

PENSION FUND EXPOSURE TO UNINSURABLE ASSETS UNDER EXTREME CLIMATE SCENARIOS

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Abstract:

This analysis examines whether global catastrophe conditions are associated with retirement savings growth, addressing the distinction between financial expansion and disaster resilience. Annual retirement savings aggregates for OECD and other reporting jurisdictions are combined with worldwide catastrophe statistics for 2010 to 2019. Separate ordinary least squares regressions use nine growth observations, HC3 standard errors and sensitivity checks involving alternative measures, individual year omissions and linear trend adjustment. Catastrophe frequency exhibits a negative association with asset growth, whereas economic and uninsured losses exhibit positive associations; all confidence intervals include zero. Uninsured losses represent approximately 66 percent of pooled economic losses, yet no stable negative relationship with retirement savings growth emerges. Several coefficients change sign when individual years are omitted. Valuation changes, contributions and recovery finance remain plausible but unidentified transmission channels. The contribution clarifies why aggregate asset accumulation cannot establish protection against catastrophe exposure or asset uninsurability. Pension oversight should connect holdings, hazard locations and insurance eligibility before translating aggregate historical relationships into portfolio risk assessments.

Key Words: Retirement Savings; Natural Catastrophes; Insurance Protection Gap; Financial Resilience; Exploratory Regression.

1. Introduction:

Growth in retirement savings assets does not establish that the investments supporting future pension payments are protected from catastrophe risk. Physical destruction can weaken corporate earnings, damage collateral and interrupt contributions while financial market gains simultaneously increase aggregate retirement wealth. Disaster consequences also extend beyond directly damaged property through disrupted production, employment and recovery finance. These distinctions matter because expanding financial aggregates can coexist with losses concentrated in particular holdings or locations. Assessing retirement system vulnerability therefore requires separating physical damage, financial transmission and observed asset accumulation (Botzen et al., 2019; Kousky, 2014).

Disaster risk theory provides a basis for connecting disruption with financial valuation. Changing expectations about disaster severity can influence risk premiums and asset prices, while climate damage can reduce the economic value underlying financial claims (Dietz et al., 2016; Gabaix, 2012). These mechanisms establish a plausible relationship between catastrophe conditions and retirement portfolios, but they do not imply that annual aggregate asset growth measures catastrophe exposure directly. Anticipated losses, realized damage and changes in accumulated retirement wealth represent distinct outcomes. Their relationships depend on exposure, valuation responses and the timing of recovery.

Economic and financial interconnections complicate this relationship. Disruptions affecting suppliers can reduce customer output and market value, particularly when specialized inputs cannot be replaced readily (Barrot & Sauvagnat, 2016). Production networks can transmit concentrated shocks into broader economic fluctuations, with the extent of propagation depending on the structure of interdependence (Carvalho & Tahbaz-Salehi, 2019). Financial connections can similarly distribute climate policy shocks across institutional portfolios, although policy transition and physical catastrophe risks involve different initiating mechanisms (Battiston et al., 2017). These contributions make exposure mapping essential: worldwide catastrophe totals do not identify which retirement portfolios hold affected claims.

Three dimensions organize the present analysis: catastrophe frequency, economic loss severity and the insurance protection gap. Frequency captures recurring disruption, while severity represents reported monetary damage. These dimensions need not coincide because a small number of events can generate substantial losses. Economic responses differ across disaster types, sectors and development conditions, challenging a uniform relationship between recorded events and subsequent outcomes (Fomby et al., 2013; Loayza et al., 2012). Persistent losses may also emerge gradually rather than appearing fully within the year of the disaster. Evidence from cyclone exposure indicates that national income effects can extend across long horizons, making contemporaneous financial growth an incomplete representation of economic consequences (Hsiang & Jina, 2014).

Insurance introduces a distinction between destruction and the resources available for recovery. Comparable asset damage can produce different consumption and investment consequences depending on borrowing capacity, compensation and reconstruction arrangements. Economic resilience therefore concerns the ability to contain subsequent losses and restore activity, rather than the initial damage alone (Hallegatte, 2014). However, uninsured losses do not establish that insurance was unavailable. Coverage gaps can reflect affordability, purchasing decisions, exclusions or restricted supply. Uncertainty about exposure and vulnerability further complicates the assessment of climate related financial protection (Kunreuther et al., 2013). The protection gap must consequently remain conceptually separate from asset uninsurability.

The dependent outcome requires similar precision. Aggregate retirement savings growth combines investment valuations, currency movements and net financial flows. It differs from portfolio returns, funding adequacy and losses on exposed holdings. Evidence that equity prices can incorporate drought information incompletely further cautions against treating observed market performance as a complete representation of environmental risk (Hong et al., 2019). The reviewed literature establishes plausible transmission mechanisms, but it does not resolve whether annual worldwide catastrophe conditions correspond consistently to growth in combined retirement savings assets. The unresolved question concerns the informational value of an aggregate association when the geographical and institutional distributions of exposure remain unobserved.

This analysis aims to assess whether catastrophe frequency, economic loss severity and the insurance protection gap are associated with annual retirement savings asset growth. It examines each dimension separately and evaluates the stability of the estimated relationships across alternative measures and annual samples. The dataset combines worldwide catastrophe statistics with retirement savings aggregates for OECD countries and other reporting jurisdictions from 2010 to 2019. Ten annual observations support descriptive analysis, while nine observations support growth regressions. Separate ordinary least squares specifications and exploratory sensitivity checks enable transparent comparisons without implying causal identification.

The findings reveal uncertain associations rather than a stable directional pattern. Frequency has a negative baseline coefficient, whereas severity and uninsured losses have positive coefficients. All confidence intervals span both directions, and several estimates change sign when individual years are omitted. The contribution is therefore a bounded empirical assessment of the distinction between aggregate financial expansion and catastrophe protection. The analysis shows why the coexistence of substantial uninsured losses and expanding retirement assets cannot establish portfolio resilience. Its international relevance concerns the interpretation of financial aggregates wherever reporting populations differ from the locations and institutions bearing physical losses.

2. Theory, Conceptual Framework and Hypotheses Development:

This analysis draws on disaster risk theory, financial network theory and economic resilience to explain how catastrophe losses may affect retirement savings asset growth. Pension institutions hold claims on firms, infrastructure and governments whose revenues depend on functioning economic systems. Physical destruction can therefore reach retirement portfolios through lower earnings, weaker debt repayment and changes in asset valuations. Gabaix in 2012 shows how changing disaster severity can influence risk premiums and asset prices. Acemoglu et al. in 2012 explain how production linkages transmit local disruptions into aggregate fluctuations. Together, these mechanisms establish a theoretical connection between catastrophe risk and financial wealth without assuming that every disaster produces measurable pension losses.

Climate risk provides a relevant application of these mechanisms. Dietz et al. in 2016 estimate potential reductions in financial asset values under alternative warming conditions. Battiston et al. in 2017 demonstrate how direct exposures and financial interconnections can transmit climate policy shocks across portfolios. These contributions concern different risk channels: physical damage and policy induced repricing. Neither establishes the relationship examined here, but both explain why retirement portfolios may face risks extending beyond directly owned physical assets. Hong et al. in 2019 further find that equity prices can respond incompletely to drought information, indicating that environmental risks need not enter valuations immediately.

The empirical framework distinguishes natural catastrophe risk burden from direct exposure to uninsurable assets. Risk burden comprises catastrophe frequency, economic loss severity and the insurance protection gap. Retirement savings asset development describes the accumulation and distribution of assets across reporting jurisdictions. Annual growth in total reporting assets provides the primary outcome. OECD assets, assets in other reporting jurisdictions, combined assets and the OECD share provide descriptive context. These measures are observed aggregates or arithmetic transformations, rather than validated indicators of a latent construct. The available catastrophe series includes geophysical hazards, while the pension series covers retirement savings vehicles beyond pension funds. Consequently, the framework supports an aggregate association analysis rather than direct measurement of climate specific portfolio exposure.

Catastrophe frequency captures the recurrence of disruptive events. Repeated interruptions may prevent firms and households from restoring productive capacity between shocks. Lower earnings can

weaken investment valuations, while interrupted employment can reduce pension contributions. Frequency therefore represents cumulative disruption pressure rather than the financial magnitude of individual events. Annual event count provides the principal measure. Changes in that count and an index relative to 2010 describe its evolution without supplying additional independent information.

The expected relationship with retirement savings growth depends on where events occur and which assets pension institutions hold. Frequent events concentrated in economically connected locations may transmit losses across firms and securities. Geographical diversification, adaptation and limited portfolio exposure can weaken this relationship. Reconstruction spending and transfers can also support recovery. The theoretical expectation is therefore conditional on financial exposure and incomplete compensation.

Fomby et al. in 2013 find that economic responses differ across disaster types, sectors and development conditions. Cavallo et al. in 2013 find that apparently persistent output losses following extreme disasters depend substantially on accompanying political disruptions. This evidence challenges a universal negative relationship and supports a conditional hypothesis. Its extension to retirement savings growth remains a theoretical proposition rather than an established empirical result.

H1: Higher Natural Catastrophe Frequency is Associated With Lower Annual Retirement Savings Asset Growth When Affected Economic Activities are Financially Relevant to Retirement Portfolios and Recovery Mechanisms Do Not Fully Offset Disruption

Economic loss severity captures the monetary consequences of catastrophes rather than their recurrence. A single event can destroy substantial productive capital even when annual event frequency remains low. Damage to infrastructure, inventories and collateral can reduce operating income and weaken repayment capacity. Annual economic losses provide the principal severity measure, while average loss per event and annual loss growth describe concentration and change.

The proposed transmission mechanism operates through both investment values and contributions. Lower corporate earnings can reduce equity valuations, while damaged collateral and weaker borrowers can affect debt securities. Employment losses can constrain pension inflows. However, economic damage does not translate proportionately into retirement asset losses. Portfolio diversification, public reconstruction and replacement investment can distribute or offset part of the initial burden. Nominal losses also reflect the value of exposed assets and price changes, so they cannot serve as a pure measure of physical hazard intensity.

Loayza et al. in 2012 show that growth responses differ by disaster severity and economic sector, with potential benefits from moderate events failing to extend consistently to severe events. Klomp in 2014 finds that natural disasters can weaken bank stability, with outcomes depending on disaster scope and institutional conditions. These findings support capital destruction and financial fragility as plausible channels, but neither directly measures retirement savings outcomes. The anticipated negative relationship therefore remains subject to portfolio composition and recovery capacity.

H2: Greater Natural Catastrophe Economic Loss Severity is Associated With Lower Annual Retirement Savings Asset Growth When Capital Destruction and Financial Impairment Exceed Recovery Related Gains

The insurance protection gap captures the portion of economic losses that insurance does not compensate. It differs from severity because comparable physical losses can generate different financial consequences depending on risk transfer. Uninsured losses measure the absolute gap, the uninsured share measures its relative size, and uninsured loss per event describes its concentration. These measures identify retained losses rather than proving that affected assets were uninsurable.

The institutional mechanism concerns how households and firms finance recovery. Without insurance compensation, affected actors may use savings, increase borrowing or postpone investment. These responses can weaken business earnings and the capacity to maintain retirement contributions. Hallegatte in 2014 distinguishes initial asset destruction from an economy's ability to contain subsequent consumption losses and rebuild. This distinction explains why similar disasters can produce different financial consequences.

Insurance coverage also reflects behaviour and institutional arrangements. Kunreuther and Pauly in 2015 show that insurance decisions for rare events can respond to experienced losses and emotions. A protection gap can therefore arise from limited demand, affordability or coverage choices, as well as restricted insurance supply. Public compensation and access to credit can weaken the proposed negative association. Kunreuther et al. in 2013 further explain why climate risk assessment must accommodate uncertainty about exposure, vulnerability and outcomes. These arguments support treating the protection gap as a financial transmission condition rather than a direct measure of uninsurability.

H3: A Larger Natural Catastrophe Insurance Protection Gap is Associated With Lower Annual Retirement Savings Asset Growth When Alternative Recovery Finance Does Not Compensate for Uninsured Losses

The conceptual framework links catastrophe frequency, economic loss severity and the insurance protection gap to annual retirement savings asset growth through proposed disruption, valuation and recovery finance channels. These channels explain the hypotheses but are not measured mediators. No composite risk score, moderator or nonlinear specification is imposed. Economic losses and uninsured

losses are mechanically related, so the dimensions should not be interpreted as independent sources of variation without further assessment. The ten annual observations from 2010 to 2019 yield nine available growth observations, supporting exploratory associations rather than a fully controlled causal model. Market returns, exchange rates, contributions and benefit payments remain potential alternative explanations. The hypotheses permit negative, null or contrary findings, and any revisions made after examining results must be identified as exploratory.

The attachment supports an exploratory analysis of aggregate catastrophe risk and retirement savings growth. It does not measure pension holdings in uninsurable assets or losses under extreme climate scenarios. Source publication and extraction dates fall outside the permitted citation window, so their actual metadata remain in the accompanying workbook rather than being assigned earlier dates.

3. Data:

This analysis establishes the provenance, coverage and construction of the annual catastrophe and retirement savings measures. It distinguishes observed source values from calculated indicators and defines the samples available for descriptive and exploratory analysis.

3.1 Data Sources, Population, and Sample Construction:

The dataset combines two published statistical sources. The OECD retirement savings series supplies assets in OECD countries and other reporting jurisdictions, identified by Figure 1.5, panels A and B, in the source report. Atlas Magazine supplies annual natural catastrophe event counts, economic losses and insured losses, attributing the underlying figures to Swiss Re Institute. The workbook identifies these sources as R2 and R1, respectively, and preserves their URLs, publication information, access date and extraction locations. The NGFS resource listed in the workbook provides methodological context only; no scenario observations enter the analysis.

The observation window extends from 1 January 2010 to 31 December 2019. The unit of analysis is the calendar year. The dataset therefore forms a single aggregate annual time series, rather than a country panel, fund panel or portfolio dataset. Retirement savings assets are stocks measured at year end. Catastrophe losses and event counts describe events occurring during each calendar year. Annual matching supports comparisons between contemporaneous catastrophe conditions and changes in retirement savings assets, although it cannot establish the timing of individual portfolio responses.

The substantive target population comprises retirement portfolios holding assets exposed to catastrophe related disruption. The accessible frame instead comprises published retirement savings aggregates and worldwide catastrophe statistics. These populations do not coincide: the geographical distribution of pension holdings is unavailable, and the catastrophe totals include locations outside the reporting retirement savings jurisdictions. The number of underlying pension funds, portfolios, securities and insured properties cannot be verified from the attachment.

All ten annual records within the specified window were retained. No sampling of funds or countries occurred. The period boundary derives from the supplied research scope, while the exploratory estimation choices were established during the present analysis without a preregistration record. Growth calculations remove the first annual record because the workbook does not supply the preceding asset stock. Table 1 distinguishes source records, merged observations and model observations.

Table 1: Sample construction

Stage	Units	Observations	Reason or rule
Retirement savings source extract	Two reporting aggregates	10 annual rows, containing 20 asset values	OECD and other reporting jurisdictions
Catastrophe source extract	One worldwide aggregate	10 annual rows, containing 30 values	Event count, economic loss and insured loss
Duplicate year exclusions	Not applicable	0	No repeated year keys
Unmatched year exclusions	Not applicable	0	Both sources cover every selected year
Merged descriptive sample	One combined annual series	10	One record per year from 2010 to 2019
Initial growth observation excluded	One year	1	The preceding asset stock is unavailable
Each exploratory baseline model	One combined annual series	9	Complete contemporaneous observations from 2011 to 2019
Each individual year omission check	One combined annual series	8	One observation removed from the baseline sample
Linear trend sensitivity analysis	One combined annual series	9	Same observations as the baseline models

3.2 Data Integration, Cleaning, and Quality Assurance:

Calendar year provides the sole integration key. The intended relationship is one annual retirement savings record matched to one annual catastrophe record. Verification identified ten distinct, consecutive years in each extract, with no unmatched years, duplicate keys or increase in the merged observation count. The original source values were retained separately from the analytical transformations. This separation makes the numerical results traceable to their inputs, consistent with the reproducibility principles discussed by Peng in 2011.

No frequency conversion, fiscal calendar adjustment or trading day alignment was required. Retirement savings amounts expressed in USD trillions were multiplied by 1,000 to obtain USD billions. Catastrophe losses expressed in USD millions were divided by 1,000. No additional exchange rate conversion was performed. The analysis did not apply a deflator because a consistent price basis across the extracted series was not established. Consequently, monetary comparisons describe reported USD amounts rather than changes in real physical damage or purchasing power.

The dataset is a retrospective compilation of published historical values. It is not an archive of information available to investors at each observation date. The extraction record also does not establish a common revision vintage across all catastrophe years. No forecasting exercise or claim about investor information sets is therefore made. The source snapshot and transformation script preserve the information needed to reproduce the calculations, following the computational documentation approach outlined by Sandve et al. in 2013.

All extracted asset values, loss amounts and event counts are present for all ten years. Annual asset growth, event count changes and economic loss growth are unavailable for 2010 because their preceding observations are absent. These values remain missing rather than being replaced by zero. No interpolation, imputation, external matching, winsorization or trimming was applied.

Verification confirmed positive asset stocks and event counts, nonnegative losses, insured losses no greater than economic losses, and insurance shares within the interval from zero to 100 percent. Insured and uninsured shares sum to 100 percent, subject to numerical precision. Extreme observations were retained because their magnitude alone does not establish an error. Original Swiss Re annual publications were not independently reconciled against the Atlas republication, leaving source transcription and revision uncertainty unresolved.

3.3 Variable Measurement, Construction, and Validation:

Natural catastrophe risk burden comprises frequency, economic loss severity and the insurance protection gap. The baseline frequency measure is annual event count. Economic losses represent severity, while uninsured losses represent the absolute protection gap. The uninsured share provides an alternative measure of relative coverage. These measures are observed statistics or arithmetic transformations, not reflective indicators of an estimated latent construct.

Retirement savings asset development comprises OECD assets, assets in other reporting jurisdictions, combined assets, annual combined asset growth and the OECD share of combined assets. Annual asset growth is the regression outcome. The remaining measures describe market scale and composition; they are not treated as five independent outcomes or combined into a composite score.

The implemented constructions are defined in Equations 1 to 5.

$$A_t = 1000[O_t + R_t]$$

In Equation 1, A_t denotes combined retirement savings assets in USD billions, O_t denotes OECD assets in USD trillions, R_t denotes assets in other reporting jurisdictions in USD trillions, and t denotes calendar year.

$$g_t = 100 \left[\frac{A_t}{A_{t-1}} - 1 \right]$$

In Equation 2, g_t denotes annual asset growth expressed as a percentage, and A_{t-1} denotes the preceding year end asset stock.

$$U_t = E_t - I_t$$

In Equation 3, U_t , E_t and I_t denote uninsured, economic and insured catastrophe losses, respectively, in USD billions.

$$Q_t = 100 \frac{U_t}{E_t}$$

In Equation 4, Q_t denotes the uninsured share of economic losses, expressed as a percentage.

$$S_t = 100 \frac{O_t}{O_t + R_t}$$

In Equation 5, S_t denotes the OECD share of combined reporting retirement savings assets, expressed as a percentage.

Table 2: Variable dictionary

Variable or indicator	Analytical role	Definition and construction	Source and identifier	Unit and frequency	Transformation and direction	Missing value rule	Coverage and limitation
Catastrophe event count	Frequency predictor	Reported annual event count	R1, annual year row	Events, annual	Higher values indicate more recorded events	No missing values	Ten years; includes geophysical hazards

Variable or indicator	Analytical role	Definition and construction	Source and identifier	Unit and frequency	Transformation and direction	Missing value rule	Coverage and limitation
Annual event count change	Alternative frequency descriptor	Current countless preceding count	R1, calculated	Events, annual	Positive values indicate increased frequency	First year unavailable	Nine changes
Frequency index	Alternative frequency descriptor	Current count divided by 2010 count, multiplied by 100	R1, calculated	Index, annual	2010 equals 100	No missing values	Rescaling of event count, not an independent measure
Economic losses	Severity predictor	Published economic losses divided by 1,000	R1, economic loss column	USD billion, annual	Higher values indicate larger reported losses	No missing values	No common constant price adjustment
Economic loss per event	Alternative severity descriptor	Economic losses divided by event count	R1, calculated	USD billion per event, annual	Higher values indicate greater average recorded loss	No missing values	Does not describe the distribution across events
Economic loss growth	Alternative severity descriptor	Current loss divided by preceding loss, less one, multiplied by 100	R1, calculated	Percent, annual	Positive values indicate increasing losses	First year unavailable	Nine changes; sensitive to the preceding loss level
Uninsured losses	Protection gap predictor	Equation 3	R1, calculated	USD billion, annual	Higher values indicate larger retained losses	No missing values	Does not establish uninsurability
Uninsured share	Alternative protection gap predictor	Equation 4	R1, calculated	Percent, annual	Higher values indicate lower insurance coverage	No missing values	Depends on the geographical and hazard composition of losses
Uninsured loss per event	Alternative protection gap descriptor	Uninsured losses divided by event count	R1, calculated	USD billion per event, annual	Higher values indicate greater retained loss per recorded event	No missing values	Arithmetic average across heterogeneous events
OECD retirement savings assets	Outcome descriptor	Published OECD aggregate	R2, Figure 1.5, panel A	USD trillion, annual year end	Higher values indicate larger recorded assets	No missing values	Broader than pension funds alone
Other reporting assets	Outcome descriptor	Published aggregate outside the OECD reporting group	R2, Figure 1.5, panel B	USD trillion, annual year end	Higher values indicate larger recorded assets	No missing values	Incomplete coverage of jurisdictions outside the OECD
Combined retirement savings assets	Outcome descriptor	Equation 1	R2, calculated	USD billion, annual year end	Higher values indicate greater aggregate scale	No missing values	Retains source rounding
Annual asset growth	Regression outcome	Equation 2	R2, calculated	Percent, annual	Higher values indicate faster nominal USD asset accumulation	First year unavailable	Combines valuation, currency and net flow influences
OECD asset share	Outcome descriptor	Equation 5	R2, calculated	Percent, annual year end	Higher values indicate greater OECD concentration	No missing values	Measures reporting composition, not portfolio geography
Insured losses	Construction input	Published insured losses divided by 1,000	R1, insured loss column	USD billion, annual	Higher values indicate larger compensated losses	No missing values	Used to construct uninsured losses
Insured share	Accounting cross check	Insured losses divided by economic losses, multiplied by 100	R1, calculated	Percent, annual	Higher values indicate greater coverage	No missing values	Complements the uninsured share

3.4 Analytical Framework, Identification, and Reproducibility:

The analysis is descriptive and exploratory associational. It estimates separate contemporaneous relationships between retirement savings asset growth and each catastrophe dimension. Equation 6 defines the implemented baseline specification.

$$g_t = \alpha_j + \beta_j X_{jt} + \varepsilon_{jt}$$

In Equation 6, g_t denotes annual asset growth, α_j denotes the intercept in specification j , X_{jt} denotes the selected catastrophe predictor, β_j denotes its unadjusted association with asset growth, and ε_{jt} denotes the residual. Event count is scaled by ten events, while economic and uninsured losses are scaled by USD 100 billion. The alternative uninsured share specification uses increments of ten percentage points.

Each specification uses ordinary least squares with an intercept and nine observations. HC3 standard errors address sensitivity to heteroskedasticity and leverage. Reported confidence intervals use a student t reference with seven residual degrees of freedom. These intervals remain illustrative because this reference distribution is not exact under general heteroskedasticity or serial dependence.

No controls, fixed effects, interactions or instrumental variables enter the models. The available data do not identify market returns, net pension contributions, benefit payments, exchange rate effects or

the geographical alignment of holdings and disasters. Accordingly, the coefficients cannot identify causal effects or isolate the conditions stated in the hypotheses. Statistical uncertainty is interpreted alongside magnitude and design limitations, consistent with Wasserstein and Lazar in 2016.

Exploratory sensitivity checks compare absolute uninsured losses with the uninsured share, remove each year individually, omit 2017, compare Pearson and Spearman associations, and remove a linear trend from both predictor and outcome. These choices are disclosed rather than presented as preregistered decisions, addressing the analytical flexibility concerns examined by Simmons et al. in 2011. Reporting alternative specifications follows the transparency rationale of Steegen et al. in 2016, although the implemented checks do not constitute a complete multiverse analysis.

Definitions and calculations align on calendar year and USD reporting units. Unresolved differences concern source vintages, price bases, geographical exposure and the distinction between catastrophe losses and pension portfolio losses. The replication package preserves the source snapshot, construction code, analytical dataset and numerical outputs.

4. Methods:

4.1 Research Design, Identification, and Model Specification

This analysis uses a retrospective observational design to examine associations between natural catastrophe conditions and retirement savings asset growth. Calendar year is the unit of analysis. The descriptive sample contains ten observations from 2010 to 2019, while the regression sample contains nine observations from 2011 to 2019. Table 1 documents sample construction, and Table 2 provides variable definitions. The initial year is excluded from growth estimation because its preceding asset stock is unavailable.

The estimand is the unadjusted linear association between annual asset growth and each catastrophe dimension within the observed period. Variation comes from annual differences in event frequency, economic losses and uninsured losses. There is no treatment assignment or separate comparison group. The design cannot isolate catastrophe effects from market valuations, exchange rates, contributions, benefit payments or concurrent economic developments. Worldwide catastrophe totals also remain unmatched to the geographical distribution of retirement portfolio holdings.

Equation 6 defines the baseline specification. Each regression includes an intercept and one contemporaneous predictor. Event count is scaled by ten events, while economic and uninsured losses are scaled by USD 100 billion. An alternative specification expresses the protection gap as the uninsured share, scaled by ten percentage points. Coefficients therefore represent percentage point differences in annual asset growth for these increments.

Separate regressions preserve the distinction between frequency, severity and retained losses without interpreting their coefficients as mutually adjusted effects. Economic and uninsured losses share an accounting relationship through Equation 3, creating substantial measurement overlap. All specifications use the same nine observations and contain no controls, fixed effects, interactions or lagged predictors. Their coefficients describe exploratory associations rather than causal effects or direct exposure to uninsurable assets.

4.2 Data Processing, Estimation, and Statistical Inference:

Processing begins with the preserved source extracts. Retirement savings amounts are converted from USD trillions to USD billions, while catastrophe losses are converted from USD millions to USD billions. Combined assets, annual growth, uninsured losses and coverage shares are constructed using Equations 1 to 5. Records are matched by calendar year and restricted to observations with defined outcome growth. No imputation, interpolation, winsorization or trimming is applied. Valid extreme observations remain in the sample.

Measurement checks assess temporal alignment, unit consistency, valid denominators, positive asset stocks and event counts, and the relationship between economic and insured losses. Descriptive calculations include valid counts, means, sample standard deviations, medians and ranges. These procedures evaluate observed statistics and arithmetic transformations rather than latent constructs. Ordinary least squares coefficients are calculated using Equation 7:

$$\hat{\theta}_j = [X_j' X_j]^{-1} X_j' g$$

Here, $\hat{\theta}_j$ contains the estimated intercept and slope for specification j , X_j contains a column of ones and the scaled predictor, and g contains annual asset growth observations. The prime denotes matrix transposition.

The implementation uses Python with NumPy for numerical calculations and SciPy for distribution functions, correlation measures and an independent verification of regression slopes. The archived materials identify these dependencies but do not preserve their original execution versions. Calculations are deterministic, require no random seed and assign equal weight to each annual observation.

HC3 covariance estimates adjust residual contributions for heteroskedasticity and observation leverage:

$$\hat{V}_{j,HC3} = B_j \left[\sum_{t=1}^n \frac{\hat{\epsilon}_{jt}^2}{[1 - h_{jt}]^2} x_{jt} x_{jt}' \right] B_j$$

Here, $\hat{V}_{j,HC3}$ is the coefficient covariance matrix, B_j is the inverse of $X_j'X_j$, $\hat{\varepsilon}_{it}$ is the residual, h_{it} is observation leverage, x_{jt} contains the intercept and scaled predictor, and n is the estimation sample size.

Standard errors are obtained from the covariance matrix diagonal. Approximate 95 percent confidence intervals use a Student t reference with seven residual degrees of freedom. This convention does not guarantee exact coverage under heteroskedasticity or temporal dependence. Small sample concerns remain consequential, as emphasized by Imbens and Kolesár (2016). Their recommended degrees of freedom adjustment is not implemented. HC3 also does not correct serial correlation, measurement error or omitted explanatory factors. Interpretation therefore considers coefficient magnitude, uncertainty and design limitations rather than significance thresholds alone (Wasserstein & Lazar, 2016).

4.3 Diagnostics, Sensitivity, and Reproducibility:

Diagnostic assessment examines measurement overlap, functional association and observation sensitivity. Pearson correlations describe linear relationships, while Spearman correlations assess dependence on ranking rather than numerical distances. The correlation between economic and uninsured losses evaluates overlap between alternative explanatory measures. R squared describes in sample fit without establishing predictive performance. A residual Durbin-Watson statistic is calculated descriptively, without a formal critical value decision or a claim of residual independence.

Sensitivity checks address measurement choice, influential years and shared temporal movement. Replacing absolute uninsured losses with the uninsured share retains the same nine observations, isolating a measurement change from a sample change. Removing each year individually produces eight observation regressions and identifies dependence on particular annual records. The specification excluding 2017 is presented separately without treating that year as erroneous. Removing a linear trend from both predictor and outcome uses all nine observations and assesses whether coefficient direction persists after this adjustment.

All checks are exploratory. No preregistration is documented, and processing rules are not changed to obtain preferred signs or significance results. This disclosure addresses concerns about analytical flexibility identified by Simmons et al. (2011). Reporting alternative constructions follows the transparency rationale of Steegen et al. (2016), without claiming a complete multiverse analysis. Table 4 presents baseline estimates and uncertainty, while Table 5 reports sensitivity in coefficient direction and magnitude.

The replication package preserves the supplied workbook, extraction and estimation code, analytical dataset, descriptive statistics and sensitivity outputs. Separating source inputs from calculated measures supports computational traceability and reproduction (Peng, 2011; Sandve et al., 2013). Published aggregate statistics are used without collecting identifiable participant information. No additional ethical approval or unrestricted redistribution licence is claimed.

The method provides a transparent assessment of aggregate associations using established tools. Limited temporal coverage, inconsistent source price bases, missing financial drivers and unmatched geographical exposure constrain interpretation. Neither diagnostic agreement nor sensitivity checks establish causality, mediation, portfolio resilience or direct exposure to uninsurable assets.

5. Findings:

This analysis examines the associations of catastrophe frequency, economic loss severity and the insurance protection gap with retirement savings asset growth. Descriptive results establish the scale and composition of the observed risks, while regression estimates assess the proposed relationships. Sensitivity analysis evaluates whether their direction and magnitude remain stable across alternative measures and annual samples.

5.1 Sample Characteristics and Descriptive Results:

The descriptive sample contains ten annual observations from 2010 to 2019, combining retirement savings assets in OECD and other reporting jurisdictions with worldwide catastrophe statistics. The regression sample contains nine observations from 2011 to 2019 because calculating annual asset growth requires the preceding asset stock. All source variables are complete within the observation window. No observations were imputed or removed as outliers.

Table 3: Descriptive statistics

Variable	Valid Observations	Mean	SD	Median	Minimum	Maximum
OECD assets, USD trillion	10	38.00	6.29	37.50	29.30	49.20
Other reporting assets, USD trillion	10	1.35	0.26	1.40	0.90	1.70
Combined assets, USD billion	10	39,350.00	6,522.31	38,900.00	30,200.00	50,900.00
Annual asset growth, percent	9	6.14	6.36	4.94	-3.04	14.13
OECD asset share, percent	10	96.58	0.29	96.63	96.04	97.02
Catastrophe events	10	187.60	11.02	189.50	169.00	204.00
Economic losses, USD billion	10	217.65	121.03	183.57	93.04	478.70

Variable	Valid Observations	Mean	SD	Median	Minimum	Maximum
Insured losses, USD billion	10	73.95	43.80	56.64	31.71	154.04
Uninsured losses, USD billion	10	143.69	83.56	115.03	61.33	333.48
Uninsured share, percent	10	65.93	8.11	67.79	50.09	77.91

Combined retirement savings assets increased from USD 30.20 trillion to USD 50.90 trillion, representing cumulative nominal USD growth of 68.54 percent. Annual growth nevertheless varied from -3.04 percent to 14.13 percent. OECD jurisdictions accounted for an average of 96.58 percent of reported assets, indicating that the combined outcome predominantly reflects developments within this reporting group.

Catastrophe frequency and economic severity followed different patterns. The highest economic loss occurred in 2011, reaching USD 478.70 billion, whereas the largest event count occurred in 2019, with 204 recorded catastrophes. Event count therefore provides an incomplete representation of financial damage. This distinction accords with Fomby et al. in 2013, who identify heterogeneous economic responses across disaster types and settings.

Across the observation window, reported economic losses totalled USD 2,176.45 billion, compared with insured losses of USD 739.52 billion. The resulting uninsured amount reached USD 1,436.93 billion, equivalent to 66.02 percent of pooled economic losses. The arithmetic mean of annual uninsured shares was slightly lower, at 65.93 percent, because the pooled calculation assigns greater weight to years with larger losses. These figures describe worldwide catastrophe protection gaps rather than losses attributable to retirement portfolios.

5.2 Catastrophe Risk and Retirement Savings Asset Growth:

Separate ordinary least squares regressions relate annual asset growth to each catastrophe dimension using the same nine observations. Table 4 reports coefficients, HC3 standard errors and approximate confidence intervals. Coefficients measure percentage point differences in annual asset growth for the stated predictor increments.

Table 4: Exploratory associations with retirement savings asset growth

Relationship	Predictor Increment	Coefficient	HC3 Standard Error	Approximate 95 Percent Confidence Interval	R squared
H1: Catastrophe frequency	Ten additional events	-0.315	2.787	-6.904 to 6.274	0.003
H2: Economic loss severity	USD 100 billion additional economic loss	0.957	3.320	-6.895 to 8.808	0.037
H3: Absolute insurance protection gap	USD 100 billion additional uninsured loss	1.245	7.049	-15.424 to 17.914	0.028
Alternative protection gap measure	Ten percentage point increase in uninsured share	0.584	7.238	-16.532 to 17.701	0.005

The catastrophe frequency coefficient is negative, consistent with the direction proposed in H1. Ten additional recorded events correspond to approximately 0.31 percentage points lower annual asset growth. However, the confidence interval accommodates substantial negative and positive associations, and the specification explains less than one percent of observed growth variation. H1 remains unresolved because the expected direction is not estimated with sufficient precision.

Economic loss severity produces a positive coefficient. An additional USD 100 billion in economic losses corresponds to approximately 0.96 percentage points higher annual asset growth. Although this direction differs from H2, the confidence interval extends from -6.90 to 8.81 percentage points. The evidence therefore neither supports the hypothesized negative association nor establishes a positive relationship. Loayza et al. in 2012 similarly show that disaster consequences vary across economic structures and recovery conditions, cautioning against interpreting aggregate damage as a uniform financial effect.

The absolute insurance protection gap coefficient is also positive. An additional USD 100 billion in uninsured losses corresponds to approximately 1.25 percentage points higher asset growth, with a confidence interval from -15.42 to 17.91 percentage points. Substituting the uninsured share yields a coefficient of 0.58 percentage points per ten percentage point increase in that share. Both estimates are imprecise. H3 remains unresolved because neither construction establishes a stable negative association.

The positive severity and protection gap coefficients do not demonstrate that catastrophe losses improve retirement savings outcomes. These unadjusted relationships combine disaster conditions with contemporaneous asset valuation changes, contribution flows and currency effects. Cavallo et al. in 2013 show that estimated disaster consequences can depend materially on accompanying institutional events.

The present estimates likewise cannot separate catastrophe transmission from other influences on aggregate financial outcomes.

5.3 Sensitivity and Stability of the Estimates:

Removing each observation in turn changes both the magnitude and, for several specifications, the direction of the estimated relationships. Table 5 reports this sensitivity results alongside estimates obtained after omitting 2017 and removing a linear trend from both predictor and outcome.

Table 5: Exploratory sensitivity analysis

Predictor and scaling	Baseline coefficient	Minimum coefficient after individual year omissions	Maximum coefficient after individual year omissions	Coefficient excluding 2017	Coefficient after removing a linear trend
Catastrophe frequency, ten events	-0.315	-2.421	0.868	-0.378	-0.916
Economic losses, USD 100 billion	0.957	-0.112	3.907	-0.112	1.212
Uninsured losses, USD 100 billion	1.245	0.073	7.991	0.110	1.857
Uninsured share, ten percentage points	0.584	-6.365	2.041	2.041	1.553

The frequency coefficient ranges from -2.42 to 0.87 percentage points after individual year omissions. Economic severity estimates range from -0.11 to 3.91 percentage points. The uninsured share coefficient exhibits the widest directional instability, ranging from -6.36 to 2.04 percentage points. These changes indicate that the estimated associations depend materially on annual sample composition.

Omitting 2017 changes the economic severity coefficient from 0.96 to -0.11 percentage points and reduces the absolute uninsured loss coefficient from 1.25 to 0.11 percentage points. The positive baseline relationships therefore depend partly on a year combining substantial catastrophe losses with strong retirement savings asset growth. Absolute uninsured loss coefficients remain positive across individual year omissions, but their magnitude varies substantially and does not support the proposed negative relationship.

Removing a linear trend leaves the frequency coefficient negative and the severity and protection gap coefficients positive. This adjustment does not produce a common negative pattern across the three dimensions. The uninsured share also yields a Pearson correlation of 0.068 and a Spearman correlation of -0.083 with asset growth. Their small magnitudes and different signs provide no consistent evidence of a monotonic relationship.

Economic losses and uninsured losses have a correlation of 0.982 within the estimation sample. Their close alignment reflects the accounting construction of uninsured losses and limits their interpretation as distinct sources of variation. Separate specifications avoid entering these overlapping measures simultaneously, but they cannot identify independent severity and coverage mechanisms.

6. Discussion:

Expanding retirement savings assets can coexist with substantial catastrophe losses, but this coexistence does not establish financial resilience. Table 4 shows a negative frequency coefficient alongside positive severity and protection gap coefficients, with every confidence interval spanning both directions. Interpreted through Equation 6, these estimates describe uncertain aggregate associations rather than evidence that disasters improve pension outcomes. The analytical contribution lies in distinguishing physical loss exposure from the behaviour of accumulated financial assets: their movements need not coincide within the same year or reporting population. Botzen et al. in 2019 distinguish direct destruction from indirect economic consequences, reinforcing the importance of this separation. The present results extend that distinction to retirement savings measurement, showing why neither aggregate asset expansion nor a weak catastrophe coefficient provides a sufficient basis for judging portfolio protection.

The transmission mechanism remains an interpretation rather than an identified mediation pathway. Equation 2 combines valuation changes, currency movements and net retirement savings flows within a single growth measure, while Equation 6 estimates their unadjusted association with catastrophe conditions. Table 4 therefore cannot reveal whether contributions, corporate earnings or recovery finance transmit the observed relationships, and differences between its separate coefficients do not demonstrate partial or full mediation. Barrot and Sauvagnat in 2016 identify losses transmitted through supplier relationships, particularly where inputs are difficult to replace. Their evidence explains how retirement portfolios could face indirect damage through investee firms even when directly owned assets remain unaffected. What changes here is the interpretation of weak aggregate associations: they leave such transmission unresolved rather than establishing that diversification or recovery mechanisms have neutralized it.

The protection gap results distinguish loss composition from causal pathway dominance. The pooled uninsured share of approximately 66 percent describes the allocation of reported economic losses between insured and uninsured amounts. Equations 3 and 4 establish this accounting relationship, but they do not decompose a total effect on retirement savings. Likewise, the correlation of 0.982 between economic and uninsured losses reflects substantial measurement overlap rather than evidence that retained losses dominate other transmission channels. Table 4 cannot rank mechanisms because its estimates use different predictor scales and remain imprecise. Kousky in 2014 reviews how disaster consequences depend on exposure, economic conditions and adaptation. Against that background, the contribution is a sharper conceptual boundary: uninsured losses measure compensation gaps, while uninsurability requires evidence about coverage availability, exclusions and eligibility. Conflating these constructs would attribute an institutional mechanism that the data do not identify.

The results also reveal a structural mismatch between where losses occur and where financial outcomes are measured. Table 3 shows that OECD jurisdictions account for more than 96 percent of reported retirement savings assets, whereas catastrophe losses represent worldwide events. Equation 5 measures reporting concentration, not the geographical location of portfolio exposures. Consequently, the positive severity coefficients could reflect geographical mismatch or unrelated financial developments, although neither explanation is established. Carvalho and Tahbaz-Salehi in 2019 show why network structure matters for translating individual disruptions into aggregate fluctuations. This perspective makes exposure mapping central to the interpretation of pension risk. Table 5 strengthens that conclusion: coefficient changes after individual year omissions demonstrate that the short aggregate series cannot provide stable evidence about institutional protection. These results identify an information requirement for risk oversight, rather than documenting a regulatory failure.

International evidence clarifies why the uncertain pension associations should not be read as a contradiction of documented disaster damage. Hsiang and Jina in 2014 identify persistent income losses following cyclone exposure in both richer and poorer countries, whereas the present outcome is contemporaneous nominal retirement savings growth. Boehm et al. in 2019 trace international disruption through identifiable production linkages, while the present dataset does not match holdings to affected firms or locations. These differences concern outcomes, horizons and exposure identification, not demonstrated differences in national resilience. Tables 4 and 5 therefore support a practical change in assessment: pension trustees and supervisors should distinguish aggregate asset growth from exposure specific protection and should avoid calibrating catastrophe loss assumptions from these coefficients. Further analysis should connect security holdings, physical locations, insurance terms and recovery finance, then separate valuation and contribution channels. That design would permit genuine mediation and pathway decomposition while testing whether the relationships in Equation 6 persist once exposure is measured directly.

7. Conclusion and Implications:

Expanding retirement wealth can coexist with substantial disaster damage, making financial growth an insufficient basis for judging protection. The estimated relationships remain uncertain and sensitive to individual years. Their differing directions establish neither insulation from disruption nor benefits from destruction. The contribution lies in distinguishing accumulated financial claims from the location, compensation and transmission of physical losses. This distinction qualifies the application of disaster risk theory to retirement systems: exposure alignment must precede interpretation of aggregate associations. The broader literature similarly separates direct destruction, indirect economic consequences and the capacity to finance recovery (Botzen et al., 2019; Hallegatte, 2014). Pension trustees should assess vulnerable holdings and insurance arrangements alongside asset growth. Supervisors should encourage reporting that connects ownership, physical locations and coverage terms while distinguishing valuation changes from contributions and benefit payments. Institutions can improve risk registers by separating uninsured losses from unavailable insurance and recording recovery financing arrangements. These recommendations address the information gaps revealed by the analysis rather than a proven dominant mechanism. Better aligned information would support decisions concerning beneficiaries' future income without treating imprecise historical coefficients as reliable stress assumptions. Financial expansion and catastrophe vulnerability therefore require separate but connected assessments before institutional resilience can be judged.

The short annual series creates opportunities for analysis using longer histories and observations for individual funds. Matching holdings to hazard locations would improve exposure measurement, while consistent price bases would strengthen monetary comparisons. Separating returns, contributions, benefits and currency effects would clarify outcome formation. Insurance eligibility and compensation records would distinguish unavailable coverage from decisions to remain uninsured. Comparative designs could then assess delayed responses, institutional differences and recovery finance. Research on production networks and persistent disaster consequences provides a basis for investigating these transmission pathways without assuming that aggregate associations identify them (Carvalho & Tahbaz-Salehi, 2019; Hsiang & Jina, 2014).

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