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Insuring Future Climate Catastrophes:

An Analysis of Insurance Pricing and Capacity in Florida under Various Scenarios of Climate Change and Adaptation Measures

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Abstract

The combined influences of a change in climate and the increased concentration of property and economic activity in hazard-prone areas has the potential to threaten the availability and affordability of insurance in some regions. This paper evaluates the premiums that private insurers are likely to charge and their ability to cover residential losses against hurricane risk in Florida as a function of (a) recent projections on future hurricane activity in 2020 and 2040; (b) insurance market conditions (i.e., soft or hard market); (c) the availability of reinsurance; and (d) the adoption of adaptation measures (i.e., implementation of physical risk reduction measures to reduce wind damage to the structure and buildings). For the residential portfolio the total price of insurance across Florida (pure premium with no loading) is estimated at $9 billion in a soft market and $13 billion in a hard market for the 1990 baseline climate conditions. For the worst case climate scenario in a hard market with the present design of Florida homes as of 2009 (*current adaptation)*, the annual total price increases to $25 billion in 2020 and $32 billion in 2040. Adaptation measures can significantly reduce losses and the total premium; for example, in a hard market, where all homes in Florida meet the current building code

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(*full adaptation*), the total insurance premium would decrease from $13 to $6 billion for the 1990 baseline. If insurers can access reinsurance they will be able to cover 100% of the loss for a 100-year return hurricane, and 63% and 55% for a 250-year hurricane in 2020 and 2040 under a *full adaptation* scenario. Property-level adaptation and the maintenance of strong and competitive reinsurance markets will thus be essential to maintain the affordability and availability of insurance in the new era of catastrophe risk.

1. Introduction

Insurance is an important risk management tool; today the insurance industry absorbs around 40% of catastrophe losses in the industrialized countries (Hoeppe and Gurenko 2006). This paper explores the potential implications of climate change for the availability and affordability of insurance in the world's largest insurance market, the USA, focusing on wind-related property insurance in Florida. Specifically, the paper evaluates the implications of current and future hurricane activity for the price of insurance and the ability of the private insurance sector to provide coverage. We also evaluate the benefits of adaptation and competitive reinsurance markets in helping to constrain prices and extend insurance coverage.

Recent experience suggests that the world has already entered a new era of catastrophe risk. Of the 25 most costly insured catastrophes worldwide between 1970 and 2010, fifteen have occurred since 2001. With the exception of the terrorist attacks on September 11, 2001, all twenty-five of these catastrophes were natural disasters. More than 80 percent of these were weather-related events with nearly three-quarters of the claims in the United States (Kunreuther and Michel-Kerjan 2011). The observed increase in the costs of disasters results from several parallel influences. These comprise rapid population growth, an increase in the value at risk (e.g. more residences and infrastructure in hurricane-prone areas), density of insurance coverage and the possible impact of global warming on the frequency and severity of hurricanes.

The state of Florida, the focus of this study, provides an example of why losses from natural disasters have increased so rapidly. Until recently the economic impact of hurricanes was limited due to the sparseness of Florida's population; in 1950, the state ranked 20th in population in the U.S. with 2.8 million inhabitants. With the large influx of new residents, Florida was the fourth most populous state in the U.S. in 2010 with 18.8 million people, nearly a 570 percent increase since 1950. It is estimated that, after correcting for inflation, the damage from Hurricane Andrew, which hit Miami in 1992, would have been more than twice as great if it had occurred in 2005 (Pielke et al. 2008).

This increased exposure to hurricanes is not unique to Florida. As of December 2007, Florida and the state of New York each had nearly $2.5 trillion in insured property value located on the coast.

The coastal insured value in the United States for the top 10 states combined accounts for more than $8.3 trillion (Kunreuther and Michel-Kerjan 2011). If one adds what is covered against flood-related damage by the National Flood Insurance Program, the insured property value at risk would be augmented by $1 trillion. These figures only reflect the insured portion of the total exposure. Such huge concentrations of value in highly exposed areas indicates that any very strong hurricane that hits these regions is likely to inflict hundreds of billion dollars of economic losses.

Cost-effective adaptation measures can play an important role in constraining losses from hurricanes. An analysis of four states, Florida, New York, South Carolina and Texas, reveals that if the latest building codes were enforced on all residential homes, damage from hurricanes would be reduced significantly. For example, losses from a hurricane with a 500-year return period hitting Florida would be reduced by more than 50 percent if all residential structures met the requirements defined by the Institute for Business and Home Safety (Kunreuther and Michel-Kerjan 2011). However, despite its experience with natural catastrophes and adequate resources to prepare for them, the United States still has inadequate loss-reduction measures in place to deal with large-scale natural disasters Recent catastrophe losses and the failure of residents in hazard-prone areas to invest in adaptation measures highlight the challenges of reducing the impact of natural disasters (Bouwer et al. 2007; Cummins and Mahul 2009; Kunreuther and Michel-Kerjan 2011).

The impact of manmade climate change on current and future risk is somewhat uncertain. The debate on whether the series of major hurricanes that affected the USA in 2004 and 2005 might be partially attributable to manmade climate change is still ongoing. It is clear that 2005 was one of the warmest years on record in the Atlantic Basin region (e.g., Knutson et al. 2010; Hegerl et al. 2007) and that higher ocean temperatures lead to an exponentially higher evaporation rate in the atmosphere, which increases the intensity of cyclones and precipitation. In the North Atlantic (Atlantic, Caribbean, Gulf of Mexico), the total number of Category 4 and 5 hurricanes rose from sixteen in the period 1975-1989 to twenty-five in the period 1990-2004; however, the short length of high quality data records mean that it is not currently possible to discern whether this apparent trend is due to manmade climate change or part of a natural cycle.

Looking forward, Knutson et al. (2010) indicates that future projections based on theory and high-resolution dynamical models consistently reveal that globally, climate change will cause a shift in tropical storm intensities towards stronger storms. But the study is also cautious, stressing that, for all cyclone parameters, projected changes for individual basins show large variations between different studies. For the Atlantic Basin, the majority of the studies reviewed by Knutson et al. project, on average, an increase in storm intensity, although a minority of individual models do project reductions. An increase in the number of major hurricanes is likely to translate into a greater number hitting the coasts, thus causing more severe damage to residences and commercial buildings in the coming years. These future projections raise issues with respect to the insurability of hurricane risk in hazard-prone areas.

To better understand the implications of future climate variability on the affordability and availability of insurance in hazard-prone areas, this paper address the following questions:

- What prices will insurers/reinsurers charge to cover wind damage from hurricanes in future years based on different climate scenarios under soft and hard market assumptions
- How much insurance protection (capacity) can the private sector provide against losses from severe hurricanes with different return periods using different climate scenarios
- What will be the impact on insurance/reinsurance prices and availability of coverage if all homeowners in Florida adopted adaptation measures (i.e., incorporated in the current statewide building code)?

2. The Price of Insurance under Different Climate Scenarios

2.1. Scenarios for Hurricane Risk in Florida

Scenarios of future hurricane risk in Florida are taken from Ranger and Niehörster (2011) (hereafter, RN2011). RN2011 uses a climate-catastrophe modeling approach to generate a set of twenty-four scenarios based on the most recent hazard projections from the scientific literature. Our analyses focus on two of those scenarios, based on the highest and lowest projections from Bender et al. 2010. Bender et al. use a technique known as dynamical-downscaling, which couples projections from a global circulation model (GCM) to a high resolution regional model able to simulate the characteristics of localized tropical storms. The two scenarios presented here are based on the GFDL-CM2.1 and UKMO GCMs. We refer to these as the *high* and *low* climate change scenarios, respectively. Further details on the hazard scenarios are given in Appendix A.

Some scientists have suggested that the range of outcomes predicted by current dynamically-based models (e.g., Bender et al. 2010) may be too narrow. For this reason, we also provide projections in Appendix B for the *upper-bound* and *lower bound* scenarios from RN2011 based on a statistical-downscaling approach as discussed in Vecchi et al. (2008). For purposes of this study, all scenarios should be treated with equal confidence.

These scenarios represent plausible long-term trends due to manmade climate change. They do not account for annual variability in hurricanes due to natural variations, such as the El Nino Southern Oscillation and the chaotic nature of weather. Such natural variations would occur in addition to the trend due to manmade climate change, meaning that losses in any particular year could be above or below the long-term trend in average annual loss. Bender et al. 2010 and RN2011 suggest that changes in storm activity driven by manmade climate change are unlikely to exceed the range of this natural variability for at least a decade and potentially several decades. This means that estimates of annual losses (and the total insurance price) given in this study represent an average value over time (here, a 5-year average). Accordingly, actual values in a single year may be significantly above or below this value.

The outputs of RN2011 are exceedance probability (EP) [3] curves for each hazard scenario. Projections are given for 5-year time slices centered on 2020 and 2040. These EP curves use proprietary loss information provided by the modeling company Risk Management Solutions, Inc. (RMS) for a synthetic portfolio representing residential property in Florida. Here, we treat this as a single insurance portfolio. The portfolio (named the "Hybrid Exposure Set") is defined in Risk Management Solutions (RMS) (2010) and includes almost 5 million residential buildings across Florida, with a total insured value of $2 trillion USD. The portfolio represents residential exposure in Florida in 2009 and will be held constant over time across all our simulations.

2.2. Pricing of Hurricane Insurance for the Studied Residential Portfolio

We investigate the price of different layers of risk for the entire residential property portfolio in Florida, where each layer represents a possible tranche of insurance or reinsurance coverage. Utilizing the EP curves from RN2011, we generated estimates of the Average Annual Loss (AAL) and standard deviations (σ) of the AAL for wind-related hurricane risk[4] for each layer of coverage under the set of climate scenarios and two vulnerability conditions: *Current Adaptation* and *Full Adaptation. Current Adaptation* characterizes the existing building code status of homes in Florida (as of 2009). The *Full Adaptation* condition upgrades all homes in Florida so they are in compliance with the Florida Building Code 2004. Given that most buildings in Florida were built prior to 2004 (eighty-five percent of the portfolio), this represents a significant upgrade in building standards in their resistance to wind and would require a significant capital investment to retrofit the existing residential building stock.

We assume that insurance is provided by one representative insurer and that this insurer is behaving in the same manner as a reinsurer does by setting prices for different layers of coverage. More specifically, consider a layer of coverage (Δ) for wind damage from hurricanes in Florida (e.g., Δ= $5 billion to $10 billion).

The price of insurance (P_Δ) for this layer of coverage is determined by calculating the average annual losses (AAL) in this layer and applying a given loading factor to it. The loading represents the additional premiums the insurer needs to charge to compensate for costs other than the expected loss (i.e., the marketing, brokerage, claims processing expenses, and taxes) while at the same time ensuring that the coverage earns a high enough expected return on equity so it is attractive so investors want to allocate some of their capital to this insurance company.

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[3] An EP curve specifies the probability that a certain level of losses will be exceeded in a specific location over a specified period of time (in this case, one year).

The price also reflects the variance of the AAL since this determines the amount of surplus[5] that should be kept liquid to protect the insurer against the possibility of insolvency or a significant catastrophe loss. As the variance of AAL increases, the insurer will charge a higher price for a given portfolio or layer of that portfolio to reflect the lower return that this portion of surplus can earn because it must be easily accessible as cash should a catastrophic loss occur.

As discussed in Kunreuther and Michel-Kerjan (2011), reinsurers often determine the premium (P_Δ) for a specific layer of coverage (Δ) that captures these concerns by using the following formula:

$$P_\Delta = E(L_\Delta)(1 + \lambda) + c \cdot \sigma_\Delta \quad (1)$$

where $E(L_\Delta)$ is the expected loss or AAL for the given layer Δ , λ *is* the loading factor, σ_Δ is the standard deviation of a pre-specified portfolio of layer Δ and *c* can be viewed as the degree of risk aversion of the (re)insurer. More specifically, a lower value of *c* translates into more capacity being provided by the (re)insurer for a given price, all things being equal.

L_Δ reflects the loss distribution for layer Δ. The higher the value of σ_Δ, the more the (re)insurer will want to charge for covering losses from layer Δ. A (re-)insurer who is highly risk averse will specify a higher value of *c* reflecting its concern with taking on any new book of business.

Of course the price a (re)insurer wants to charge depends on market conditions. We first look at what is often referred as a “soft” market in the insurance industry. Soft markets typically are characterized by new entrants into the business, generous underwriting provisions, and aggressive discounting of premiums to gain volume. Hard markets occur when insurers and reinsurers want to charge a much higher price because they have suffered large losses from recent catastrophes and face a higher cost of capital to protect themselves against catastrophic losses.

To reflect these two market conditions in our equation (1), we assume that $c = 0.4$ in a soft market and $c = 0.7$ in a hard market. Six loss layers were specified, using attachment and exhaustion points so that losses double from one layer to the next (Figure 1); that is, $0 and $5 billion for *Layer 0*, $5 billion to $10 billion for *Layer 1,* $10 billion to $20 billion for *Layer 2,* $20 billion to $40 billion for *Layer 3,* $40 billion to $80 billion for *Layer 4,* and greater than $80 billion for *Layer 5,* the residual layer. With these defined layers, a loss model was run to determine $E(L_\Delta)$ and σ_Δ for each layer Δ.

Figure 1 depicts the return periods associated with the attachment and exhaustion points for the Florida portfolio under the baseline climate conditions (i.e., 1990), as well as the average annual loss and standard deviation for each layer. For example, Layer 4 which covers insured losses from

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[4] Storm surge losses are not included here.
[5] By surplus we mean the difference between an insurer's assets and liabilities, i.e., its net worth.

$40 billion to $80 billion (i.e., $40 billion in excess of $40 billion using (re-)insurance terminology) has an attachment point with an annual probability of 1 in 40 and an exhaustion point with annual probability of 1 in 145.

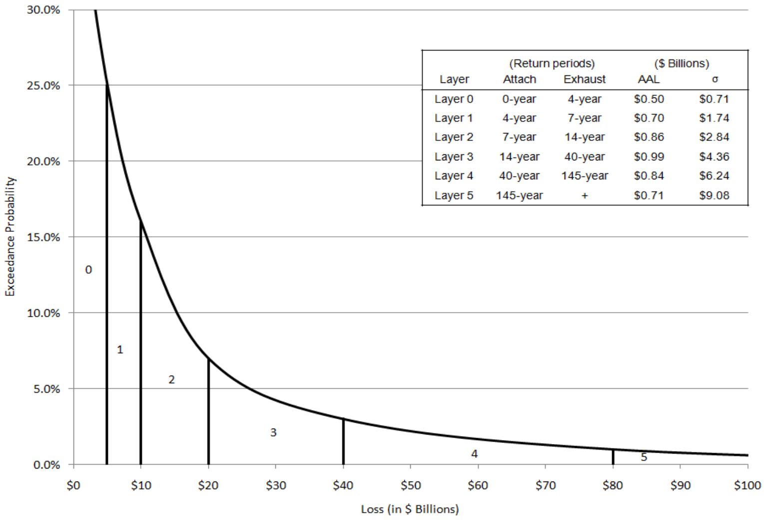

Fig 1. Loss Layers of the Florida Residential Portfolio for Different Return Periods (baseline 1990 climate conditions and current adaptation)

In this paper, we assume that there is no loading factor on the top of the pure premium (i.e., $\lambda = 0$ in equation (1)) so $P_{\Delta} = E(L_{\Delta}) + c{\cdot}\sigma_{\Delta}$.[6] Tables 1a and 1b summarize the price of insurance for (a) different layers under the two market conditions (soft/hard market), (b) different years (1990, 2020, and 2040), and (c) the low and high climate change projections, assuming current adaptation levels for residences in Florida.[7]

Table 1a Price of Insurance under the Low Climate Change Scenario

Low Estimate		All Layers	Layer 0	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5
			0-4 yr	4-7 yr	7-14 yr	14-40 yr	40-145yr	145yr +
1990	PRICE (SOFT) $ billion	$9.3	$0.8	$1.4	$2.0	$2.7	$3.3	$4.3
	PRICE (HARD) $ billion	$12.9	$1.0	$1.9	$2.9	$4.0	$5.2	$7.1
2020	PRICE (SOFT) $ billion	$7.3	$0.3	$0.9	$1.5	$2.2	$2.6	$3.9
	PRICE (HARD) $ billion	$10.3	$0.4	$1.2	$2.1	$3.19	$4.1	$6.4

[6] It is also possible to compute the ratio $c{\cdot}\sigma_{\Delta} /(E(L_{\Delta})$ to measure the effect of volatility on reinsurance prices but this is outside the scope of this paper.

[7] We assume that only one insurer provides coverage for the more than 5 million residencies in the portfolio. Hence we cannot compare these results with what each insurer doing business in Florida in 1990 was actually charging for its individual portfolio.

2040	PRICE (SOFT) $ billion	$6.6	$0.2	$0.7	$1.3	$1.9	$2.4	$3.7
	PRICE (HARD) $ billion	$9.3	$0.3	$0.9	$1.8	$2.9	$3.7	$6.0

Table 1b Price of Insurance under High Climate Change Scenario

High Estimate		All Layers	Layer 0	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5
			0-4 yr	4-7 yr	7-14 yr	14-40 yr	40-145yr	145yr +
1990	PRICE (SOFT) $ billion	$9.3	$0.8	$1.4	$2.0	$2.7	$3.3	$4.3
	PRICE (HARD) $ billion	$12.9	$1.0	$1.9	$2.9	$4.0	$5.2	$7.1
2020	PRICE (SOFT) $ billion	$9.8	$0.8	$1.5	$2.1	$2.9	$3.5	$4.5
	PRICE (HARD) $ billion	$13.5	$1.1	$2.1	$3.1	$4.30	$5.5	$7.3
2040	PRICE (SOFT) $ billion	$10.3	$0.9	$1.7	$2.3	$3.1	$3.7	$4.6
	PRICE (HARD) $ billion	$14.2	$1.2	$2.3	$3.3	$4.6	$5.8	$7.5

Table 1 shows the price of insurance (from Eqn. 1) under the two climate change scenarios and for the baseline (representing 1990). Clearly, there are important differences in the prices depending on the condition of the insurance markets and the climate change scenario used to generate losses in 2020 and 2040. For the baseline climate case of 1990, the premium for all layers of coverage ranges from $9.3 billion (soft market) to $12.9 billion (hard market). When projecting future losses, the insurance price to cover the portfolio falls by over 21% in 2020 and 27% in 2040 relative to the 1990 base case for low climate change scenario, and are projected to rise by around 5% in 2020 and 10% in 2040 for the high climate change scenario. The worst-case and best-case risk scenarios from RN2011 give an even broader range of possible future prices (see supplementary materials for full data); from a baseline of $12.9 billion in 1990, to $4.7 to $24.2 billion in 2020 and $4.7 to $32.1 billion in 2040 under hard market conditions.

3. Impact of Adaptation on Insurance Price

This section examines the role that adaptation (i.e., implementation of physical risk reduction measures to make buildings more resilient to wind) can play in reducing the price of insurance. The adaptation measure we consider is the adoption of a package of physical property-level resistance and resilience measures consistent with the current Florida building code. We evaluated the impact of *Full Adaptation* on wind-related losses from hurricanes by calculating new EP curves based on proprietary information provided by Risk Management Solutions.

Table 2 compares the price of insurance for the *Current Adaptation* and *Full Adaptation* scenarios for a hard market (where $c = 0.7$ in Eqn. 1) for the two climate change scenarios. When all structures utilize adaptation measures as specified in Florida's building code for hurricane-prone areas (*Full Adaptation),* the price of insurance falls significantly. For example, under baseline climate conditions, the total price to cover all structures in Florida decreases from $12.6 billion in the *Current Adaptation* scenario to $6 billion in the *Full Adaptation* scenario.

Table 2 Change in price of insurance over time under full adaptation for hard market

Year	High Climate Change Scenario		Low Climate Change Scenario	
	Current Adaptation	Full Adaptation	Current Adaptation	Full Adaptation
1990	$12.9 billion	$5.8 billion	$12.9 billion	$5.8 billion
2020	$13.5 billion	$6.3 billion	$10.3 billion	$5.0 billion
2040	$14.2 billion	$7.2 billion	$9.3 billion	$4.4 billion

The change in price in 2020 and 2040 with climate change, with and without adaptation, is depicted graphically in Figure 2, where the arrows represent the price difference with adaptation.

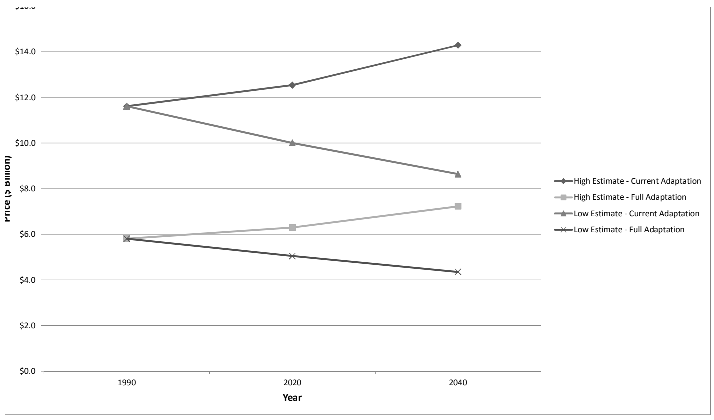

Fig 2 Change in Price of Insurance with Full Adaptation for the High and Low Climate Change Scenarios

We also look at events with specific return-period. Table 3 compares the gross wind losses in Florida from hurricanes with return periods of 100, 250 and 500 years with current and full adaptation measures in place. The impact of Full Adaptation is highly significant, cutting the loss by more than 50 percent for the 100-year return period, and by approximately 45 percent and 40 percent for the 250- and 500-year return period hurricanes, respectively.

Table 3.Effect of Full Adaptation on Hurricane Wind Losses ($ billions)

Adaptation case	Return period (years)	1990	2020		2040	
		All	Low Climate Change Scenario	High Climate Change Scenario	Low Climate Change Scenario	High Climate Change Scenario
Current Adaptation	100	$51	$44	$55	$36	$63
	250	$80	$73	$88	$64	$100
	500	$113	$107	$116	$92	$126
Full Adaptation	100	$24	$20	$27	$15	$34
	250	$46	$39	$51	$35	$57
	500	$68	$60	$72	$51	$78

4. Ability of Insurers to Cover Losses with and without Adaptation

This section examines the ability of the insurance industry to cover losses from hurricanes. Specifically, we determine what fraction of losses from a 100-year, 250-year and 500-year hurricane the private insurance market could cover in scenarios with and without climate change and adaptation, and with available reinsurance. To determine how much capacity insurers are willing to provide to cover losses from such hurricanes in a competitive market, we follow the methodology developed in Kunreuther and Michel-Kerjan (2011) and outlined in Appendix C. We assume that each insurance group operating in Florida is willing to risk 10 percent of its surplus to provide coverage for wind losses from hurricanes that have a 100-year, 250-year or 500-year period. This 10 percent figure was confirmed as a reasonable assumption for these analyses by the insurers and rating agencies with whom we spoke. The total amount of coverage that insurers would have available to cover losses from hurricanes in Florida that reflects 10% of their surplus would by $15.4 billion.[8]

We analyze the percentage of loss covered and the required surplus for full coverage of the risk by the private insurance industry, under the assumption that (a) insurers cannot purchase reinsurance (see results in Appendix D, Fig A.4 and A.5) and (b) that they can purchase reinsurance to provide more hurricane risk coverage (Figure 1). The methodology is described in Appendix C.

[8] In reality, of course, the determination by each insurer as to how much surplus it is willing to assign to a specific risk (e.g., wind damage) in Florida depends on its financial characteristics (assets, credit rating), the distribution of its portfolio for that risk and other risks in Florida as well as other states and other countries, and how much state insurance regulators allow it to charge to cover the risk

Table 4 Percentage of loss covered and required surplus for full coverage by insurers with reinsurance. Comparison of Current and Full Adaptation ($ billions)

Year	Scenario	Return Period (years)	Gross Losses	Reinsurance Coverage	Un-reinsured Losses	Percent of Market Covered	Gross Losses	Reinsurance Coverage	Un-reinsured Losses	Percent of Market Covered
			Full Adaptation				Current Adaptation			
1990		100	$24	$14.3	$9.4	100%	$51	$30.6	$20.1	76%
		250	$46	$23.6	$22.1	70%	$80	$41.5	$38.8	40%
		500	$68	$29.2	$38.6	40%	$113	$48.5	$64.0	24%
2020	High Climate Change Scenario	100	$26.9	$16.2	$10.7	100%	$54.8	$33.1	$21.8	71%
		250	$50.8	$26.2	$24.5	63%	$87.8	$45.4	$42.4	36%
		500	$72.4	$31.2	$41.2	37%	$116.4	$50.2	$66.2	23%
	Low Climate Change Scenario	100	$19.9	$12.0	$7.9	100%	$43.5	$26.3	$17.3	89%
		250	$38.5	$19.9	$18.6	83%	$72.5	$37.5	$35.0	44%
		500	$59.8	$25.8	$34.0	45%	$106.9	$46.1	$60.9	25%
2040	High Climate Change Scenario	100	$34.1	$20.6	$13.5	100%	$62.9	$37.9	$25.0	62%
		250	$57.4	$29.7	$27.7	55%	$100.0	$51.7	$48.3	32%
		500	$77.9	$33.6	$44.3	35%	$125.7	$54.2	$71.5	21%
	Low Climate Change Scenario	100	$15.0	$9.1	$6.0	100%	$35.9	$21.7	$14.3	100%
		250	$34.9	$18.0	$16.8	91%	$64.2	$33.2	$31.0	50%
		500	$51.4	$22.2	$29.2	53%	$91.6	$39.5	$52.1	29%

Note: A graphical representation of these results along with those without reinsurance is provided in Appendix D

Table 4 focuses on the second assumption where insurers are provided with reinsurance. These findings indicate that with the current status of buildings in Florida (*Current Adaptation*) the insurance industry is not able to cover a significant portion of the losses even for hurricanes with 100-year return periods. Table 4 also indicates the significant impact that enforcement of building codes and retrofitting of existing properties would have on the ability of insurers to cover losses from these severe hurricanes (*Full Adaptation*).[9] To see this, one only has to look at the percentage of losses covered by insurers in the *Current Adaptation* case. For example, with the high climate change scenario and *Full Adaptation*, all structures will be insured for the 100-year hurricane in the year 2040 compared to only 62 percent in the *Current Adaptation* scenario. When reinsurance is available and all homes meet current building codes, insurers are able to cover all losses from hurricanes with 100-year return period and between 55 percent and 91 percent for hurricanes with 250-year return period as shown in Table 5. This percentage of coverage is much larger than for the *Current Adaptation* scenarios with reinsurance in place where insurers can cover between 32% and 50% of the losses from a hurricane with a 250-year return period. Further results given in Appendix D indicate that the proportion of losses covered is much smaller in all cases where reinsurance is unavailable. For example, under current adaptation, the private market would be able to cover less than 30% of losses.

5. Discussion

This paper constitutes a first attempt to systematically measure the implications of future climate scenarios for the pricing of catastrophe risk insurance, using the case of hurricane risk in the state of Florida, under various conditions of adaptation and reinsurance availability. Without adaptation and under a high climate change scenario, the price of insurance could increase significantly with insurance then becoming unaffordable for many people in Florida. Reinsurance and loss reduction measures can thus maintain the availability and affordability of insurance in Florida, even under a worse-case climate change scenario. Enforcing adaptation measures based on existing building codes, as well as retrofitting existing properties, should enable insurers to cover a much larger percentage of the losses in Florida.

Not only does adaptation significantly reduce the estimated price for any given climate scenario, but it also substantially reduces the uncertainty in the price of insurance. For example for a hard market in 2020 the range for the high and low climate change scenarios under the *Full*

[9] The current analysis only reflects the benefits of adaptation measures. Some of these measures may not be cost-effective on existing structures but worthwhile undertaking when they are integrated into the design of new construction as shown by Aerts and Botzen (2011a) and Jones, Coulborne, Marshall, and Rogers (2006) for the design of buildings with respect to the flood risk.

Adaptation scenario (i.e., with all buildings retrofitted to meet the Florida Building Code 2004) is $5-6 billion compared to a premium range of $10-14 billion with the existing status of buildings (*Current Adaptation)*.

These results have important public policy implications given the recent changes in the dynamics of insurance markets in Florida. In the aftermath of the devastating 2004 and 2005 hurricane seasons, primary insurers filed for rate increases but only a portion of their requests were approved by the state insurance regulator.[10] This led many large insurers to significantly reduce the amount of coverage they provided in hurricane-prone regions of the state. During this same period, the state-run insurance company, Citizens Property Insurance Corporation, was permitted by the legislature to charge lower (subsidized) rates than many of its private competitors, so that it became the largest provider of homeowners' insurance in Florida.

According to the law, Citizens will be able to recoup any deficit it faces in the aftermath of another major hurricane against its private competitors in Florida (so-called post-event assessment). Those insurers will then have to levy this amount against their own policyholders. This move from private insurance to hybrid public insurance with post-disaster funding against the private sector occurred because many residents on the coast felt that they were being charged too much by private insurers after the hurricanes of 2004 and 2005. However, this immediate benefit to the consumer may result in reduced societal resilience to hurricane risk and greater impacts in the long-term. Kunreuther and Michel-Kerjan (2011) show quantitatively that following the 2004-2005 hurricane seasons, Citizens did not have the necessary reserves to handle another series of major hurricanes because its premiums were inadequate to cover the risks. While Citizens has seen its reserves grow in the past few years due to the absence of Florida hurricanes, its financial situation is unstable in the long term due to the subsidized prices it charges for coverage. If there is an increase in hurricane activity in Florida, Citizens financial situation will be even more precarious.

Future research could expand the scope of the analysis undertaken in this paper by integrating other climate projections and incorporating the cost of adaptation measures into the analysis. One could then undertake a meaningful benefit-cost analysis under different annual discount rates and time horizons. The resulting premium reductions provided by insurers to property owners could then be compared with the costs of a multi-year loan designed to encourage investment in these risk reduction measures. The *Full Adaptation* scenario, which represents retrofitting eighty-five percent of properties so that they meet the Florida Building Code 2004, is an extreme measure that will be costly to implement. Further research should explore other options, such as retrofitting the highest risk homes and strengthening codes in areas with the highest hurricane risk.

[10]There has been considerable tension in the past few years between the private insurance industry and the state-run insurance regulator in Florida. Insurers want to increase premiums to reflect a change in market conditions while the insurance regulator wishes to suppress premiums so as to make the cost of insurance affordable.

This study has explored only the impacts of climate change on losses. An important (and much less uncertain) driver of losses in Florida is population growth and the accumulation of assets in hurricane-prone areas. Projections of the U.S. Census Bureau suggest that by 2020, the population of Florida could be more than 20 percent higher than in 2010. If we assume that the spatial distribution of exposure remains constant, this suggests that aggregate losses could increase by an additional 20 percent higher in 2020 (and much more in some counties of the state). Exposure is growing fastest in hurricane and flood prone locations in urban areas on the coast. The effect of this trend on the availability and price of insurance is an open question for further study.

Research is also required to explore approaches to enhance the uptake of risk reduction measures. Our study demonstrates the considerable financial benefits of adaptation, but empirical evidence reveals that many people do not invest voluntarily in such measures even when they are cost effective. It is thus important to appreciate the challenges in incentivizing individuals and enterprises located in disaster-prone areas to invest in those measures and purchase adequate levels of insurance coverage so as to reduce the need for government disaster relief (Kunreuther, Meyer and Michel-Kerjan, in press). Jaffee et al. (2010) and Michel-Kerjan and Kunreuther (2011) propose encouraging homeowners to invest in cost-effective adaptation measures through multi-year insurance contracts. These multi-year contracts would make the probability of a disaster occurring during the length of the contract more salient and the benefits of adaptation clearer.[11]

6. Conclusions

Recent state-of-the-art climate projections indicate the potential for an increase in hurricane risk in Florida. This paper has attempted to systematically measure the implications of such scenarios for the affordability and availability of private insurance for homeowners. We focus our analyses on two scenarios that represent an upper and lower bound based on current dynamically-based model projections.

We find that the total price of insurance for Florida (assuming constant exposure) could increase significantly by 2040, from $12.9 billion (in 1990) to $14.2 billion, under hard market conditions. Under the lower bound projection, premiums could decline to $9.4 billion by 2040. Taking a broader range of climate change scenarios, prices could be between $4.7 and $32.1 billion by 2040. The upper end of this range could suggest that insurance becomes unaffordable for many people in Florida. Adaptation significantly reduces losses and premiums under all scenarios and extends the amount of coverage that could be provided by the private insurance market. The implementation of loss reduction measures and provision of reinsurance against catastrophic losses

[11] See Aerts and Botzen (2011b) for an application of this concept to flood in the Netherlands.

can increase the availability of insurance in Florida and make it more affordability to residents of the state even under a high loss climate change scenario.

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APPENDICES

A. Scenarios of Future Hurricane Risk

This paper uses scenarios of future hurricane risk in Florida generated by Ranger and Niehörster (2011) (hereafter, RN2011). RN2011 generate a broad set of twenty-four scenarios that aim to explore the plausible range of future hurricane activity given current knowledge and are based on state-of-the hazard projections from the scientific literature. Six representative scenarios are selected from the RN2011 set and are depicted in Table A.1.

Table A.1 Six climate scenarios studied in this paper

	Model Type	Description
Model A	Statistical Model	An upper-bound projection of future hurricane activity using a statistical model that represents only the effects of increases in sea surface temperatures on hurricane activity and uses an upper-bound forecast of future sea surface temperature from the IPCC model ensemble (Ranger and Niehörster (2011) scenario name: MDR-SST_max)
Model B (high risk scenario)	Dynamical Model	Based on a dynamical-model forecast of future hurricane activity from Bender et al. 2010 using the global circulation model (GCM) GFDL-CM2.1.
Model C	Dynamical Model	As above, using MRI-CGAM (Bender et al., 2010)
Model D	Dynamical Model	As above, using MPI-ECHAM5 (Bender et al., 2010)
Model E (low risk scenario)	Dynamical Model	As above, using UKMO (Bender et al., 2010)
Model F	Statistical Model	A lower-bound projection of future hurricane activity using a statistical model that represents the effects of changes in the relative sea surface temperature of the Atlantic Basin. It uses a lower-bound forecast from the IPCC ensemble (Ranger and Niehörster (2011) scenario name: Rel-SST_min)

Each of the six scenarios are based on the A1B greenhouse gas (GHG) emissions scenario of the Special Report on Emissions Scenarios (SRES), which was prepared by the Intergovernmental Panel on Climate Change (IPCC) in the year 2000. The A1B SRES scenario assumes that GHG emissions will increase until 2050 and then gradually decline.[12] The scenarios are associated with global average temperature rises of between 1.7 and 4.4°C above 1990 levels by the 2090s (IPCC, 2007). The hazard projections for the six scenarios are given in Figure A.1.

[12] The SRES A1B greenhouse gas emissions scenario remains close to the centre of the range of the six SRES emissions scenarios commonly used by the Intergovernmental Panel on Climate Change (IPCC).

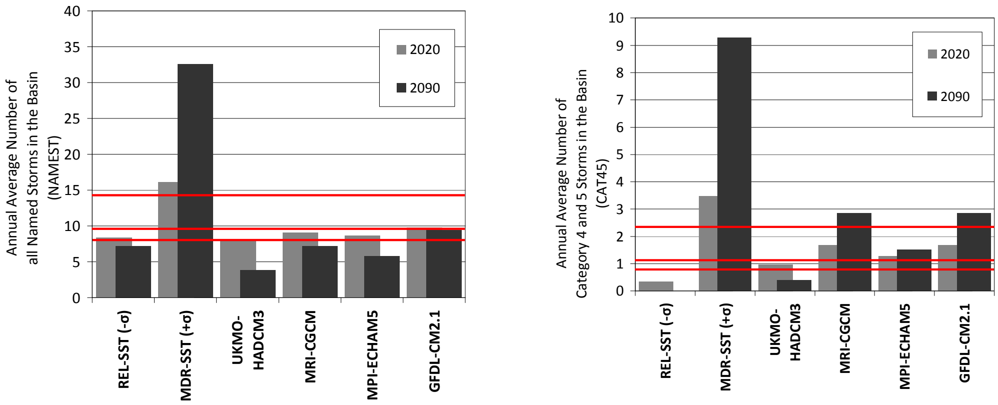

Figure A.1 The hazard scenarios: (left) projections of the average annual number of all named storms in the Basin and (right) projections of the average annual number all Category 4 and 5 storms in the Basin for 2020 and 2090. The three horizontal lines (in red) show benchmark points: the center line is the 1990 baseline level and the outer lines are the average rates over the recent active (defined as 1995-2010) and inactive (defined as 1972-1994) periods. Source: RN2011

Four out of the six scenarios are based on state-of-the-art simulations from Bender et al. (2010), each using different global circulation models (GCMs; GFDL-CM2.1, MRI-CGAM, MPI-ECHAM5 and UKMO) (Table S1). A challenge in using GCMs to simulate storm activity is that these models do not have adequately high resolution to fully represent the important small-scale features of tropical storms. For this reason, GCM simulations must be *downscaled* to produce estimates of future tropical storm activity. Bender et al., (2010) uses a technique known as *dynamical downscaling*, which couples the GCM simulations to a much higher resolution regional model that is better able to simulate localized tropical storms. In this case, two operational hurricane models were used (versions run by the U.S. National Weather Service and the U.S. Navy as of 2010). Note that the four scenarios generated are not ranked relative to each other and should be treated with equal confidence.

The remaining two scenarios are based on an alternative approach, known as *statistical* downscaling. *Statistical* downscaling provides estimates of future storm activity by applying empirical relationships between storm activity and predictor climate variables (including sea surface temperatures and windshear in the Main Development Region of the Atlantic) to projections of those climate variables from GCMs. The two scenarios selected from RN2011 are the highest and lowest projections from the set.

These scenarios do not account for annual variability in hurricanes due to natural variations, such as the El Nino Southern Oscillation and the chaotic nature of weather; such natural variations would occur in addition to the trend due to manmade climate change meaning that losses in any particular year could be above or below the trend in average annual loss.

It is plausible to assume that the scenarios based on dynamical models have a higher degree of confidence than those based on statistical models. For example, Ranger and Niehörster (2011) note that some experts have suggested that Model A (the MDR_SST_max model) has a low degree of confidence as it does not incorporate processes that tend to moderate hurricane activity (e.g., wind shear) and so tends to produce artificially high estimates of future hurricane activity. On the other hand, an expert meeting between the LSE, the Wharton Risk Center and several leading climate scientists in March 2010 revealed that scientists feel that the range of outcomes predicted by current dynamically-based models (e.g., Bender et al., 2010) may be too narrow. For this reason, we believe there is value in also incorporating the statistical models in our analysis as they provide a broader range of future outcomes.

B. Projected Premiums for Six Hurricane Risk Scenarios

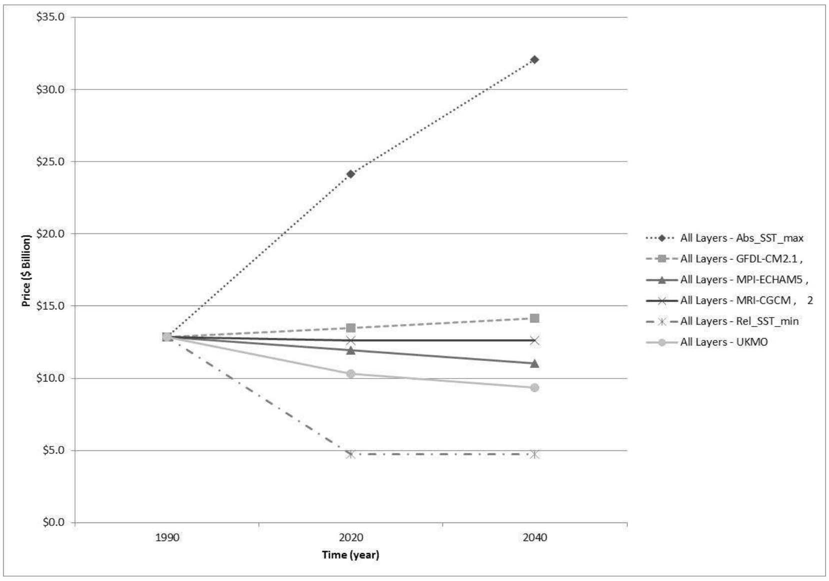

Figure A.2 Change in Insurance Prices over Time and Across Climate Scenarios: Illustration with a Hard Market

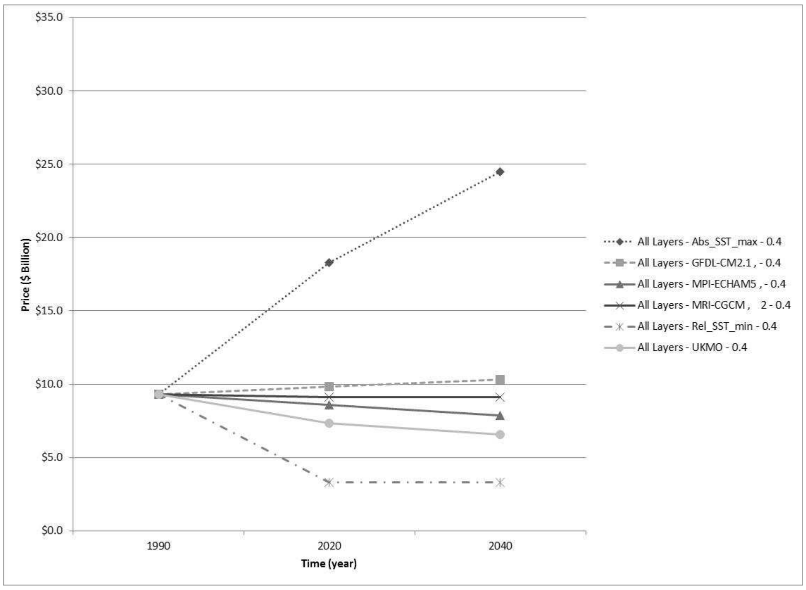

Figure A.3 Change in Insurance Price over Time and Across Climate Scenarios: Illustration with a Soft Market

C. Calculations of the Percentage of Loss Covered by the Private Market

To estimate the ability of the insurance industry to cover losses with reinsurance in place we first estimate the cession rates (i.e., the fraction of loss reinsured) based on historical data. Cession rates are based on estimated gross and net probable maximum loss (PML) for Florida from A.M. Best. The gross PML is the total projected loss from a catastrophic event for an insurer, while the net PML is the total projected loss from this event after subtracting payments from reinsurance and other alternative risk transfer. The percentage of losses paid by reinsurance is derived by the following formula:

$$\% \text{ Reinsurance} = 1 - (\text{net PML}/\text{gross PML}) \qquad (2)$$

We use the national pre-tax per-occurrence hurricane gross and net PMLs for the 100-, 250- and 500-year return periods for 90 groups categorized within the personal lines and homeowners' segments using 2005 data.[13] Although some groups were omitted from the analysis, we believe this is an accurate portrayal of the industry. Furthermore, we used PML ratios, not the absolute value. These ratios from our sample should be generally applicable to the entire industry.

To illustrate, suppose that for a 100-year return period, an insurer had a gross PML from hurricanes in Florida of $500 million and a net PML of $300 million. Then equation (2) implies that the percent Reinsurance = 1-($300/$500) = 40 percent.

A.M. Best estimated gross and net PMLs for the insurance industry from hurricanes using data at the group level for the 100-, 250- and 500-year return periods. This enabled us to estimate the percent of reinsurance that insurers had purchased for these catastrophic losses as shown by Table S.2.[14]

Table A.2 Estimating reinsurance percentages using PML data on homeowners' losses from hurricanes in Florida

Return Period	Gross PML	Net PML	Net/Gross	Reinsurance (incl. ART)
100	21.3	8.5	39.7%	60.3%
250	33.3	16.1	48.3%	51.7%
500	44.7	25.4	56.9%	43.1%

Source: Data from A.M. Best; Authors' calculations

[13] The 90 groups included in the analysis represent companies submitting a Supplemental Rating Questionnaire (SRQ) to A.M. Best.

[14] See chapter 13 (pp. 278-80) in Kunreuther and Michel-Kerjan (2011) for more details on how aggregated reinsurance amounts were estimated.

D. Graphical Representation of the Benefits of Reinsurance and Full Adaptation Measures

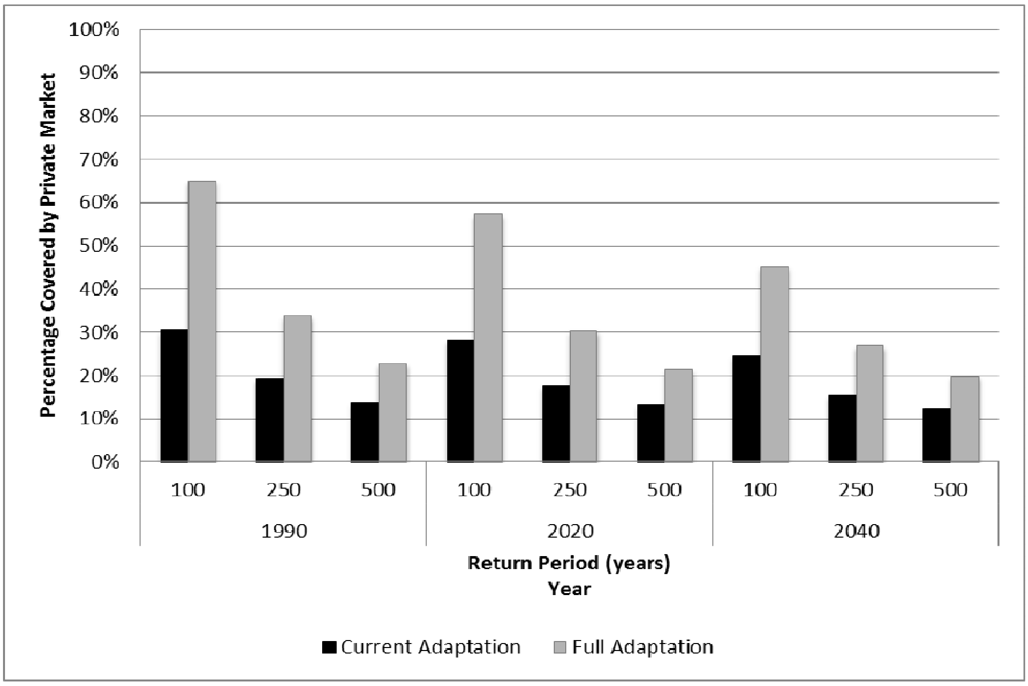

Figure A.4 Percentage of Insurance Coverage by Private Market with No Reinsurance (High Estimate)

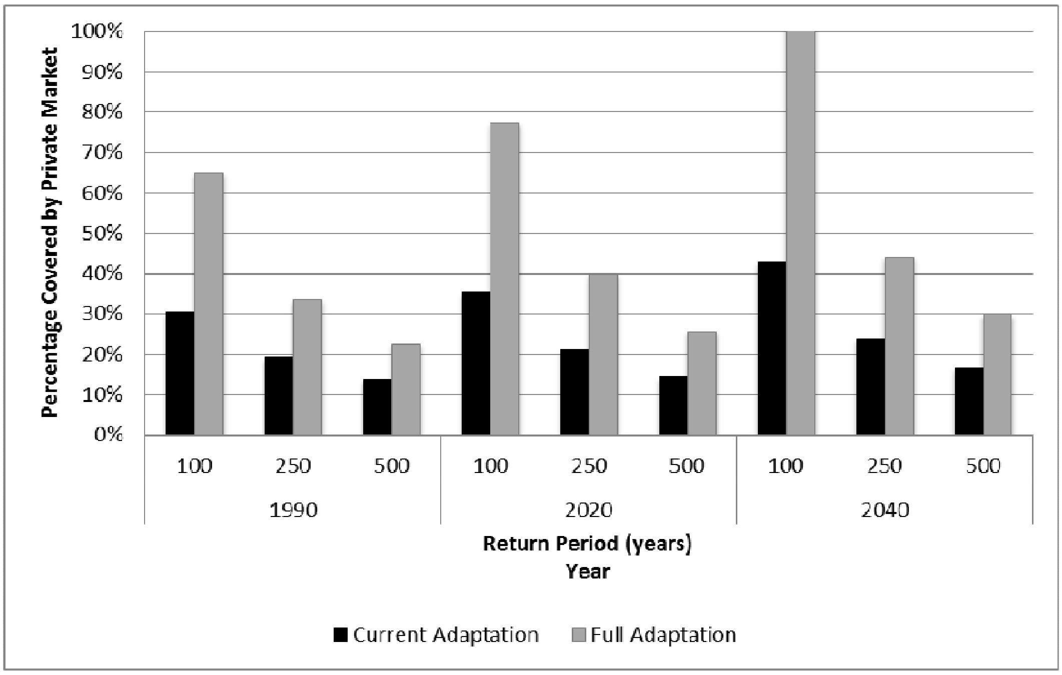

Figure A.5 Percentage of Insurance Coverage by Private Market with No Reinsurance (Low Estimate)

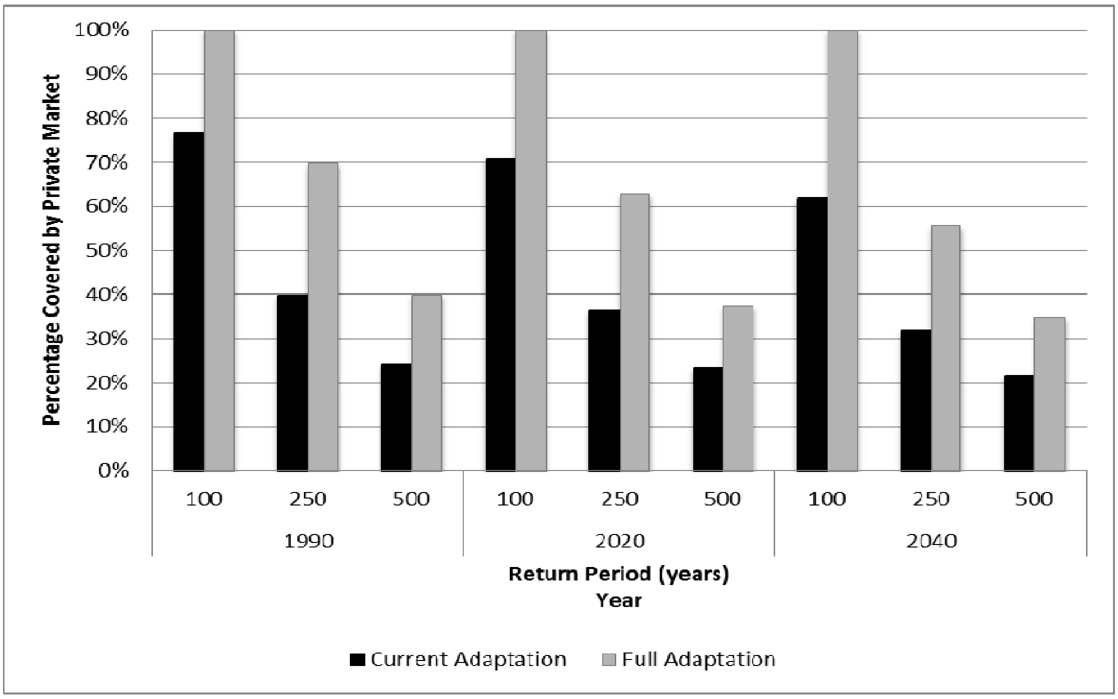

Figure A.6 Percentage of Insurance Coverage by Private Market with Reinsurance (High Estimate)

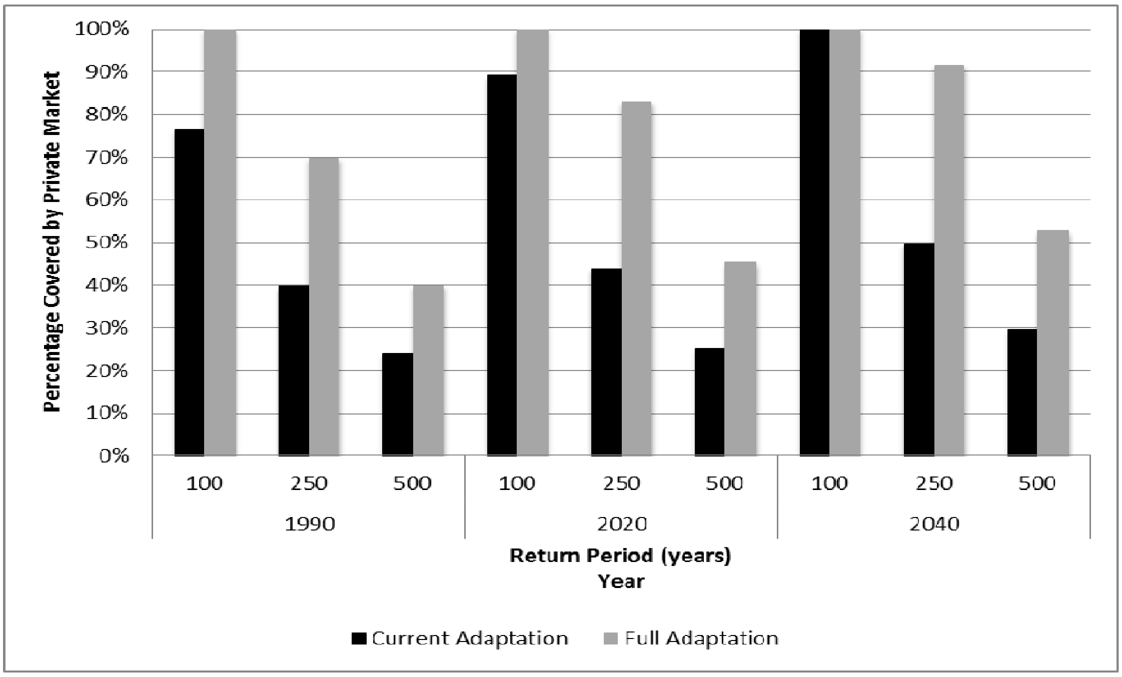

Figure A.7 Percentage of Insurance Coverage by Private Market with Reinsurance (Low Estimate)