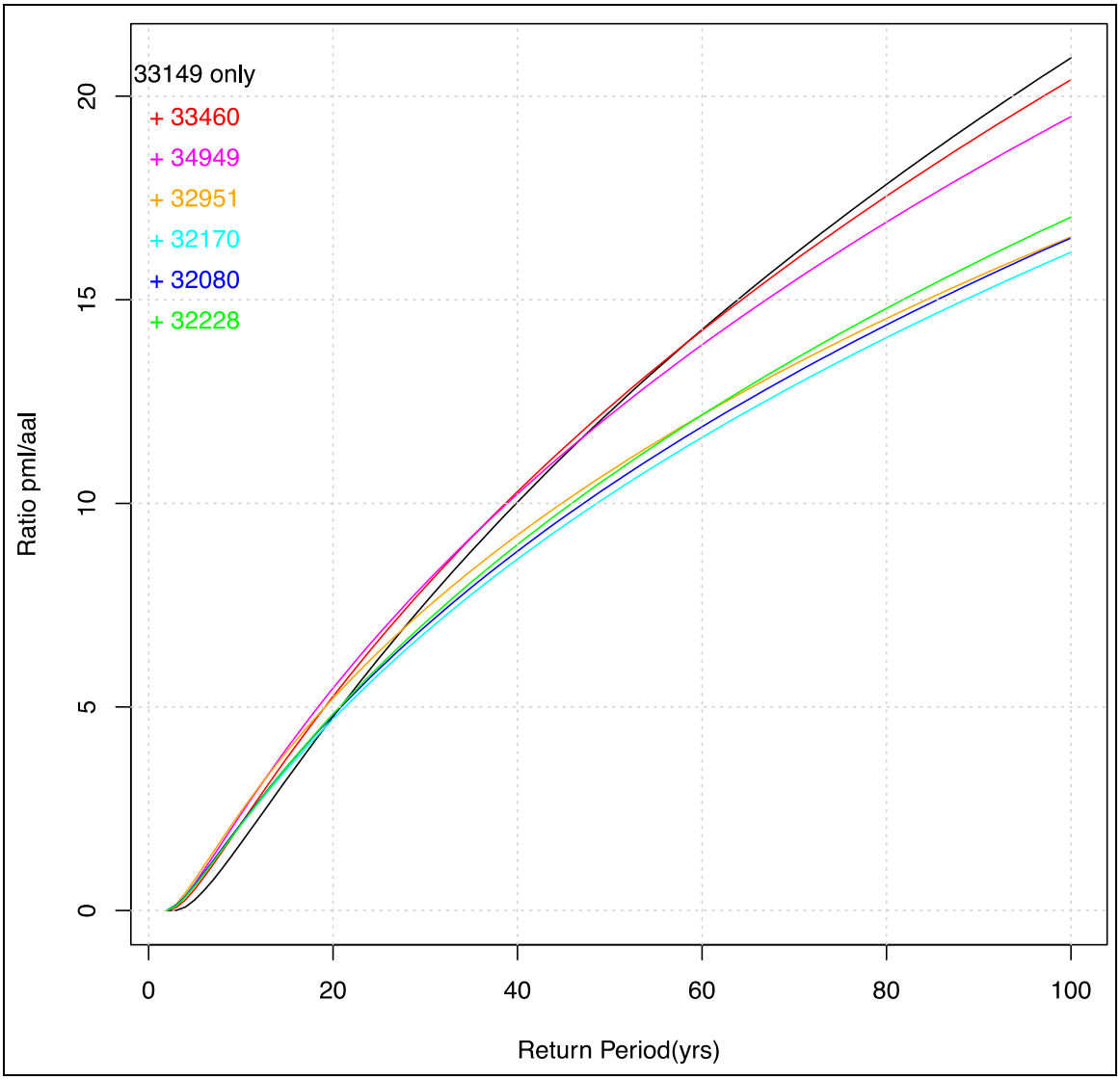

Figure 3: Experiment One Case 2 (Single Structure Combinations)

Experiment Two—County Level Aggregation of Single Exposures

The results for isolated exposures within ZIP Codes are elementary, but establish the groundwork for understanding more realistic situations (Figure 4). A natural extension is to consider the collection of ZIP Codes in a county and again, for simplicity, we place a single exposure (a standard construction valued for simplicity at $100,000 with $60,000 in contents) at each ZIP Code centroid. As before, damage includes wind, wave, flooding, and storm surge

perils. We then begin to aggregate various combinations of counties and assess the relative performance of each combination.

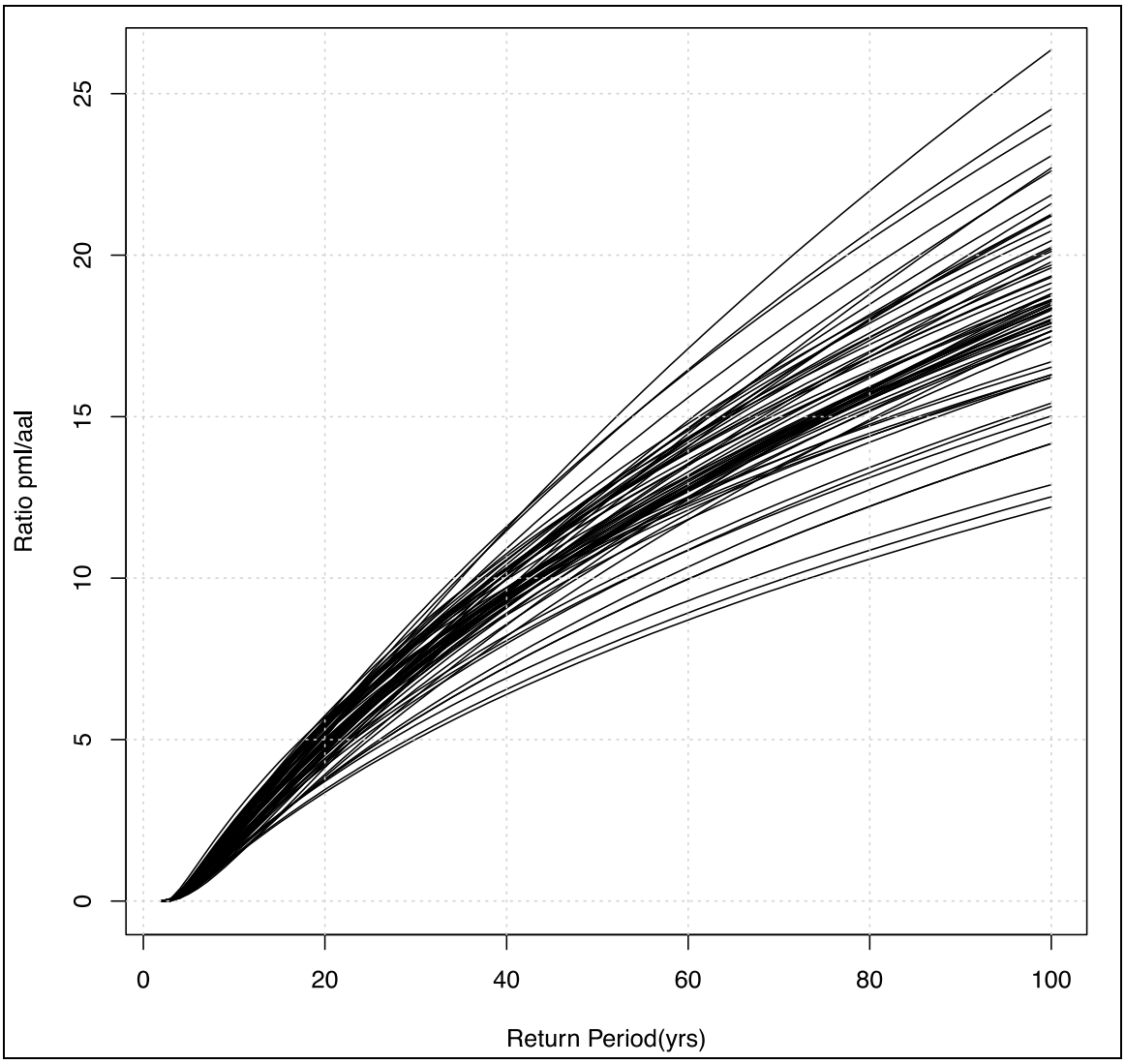

Figure 4: (All Florida Counties in Isolation)

Figure 5 shows detailed results of representative combinations of Monroe County and selected other counties. The black curve shows Monroe County in isolation. The Red curve shows the combination of Monroe and Miami-Dade indicating a relatively modest improvement in the ratio of PML to AAL as return period increases. However, as we consider augmenting the portfolio of Monroe County with those of more distant counties, the performance at the high end improves rapidly. Adding Bay County, which is located across the state from Monroe, and in the different climatology of the Gulf Coast, results in a dramatic improvement over the other

combinations. The 100 year loss for the combination of Monroe and Pinellas, separated by approximately 180 nautical miles, is approximately 18 times the AAL. In contrast, for the combination of Monroe and Bay Counties, separated by 420 nautical miles, the 100 year loss is less than 11 times the AAL. The curves for Bay and Pinellas counties noticeably separate from the others beyond the return period of 60 years.

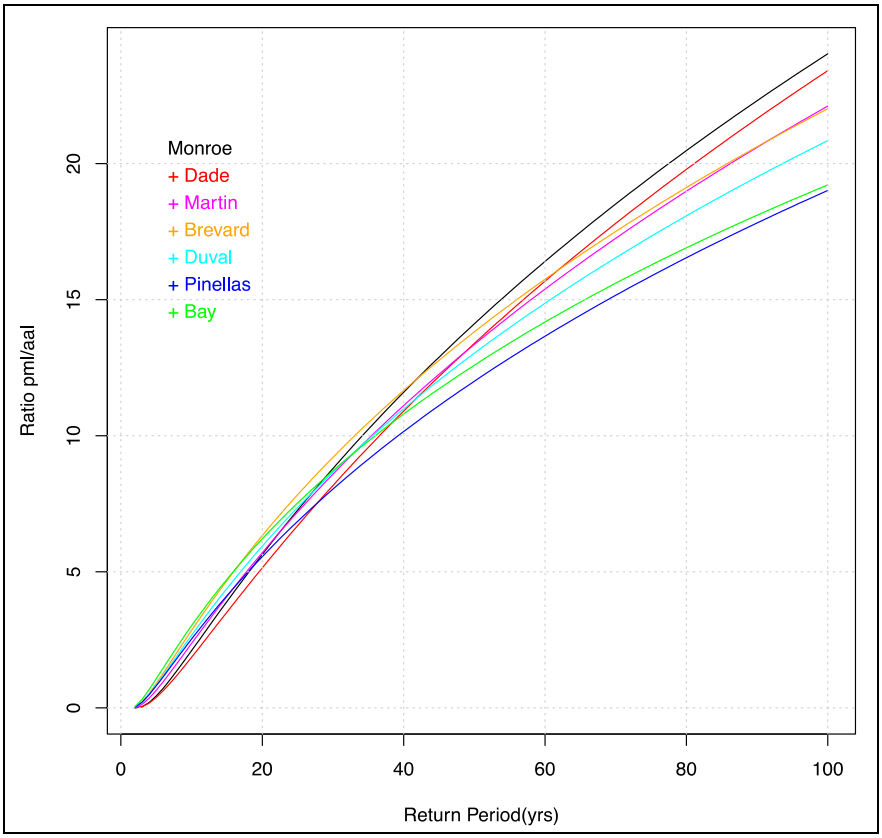

Figure 5: Combinations of Monroe and selected counties.

Figure 6 shows a plot of several portfolios within the state of Florida. The red curve shows the performance of a portfolio consisting of all of the residential exposures in Miami-Dade County. The magenta, orange, blue, and green curves depict the performance of Monroe, Pinellas, Bay, and Duval counties, respectively. The black curve shows the performance of a portfolio consisting of the entire residential inventory of the State of Florida. Note that the state-wide portfolio outperforms any individual county for events more severe than one in 25 years. For rare events the state-wide portfolio requires significantly less claims paying capacity relative to AAL than any individual county.

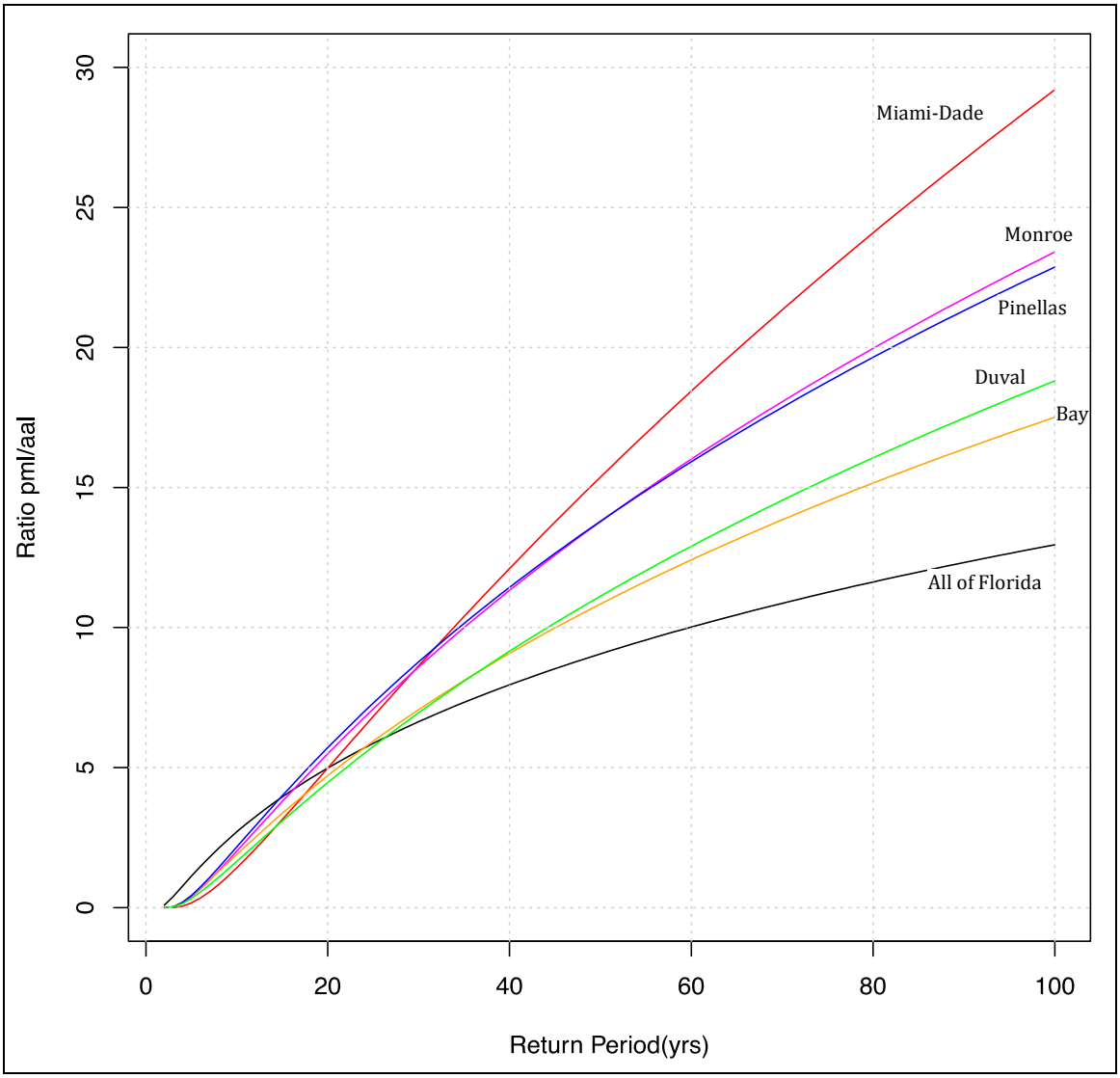

Figure 6: Performance of various Florida Portfolios

As discussed earlier, the debate about subsidies can also occur within specific states where there are significant differences in risk by location. For example, the ongoing debate in Florida relates to the potential subsidization that inland exposures provide to the coastal exposures. Research (e.g., Nyce and Maroney, 2011) has shown that inland to coastal subsidies exist in the Florida market but they also note that subsidies exist between properties directly on the coast and properties that are located immediately inland from the coast (e.g., coastal properties versus properties located 1 mile from the coast). One way of examining the coastal versus inland question is to look at the resilience of coastal counties versus inland counties. Figure 7 shows the plot of the ratio of the loss to Average Annual Loss (AAL) by return period for coastal and inland properties. At first inspection, the plot may seem counterintuitive in that the purely inland exposure seems to perform worse than the state-level or coastal areas. The primary explanation for this is that the Florida inland areas are less geographically diverse than the entire state. In addition, while the AAL decreases dramatically due to fewer damaging events overall, the losses from individual events for these areas do not decrease so dramatically. Thus, while the total losses for a purely inland portfolio would be lower, rates or reserves would have to be higher, relative to its AAL, than a statewide or even purely coastal portfolio.

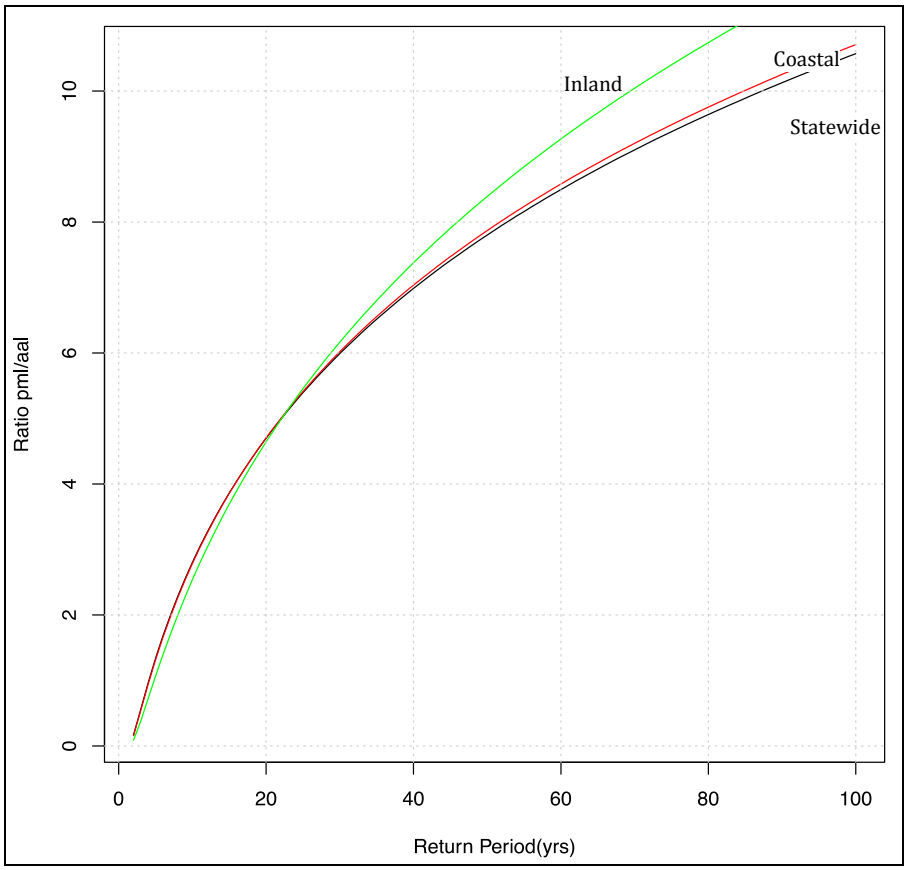

Figure 7: Florida Statewide, Inland and Coastal Portfolios.

Finally, we examined the performance of portfolios drawn from various combinations of states. As with state level combinations, as we increase the geographic diversity of a portfolio, the absolute magnitude of the losses increases, but the relative magnitude of the losses with respect to the risk for less frequent events decreases. The benefits from aggregation are most evident in the case of a portfolio consisting of all US coastal states from Texas to Virginia, since the claims paying capacity relative to AAL is significantly less with this entire region than that required to cover insured losses for any selected subgroup for events less frequent than once in 18 years. Figure 8 is the plot of representative individual states, four combinations of states, and all coastal states from Texas to Virginia, as indicated.

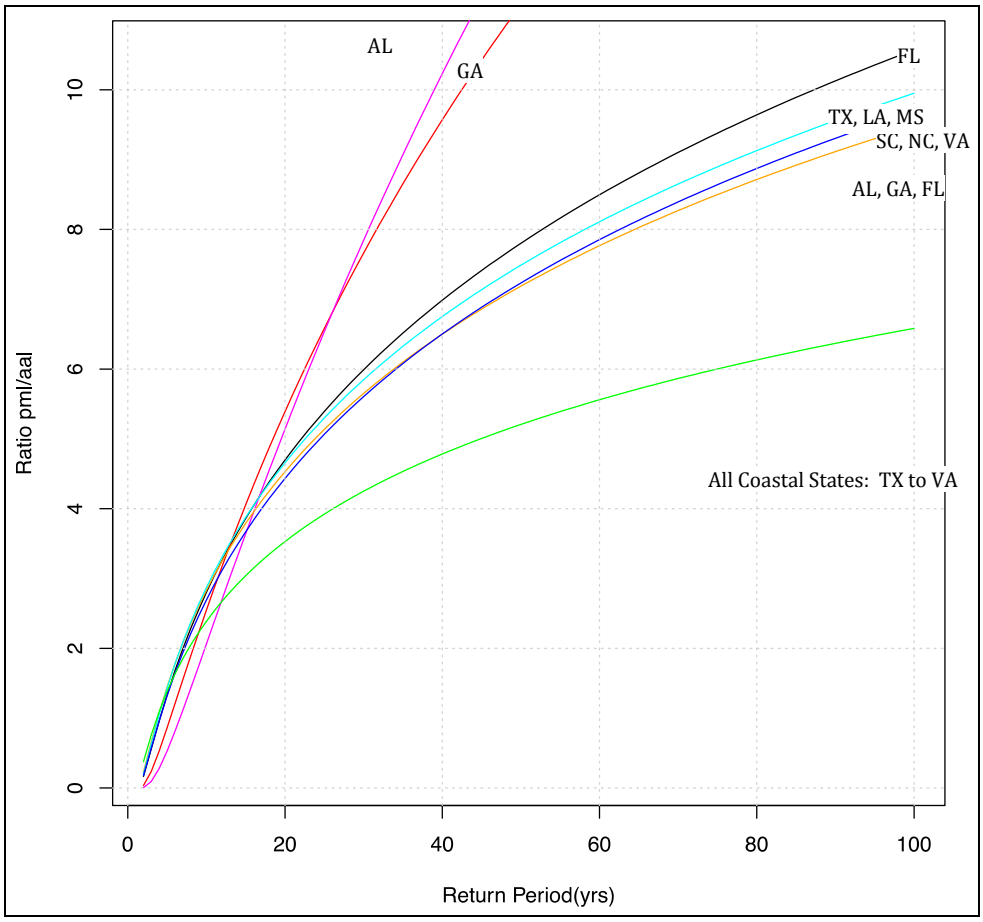

Figure 8: Individual states vs. multi-state groups

In considering multi-state compacts, Florida would be viewed as carrying a disproportionate risk relative to other states. Our analysis indicates this concern is misplaced, with virtually no change in the performance of the portfolio at higher return periods. While Florida obviously has higher total losses, if premiums are correct and adequate, Florida also generates higher total premiums, and the decision to include or exclude Florida is likely far less consequential than the decision to aggregate multiple states over any individual state alone.

Experiment 3 – Realistic Exposures

The combinations and aggregations presented in Experiments 1 and 2 involve single exposures at ZIP Code centroids. This approach provides an approximation to the distribution and behavior of actual exposures in a controlled way, and significantly simplifies the analysis from a computation standpoint, but lacks the complexity and realism of an actual exposure

database. For Experiment 3, an exposure database was created by using the US Census Bureau American Community Survey (ACS) database (US Census Bureau, 2009). The processed exposure portfolio contains construction type in eight categories, number of units and value, as well as date of construction, which was used to create building quality modifiers based on codes in effect at the time of construction. Hence, this exposure database should be a realistic depiction of the actual residential exposures in the study area.

Experiment Three, Case 1 is essentially a duplication of Experiment Two Case 1, with each county in isolation. The results in Figure 9 are similar to those shown in Figure 4 for Experiment Two.

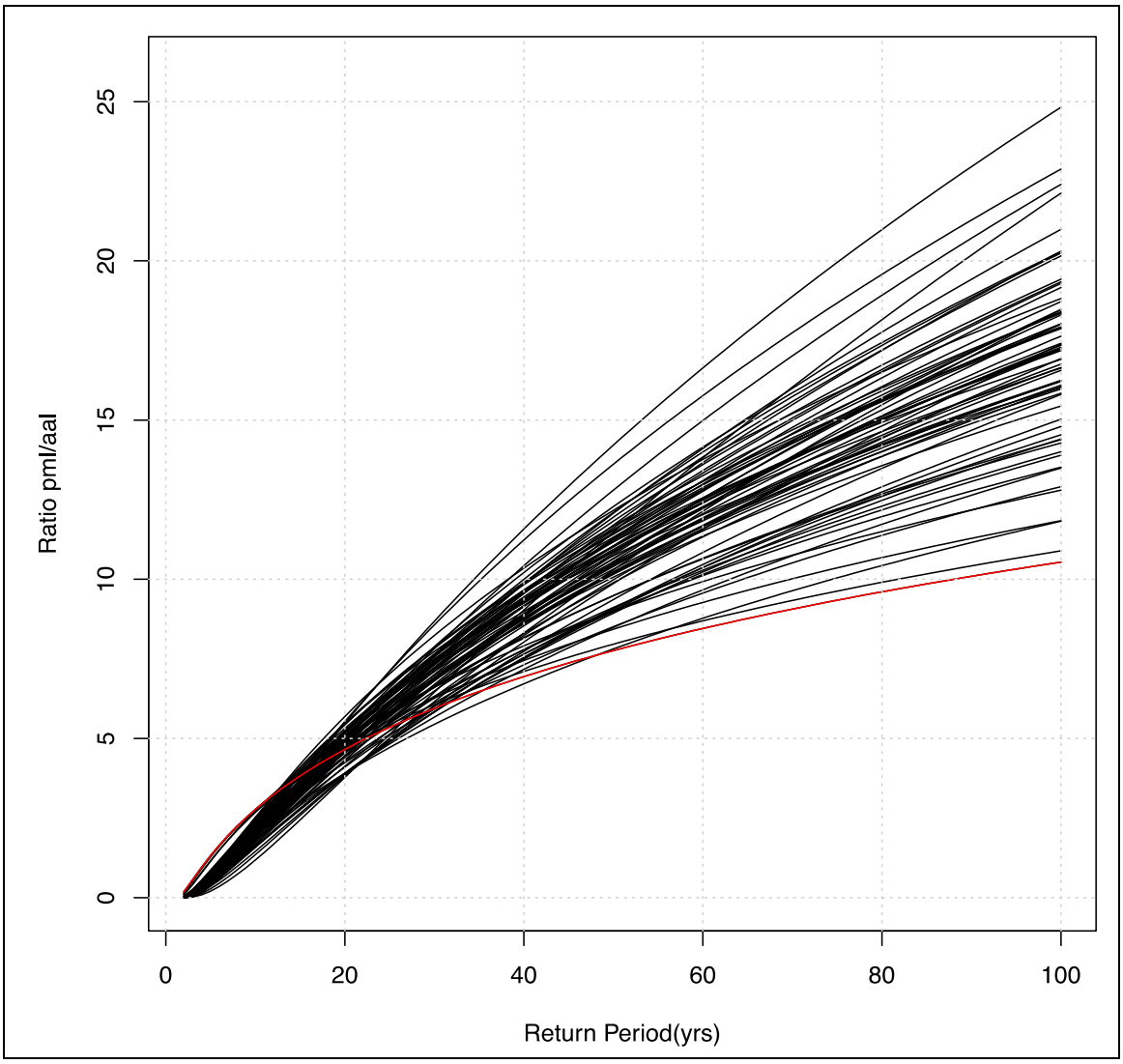

Figure 9: Experiment 3 Case 1 (All Florida Counties Individually, ACS)

Figures 10 and Figure 11 show the loss curves for the ACS portfolio at the individual state and multi-state level aggregations, paralleling Figures 9 and 10. As with the simplistic, single exposure per ZIP Code simulations, the much more complex and realistic ACS based simulations clearly indicate the advantages of multi-state portfolios. The individual state simulations shown in Figure 10 have somewhat less diversity in performance than the ZIP Code simulations.

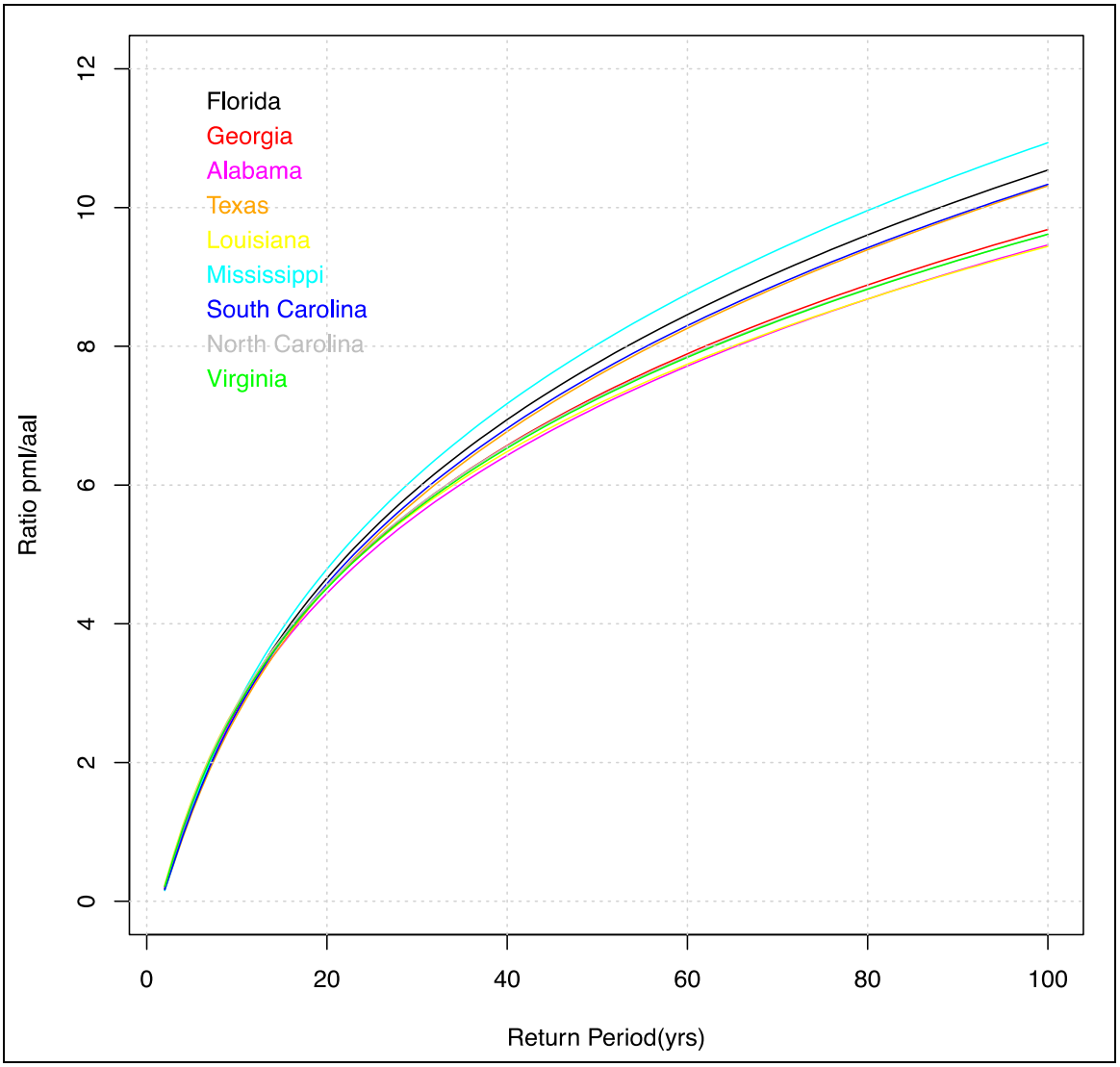

Figure 10: ACS Exposure Individual States

However, as with the ZIP Code based simulations, aggregation carries clear benefits. No combination of states performed less well than the best performing member of the aggregation.

In other words, any aggregation of any two or more states outperforms any single state, or lesser combination of states. Figure 11 shows several natural combinations of southeastern states.

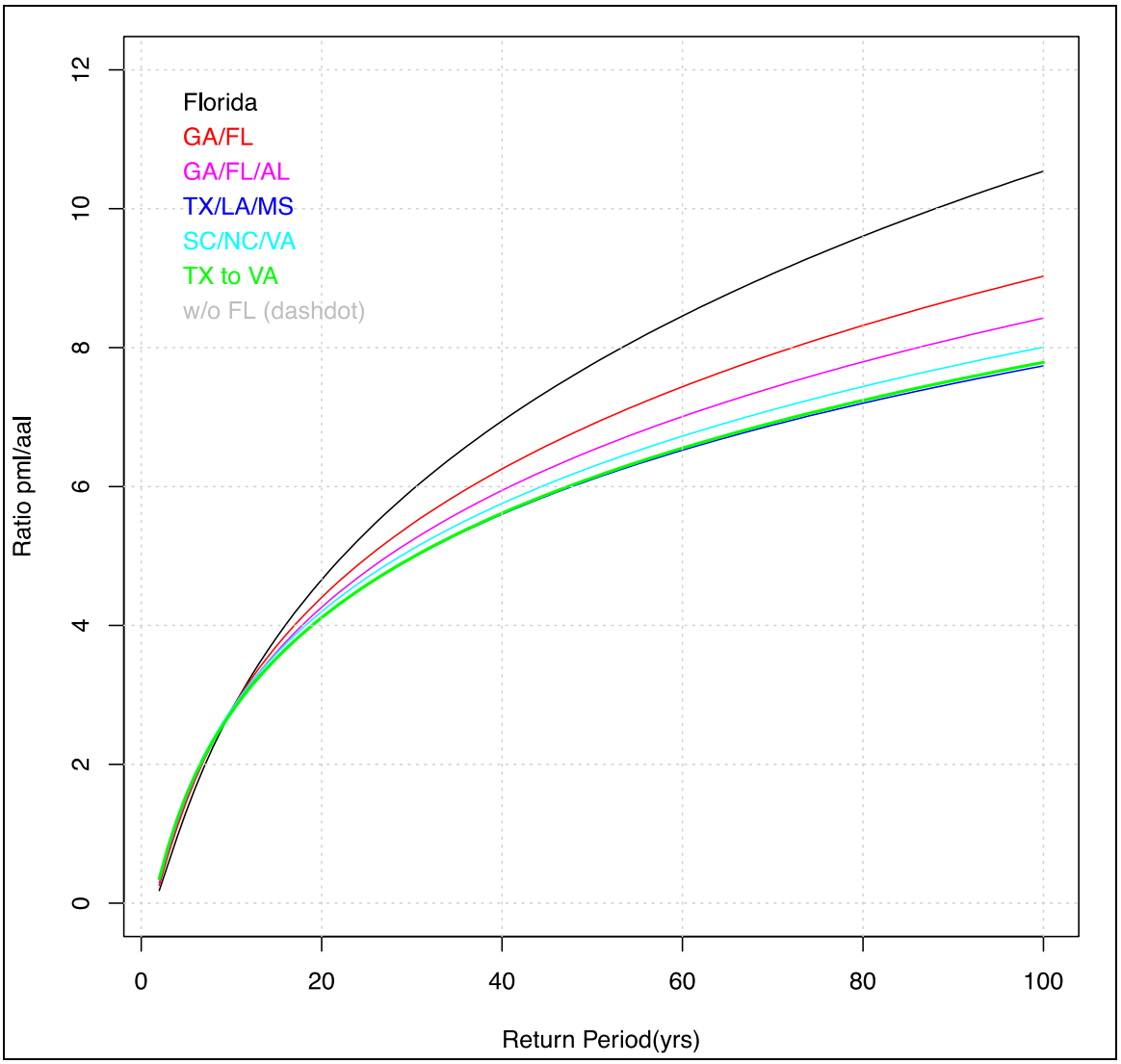

Figure 11: Multi-state combinations, ACS

In discussions of various regional plans, one of the primary objections to regional risk pooling is that the low risk areas see no benefit to this approach as they assume they will end up subsidizing the high risk areas. In our simulations, all risks were proportional – no subsidies or transfers were included. Dropping Florida from the portfolio, for example, results in virtually no change in the performance of the portfolio. In Figure 15, the "No Florida" curve is obscured by the virtually identical "TX to VA" and "TX/LA/MS" lines. Once the critical radius of geographic diversity is reached, there is no disadvantage to including high-risk areas. Likewise, excluding low risk areas has little impact on portfolio performance relative to AAL.

The benefits of aggregation are even more apparent if we examine the claims paying capacity required to cover losses from a 100-year event. Table 3 indicates the expected loss for that event. Treated in isolation, the sum of the claims paying capacity required would be just over $130 Billion. However, the 100-year event for the entire region is just over $71 Billion. The reason for the difference is obvious: it is extremely unlikely that any one, or even two or more, states to have a 100-year event in the same year. As such, it takes 54.7% of reserves to cover each 100-year loss for the entire region as opposed to treating each state in isolation.

Table 3: Capacity required to cover a 100 year Loss

Territory	**100 Year Loss**
Texas	$26,495,700,000.00
Louisiana	$18,337,501,250.00
Mississippi	$4,751,439,400.00
South Carolina	$5,624,569,400.00
North Carolina	$8,231,516,250.00
Virginia	$4,810,914,050.00
Florida	$49,483,235,000.00
Georgia	$3,349,056,550.00
Alabama	$8,955,484,400.00
Sum of each state:	$130,039,416,300.00
Multi-state Aggregate:	$71,110,875,000.00
Percent aggregate:	54.7%
Ratio aggregate to individual	1.83

Seen from another perspective, if there were $72 Billion available for insurance and it were assigned to each state proportionately to that state's individual risk, only a 40 to 50 year event could be covered in each state, whereas the $72 Billion reserve could cover the 100 year event for the entire combined portfolio.

Summary and Conclusion

The most often expressed argument against establishing any larger risk pool is that it potentially provides a subsidy for the higher risk members of that particular pool. In

considering catastrophic risk more broadly, this argument in the United States is made as "Why should someone in the state of North Dakota subsidize Florida wind or California earthquake risks?" In considering catastrophic wind risk, a related question is "Why should someone in the state of Alabama subsidize Florida or Texas wind risk?" As our results indicate, those arguments are invalid as each state in the pool benefits from geographic diversification if each exposure is assessed independently according to its own risk.

What is missing in the public policy debates regarding the aggregation of catastrophic risk is meaningful empirical analysis of whether benefits do accrue by aggregating catastrophic risk across increasingly wide geographic areas. The focus of this paper is on tropical cyclone hazards (wind, wave and storm surge), and in our experiments the AAL of each individual exposure was computed in isolation and no subsidies or biases were included. Thus, each exposure was assessed strictly according to its own individual risk, and the benefits of aggregation left to stand or fall on their own merits. To our knowledge, this is the first study to examine this broader question empirically by using catastrophe models to examine the impact of geographic diversification on catastrophic tropical cyclone risk.

As the results of this study indicate, there are two answers to the question of the impact of geographic diversity. For less severe but more likely losses reflected in return periods of 20 to 25 years, there appears to be no benefit to geographic diversification. For higher return periods (i.e., beyond 25 years), the answer is much different as there are clear diversification benefits and these benefits increase as the return period increases. The situation is analogous to building a portfolio of stocks where the benefit of the portfolio of stocks over the individual stock is the positive effect that diversification has on overall investment risk. As shown here the same is true at the higher return periods for aggregating wind risk across multiple states.

With respect to improving the current hurricane wind insurance system, these results have important implications for market design and suggest a two-tiered approach to managing catastrophic wind risk. The first tier would include losses associated up to the 20 to 25 year event. Here there would be no external pooling of wind risk and wind risk would be managed based on the company's appetite for this risk (i.e., no change from current practice).

The second tier would be a wind risk pool that captures multiple states and it would respond for losses above the 25 year return period. Ideally, the pool would include all states with

a coastal wind risk exposure; however, our results also indicate clear advantages for a wind pool comprised of a smaller number of states over individual states.

While this approach has a strong intellectual appeal, there are some challenges associated with it.[2] If losses associated with a particular return period are selected, then those losses (or the return period) would serve as a trigger mechanism to access the multi-state wind pool. Defining the trigger mechanism therefore becomes critically important. If the modeling process is used to generate a parameterized trigger, the use of models potentially comes with its own set of issues. A system similar to that established for the Caribbean Catastrophe Risk Insurance Facility (CCRIF) is one possible solution to this question, and moreover CCRIF has been successfully operational for over 5 years (Vaughan and Vaughan, 2008).

The intent of this paper is to determine the benefits of geographic diversification on tropical cyclone portfolios. It has been demonstrated that for the most important part of the loss distribution from a systemic perspective, the benefits of geographic diversification are significant. This conclusion creates the opportunity for a re-evaluation of the existing, highly fragmented system, and the creation of a system that incorporates these important findings. As such, these finding are an important first step in a longer process that focuses on the implementation issues involved with designing a workable structure for this type of pool.

Potential players in this second tier could include 1) existing or new multi-state compacts, 2) the reinsurance community, 3) a federal level organization, or 4) a private/public partnership. We would note here that securitization options would exist for this second tier of catastrophic risk and given the size and characteristics of this pool, it may provide the impetus for additional innovation in the securitization area.

Proponents of the federal regulation of insurance would view the creation of a regional risk pool as a natural progression towards the federal regulation of insurance. A national catastrophe plan, incorporating all catastrophic natural hazards risk, could be seen as a logical conclusion of the process begun with the creation of the National Flood Insurance Plan. As with the issues involving trigger definitions (or the separation between tier 1 and tier 2), the question of the aggregate pool design requires significant discussion and research.

[2] Nutter (2002) provides some historical context of the difficulties that various private-public options for catastrophic risk have encountered in the time leading up to 9/11 and suggest that the role of government in financing catastrophes lacks a clear policy direction.

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