Supplementary Material
Insuring the Future: The Insurance Industry's Role in Climate Change Mitigation
Humanities and Social Sciences Communications

1. Data

1.1. Past data

1.1.1. Past data sources:

We used the following data sources to estimate the model parameters:

- NAIC- Dwelling Fire, Homeowners Owner-Occupied, and Homeowners Tenant and Condominium/Cooperative Unit Owner's Insurance Report- annual report provided information of premium and exposure (expressed in house-years) by policy type and insured amount (available for the years 1997-2017, excluding 1998). This source was used for the count of annual outstanding policies calculating past average premium per policy.
- EM-DAT- Publicly available database by the Centre for Research on the Epidemiology of Disasters (CRED), compiled from various official and commercial sources. This source was used to estimate past annual average total hurricane damage, total and insured.
- FEMA NFIP Redacted Claims report- This source allowed us to eliminate hurricane damage insured by the NFIP in order to reach the sum of hurricane damage insured by the private market. The sum of hurricane damage covered by the NFIP was obtained by the location and dates of reported hurricanes. NFIP hurricane claims were also used as a proxy for calculating the correlation coefficient between hurricane damages between different states.
- NAIC- Statistical Compilation of Annual Statement Information For Property/Casualty Insurance Companies- This source includes the annual damage covered by private insurers for P&C policies, used to calculate the annual coverage rate.
- U.S. Property and Casualty Insurance Industry by the NAIC Financial Analysis and Examinations Department- This source was used to calculate the insurers average cost per coverage unit.
- NAIC- Insurance Department Resources Report- This source included the annual count of P&C insurers.
- NAIC- Statistical Compilation of Annual Statement Information for Property/Casualty Insurance Companies- This source was used to obtain annual profit (utility) for the P&C sector.

1.1.2. data processing

a) Average loss: The loss amount per potential insured was compiled from multiple sources, calculated as the sum of loss from natural hazards and other (general) property damage loss per housing unit.

a.1. We calculated the general P&C loss by subtracting the Sum of insured damages from natural hazards (EM-DAT) from the total insured property loss from NAIC's report "Statistical Compilation of Annual Statement Information for Property/Casualty Insurance Companies- Incurred Loss, Defense and Cost Containment Expenses Incurred, and Adjustment and Other Expenses Incurred".

a.2. The rate of insured homes was calculated by dividing the count of insurance policies written by the sum of total housing units (the U.S. Census data).

a.3. We calculated the potential general loss by dividing the general P&C loss (a.1) by the rate of insured homes (a.2).

a.4. Dividing the general insured by the rate of insured homes resulted in the total general loss potentially insurable.

a.5. We calculated the total damages from natural hazards per potential insured by dividing the sum of insured damages from natural hazards (EM-DAT) by the count of U.S housing units (the U.S. Census data).

a.6. We added the general damage per potential insured (a.3) and natural hazards per potential insured (a.5) to reach the actual loss per insured and PCI adjusted to 2017 USD values.

b) Coverage rate –

b.1. We estimated the coverage rate for natural catastrophe insurance by using EM-DAT database, used for calculating the portion of the insured natural catastrophe loss of total natural catastrophe loss.

b.2. General homeowners' insurance penetration rate was calculated as the share of total homeowners' policies for each year divided by the total occupied housing units in the United States, according to the U.S. Census data.

b.3. We estimated the combined coverage rate as the average weighted by general damage and natural catastrophe damage for the portion of all other property insured damage.

c) Count of insurance firms was published by the U.S Insurance Department in "Resources Report" and re-published by the National Association of Insurance Commissioners (NAIC).

d) Additional costs of the insurance firms were made available from the NAIC by the report "Statistical Compilation of Annual Statement Information for Property/Casualty Insurance Companies in 2019".

e) Correlation coefficient between insured losses-e.1. We rely on insurance economics theory [1,2] and assume that the losses arising from events other than natural hazards are independent, and the correlation did not change significantly since the insurance data (losses, premiums, and policy count) is for general dwelling and homeowners' insurance.

e.2. We used insured NFIP flood claims as a proxy to calculate the correlation coefficient between storm damages, as floods are often result of intense storms.

e.3. We extracted claims data for dates and locations in which major storms were reported between the years 1977 and 2020.

e.4. We calculated the correlation coefficient between states, calculated over 25 overlapping periods, 18 years long each.

e.5. The correlation coefficient ultimately used in the analysis is for the most recent period (2002-2020).

f) Premium amounts were obtained from NAIC's report "Statistical Compilation of Annual Statement Information for Property/Casualty Insurance Companies"- Premium Written Allocated To Lines Of Direct Business, and were PCI adjusted to 2017 USD values.

g) Expected hurricane damage resulting from CC-

g.1. We used the additional hurricane damage resulting from population growth to extrapolate the population growth's impact of general and total damage.

g.2. We added the additional hurricane damage resulting from CC to the resulting population-adjusted damage predictions.

g.3. We estimated the number of potential insureds by the end of the century using the "Congressional Budget Office demographic predictions" population estimate [3] multiplied by the factor of population per housing unit [4].

g.4. The total predicted damage by the end of the century was divided by the estimated number of housing units to reach the predicted annual hurricane damage per potential insured, increased due to CC.

1.2. Model variables

Table SM-1: *Model variables values*

Symbol	Purpose	Estimate	Remarks
Exogenous Variables			
L	Expected loss per household (average annual loss)	\$875 \$1,634 \$2,026	Modeling results [5,6], adjusted by expected population & converted to households' terms
Var	variance of annual damage	\$65,754	Own calculations based on past NAIC data
C	Cost loading factor- insurance costs per unit of coverage	30% of premium	Own calculations based on past NAIC data
B	Reservation utility	\$10,000	Contract Theory- value greater than but close to 0, followed by a sensitivity analysis.
P	Damage correlation coefficient	0.04	Own calculations based on past NFIP data
Λ	Insured's absolute risk aversion	0.01105	Estimated by past data (see model calibration subsection), R^2 between 0.87 and 0.92
Ψ	Insurer's absolute risk aversion	0.00000006	Estimated by past data (see model calibration subsection), R^2 between 0.87 and 0.92
Endogenous Variable		Time-series	
W	Premium	Time Series	Own calculations based on past NAIC data
Φ	Coverage rate	Time Series	Own calculations based on EM-DAT database
N	Insurance contracts per firm	Time Series	Own calculations based on past NAIC data

1.3. Projected parameter values

Table SM-2: *Insured loss projections and estimate-related data*

	Mendelsohn & Emanuel, Minimum pressure damage model (Model A)	**Mendelsohn & Emanuel, Maximum wind damage model (Model B)**	**Dinan (Model C)**
Base Year	2010	2010	2015
Total base Damage (USD)	86,416,239,568	86,416,239,568	94,124,600,273
Emission Scenario	A1B (720 ppm)	A1B (720 ppm)	RCPs 8.5 & 4.5
Projection Year	2100	2100	2075
Added damage due to socioeconomic development (USD)	171,097,799,009	432,371,166,616	397,559,650,202
Added damage due to CC (USD)	41,600,000,000	39,500,000,000	57,000,000,000
Projection Year Damage (USD)	299,114,038,577	558,287,406,184	371,346,926,013
Population estimate	430,951,173	430,951,173	402,500,000
Household estimate	341,754,927	341,754,927	319,192,443
Expected Annual Average Loss (Projected Damage per Household, USD)	875	1,634	2,026

1.4. Risk aversion decrease-

1.4.1. To decrease future insureds' risk aversion, we used the U.S economic growth estimation by the year 2060 (lonsgest available), 1.36%.

1.4.2. The expected population growth rate for the U.S. is estimated at 0.49% by the year 2060.

1.4.3. The difference between the total and population growth rate was compounded for the end of the century and we decreased the risk aversion by the resulting factor. Here we consider economic growth as resulting from increased productivity and technological developments. The specific mix of growth drivers is out of scope for this research, as other drivers, such as immigrating population, should be considered along with other variations in population's preferences towards risk. Our analysis takes a more inclusive approach by accounting for the case uniform risk preferences in the population, to illustrate the minimal acceptable risk aversion reduction. Further research certainly can benefit from considering such potential variations.

1.5. CC mitigation factors

- Financial reports reveal that while the P&C insurance industry's underwriting activity results tend to be volatile, the premium amounts held before loss incurs and liabilities are paid are used by insurers in their investment activity, generating stable investment gain far greater than the underwriting profit. Although investment activity's results are influenced in part by the capital markets, premium reserves are a mandatory condition and the driver of any investment gain. For this reason, the potential profit amount we accounted for is the total pre-tax profit or loss, including investment gain. The average profit of an insurance company for the 10-year period ending December 2020, totaled 49,830 million USD, serves as the reference case to the utility projected under CC.
- The total greenhouse gas emission during 2020 totaled about 36 billion tonnes. In order to meet the 1.5 degrees Celsius target, as of 2019, global greenhouse gas emissions are to be reduced annually by 7.6%- about 2.7 billion tonnes (Gt) CO_2 equivalent, consistent with UNEP latest emission gap report setting the target by 2030 at 25 Gt (although emission reduction target is set for the next decade, for simplicity, we will account for this amount as the annual reduction until the end of the century) [7].
- The discount rate is an important parameter when considering the present value of the potential loss. As references, we use the United States Treasury Yield for 30 years- the longest available duration- at 2% when held to maturity (1.25% for a 10-year duration and 0% for a 12-month duration), and the 10-year average annual investment yield for the US P&C insurance industry, 3.23% as of the year 2020. To reflect the ethical aspect of the CC cost, we additionally explore the possibility of a 0% discount rate. Accordingly, the analysis was performed for the following range of discount rates: 3.23%, 2%, 0%.
- For the cost of emission reduction, we accounted for the voluntary markets' price that ranges, according to S&P, from cents to 15-20$ per tonne CO_2 equivalent [8]. The US insurance market is not obliged to offset any emissions.

1.6. Analysis boundaries

1.6.1. Residual market

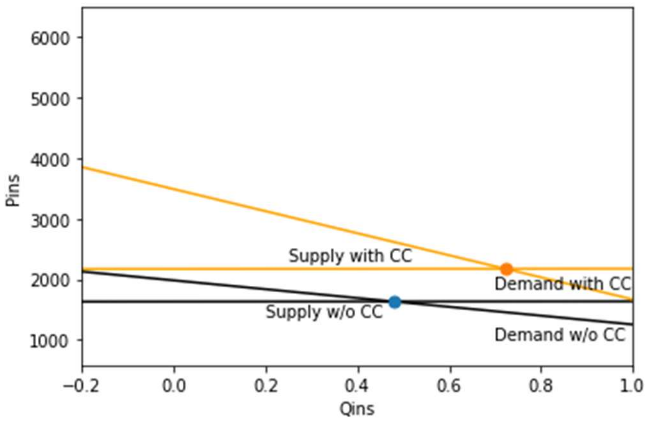
Natural catastrophe insurance in the U.S is traded, in addition to the commercial market, in the residual one. Residual markets are designed to provide insurance access to homeowners declined by the commercial markets in some high-risk regions. These insurance programs are backed by public funding and are, by definition, not acting as competitive markets. As the available NAIC reports included residual market data, we considered whether including residual market data will distort our analysis. To do that, we sampled data retrieved from The Property Insurance Plans Service (PIPSO). The data did not demonstrate any anomalies that might arise from including the residual market in this analysis and we carried out the analysis including the residual market data with no concerns of significant bias.

1.6.2. Reinsurance

For this analysis, we excluded data available in terms of net reinsurance. We find that the reinsurance scheme applied in practice does not match the reinsurance scheme described in the theoretical model. Other models for reinsurance under catastrophic risk are available in the literature, but not for the synergy of both insurance markets- primary and reinsurance- under catastrophic risk.

2. Additional Results

Figure SM-1 illustrates the combined impact of the same mean damage increase as in figure 1 (main text), in addition to a 250% increase in the hurricane damage interannual variability, resulting from unmitigated CC. The increased interannual variability changes the slope of the demand curve and further shifts the demand higher with individuals willing to pay more, while the supply is further reduced. Under these conditions, the coverage level is expected to increase, providing the market structure and regulation that allows a substantial entry of insurance providers to the market. The expected economic growth is well below the insurance industry growth that can support the equilibrium in this case, raising doubts of its feasibility, however this constraint is outside the scope of this analysis. If feasible, this equilibrium is expected to result in producer utility declining by 20%, as presented in table 1, main text.



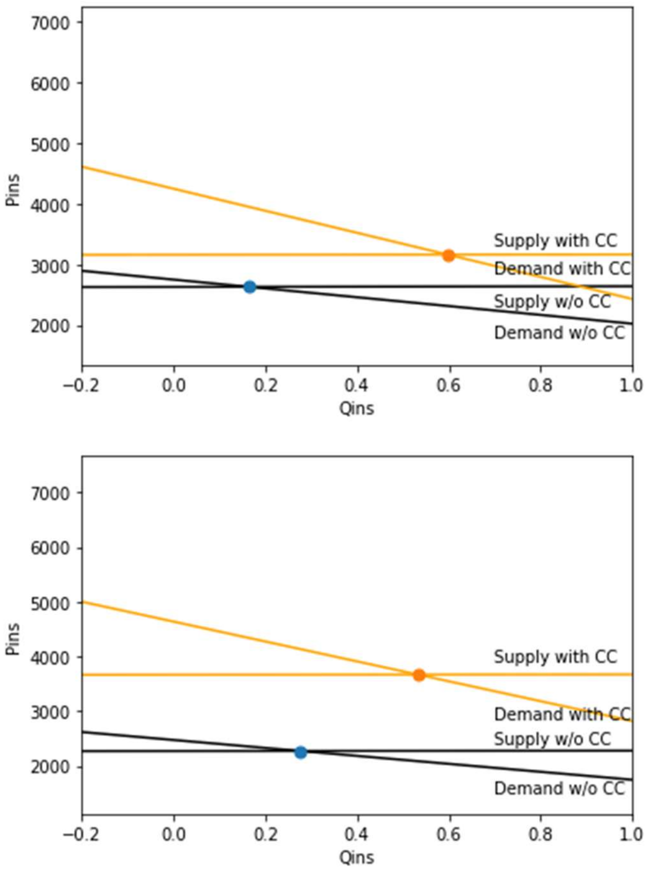
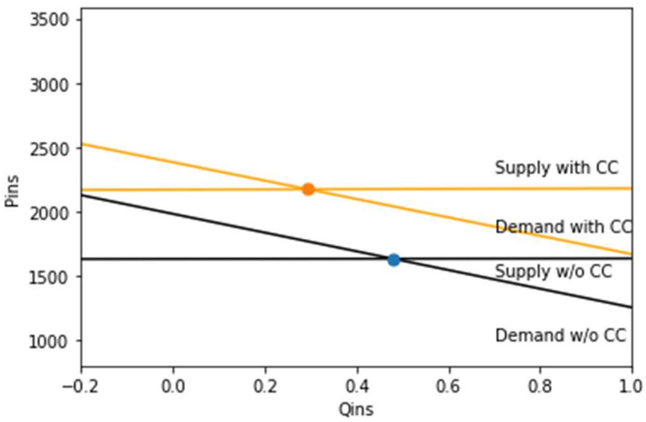


Figure SM-1: *Projected shift in market equilibrium attributable to CC driven increase in mean and variance of damage (premium, coverage level and number of firms)*

Figure SM-2 illustrates the additional impact of decreased risk aversion. We use the same damage prediction resulting from CC, including a substantial (250%) increase in the interannual variability, that moderates the impact of mean damage increase, as in Fig SM-2. The resulting equilibrium is characterized by a negative coverage rate, indicating a market failure.



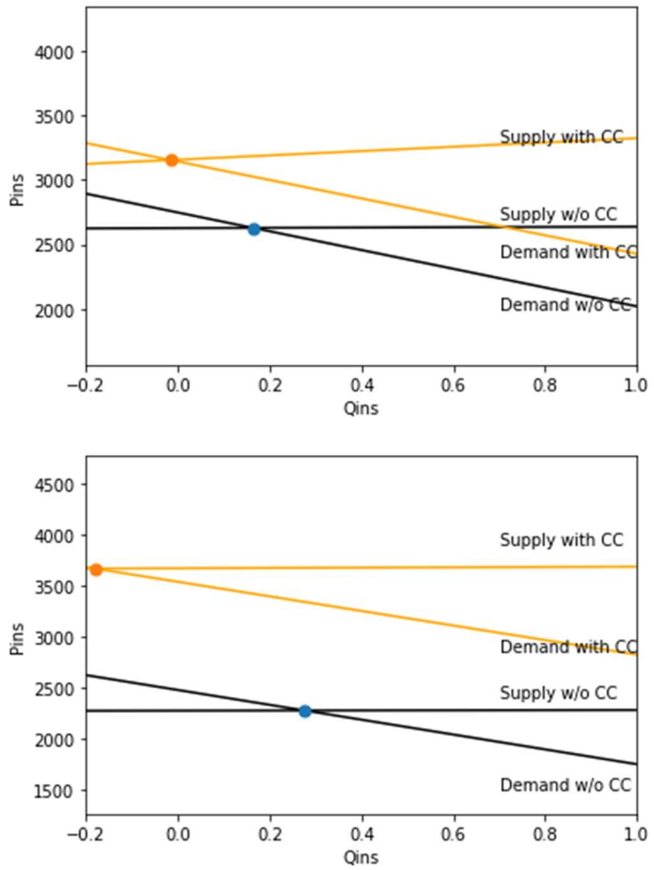


Figure SM-2*: Projected shift in market equilibrium attributable to CC driven increase in mean and variance of damage under decreased risk aversion*

3. Limitation

It is important to recall that this analysis was made nationwide, due to the nature of the risk and the structure of the US insurance market. Global factors influence both the risk and the capital market, and hurricane risk has broader implications beyond coastal regions due to the practice of cross-subsidizing insurance premiums across states. However, the global scale limits the ability to address the meaningful variability of vulnerability and the demand for insurance through risk aversion, as well as potentially lead to a mean effect. We therefore conducted our analysis for the entire U.S., as a domain relatively homogenous in its economic activity to analyze the entire market and is exposed to a dominant risk of hurricane damage.

The data retrieved from EM-DAT database contains the cost of all hurricane damages, including the commercial and public sectors. However, we did not find substantial differences between including these data and using homeowners' coverage rate alone as a proxy of covered damage. It is also worth noting that EM-DAT is not a complete database of all insured damages, and future research that builds on cooperating with the insurance industry itself can have a meaningful contribution to both research and the insurance sector.

The theoretical model emphasizes insurers' ability to diversify risk as a critical factor in the supply of natural catastrophe insurance, as expressed in the model through the correlation coefficient between any two insureds. In this analysis, we used the correlation for any two states as a proxy and did not account for future changes in this correlation, as the literature lacks climatic predictions of CC effects on the geographical variation. Emerging climate research of CC-induced changes in storms' tracks may allow further research to address variation in the spatial distribution of hurricane damages and the resulting change in risk correlation.

The limitation of our model is its theoretical treatment of income elasticity. The model does not account for budget constraints or the availability of substitute products. As a result, the insureds are assumed to accept the insurance price even in scenarios where risks are fully correlated, negating any advantage that insurance might offer over simply saving money.

Data availability is another potential limitation, as it may be biased in describing solely the trend observed in this time frame, not capturing any trends, or driving forces that may span in other periods.

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