Tuesday July 11th, 2017

Pathfinder Webinar on Systemic and Multi-Line Risk Research

Centre for
Risk Studies

UNIVERSITY OF CAMBRIDGE
Judge Business School

4pm BST/ 11am EST / 8am PST

Logistics

- Webinar is being recorded, and will be made available to attendees later this week
- If you are unable to hear the audio component
  a) Check that your volume is turned on
  b) Check that Adobe Connect volume is turned up
  c) Email Kayla Strong at k.strong@jbs.cam.ac.uk
- If we have time, we will address questions at the end of the call
  - Please email questions during the to Kayla Strong (k.strong@jbs.cam.ac.uk)
- We have sent out a feedback form – we would be grateful if you could fill it out and submit it at the end of the presentation
  - This will help guide and prioritize our future research

The Pathfinder Webinar:
Exploring Current Activities at the Centre for Risk Studies

- Overview of three research tracks being pursued by the Centre for Risk Studies.
- Attendance by Centre for Risk Studies support network
  - Global Exposure Accumulation and Clash Committee
  - Formed as a result of the Multi Line Data Schema Development Project
- Identify projects which are outside of current partnership scheme.
- Aid in developing an holistic view of the Centre for Risk Studies projects and capabilities

Meeting Agenda and Speakers

- The Potential for Multi-Line Insurance Clash from Solar Storm Events

Simon Ruffle
Director of Research & Innovation
Cambridge Centre for Risk Studies

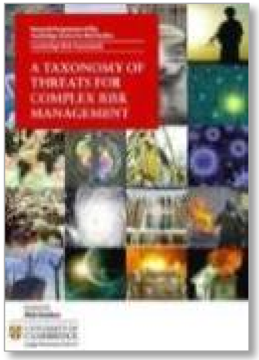
- Natural Catastrophes and their Potential Impact on Financial Markets

Dr. Andrew Coburn
Director of the External Advisory Board, Centre for Risk Studies & SVP, RMS

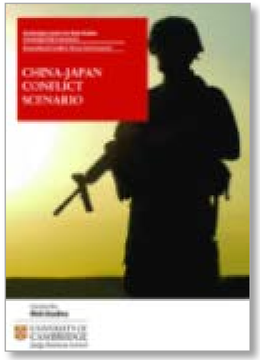
- The Insurance Gap and Benefits of Insurance in Improving Catastrophe Recovery

Jessica Tsang, Research Assistant, Cambridge Centre for Risk Studies

CCRS Research Outputs: Publications Available Online

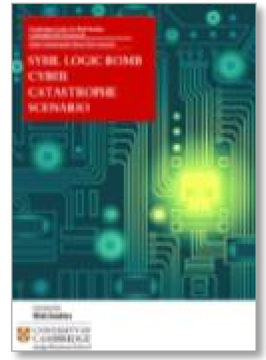


Taxonomy of Threats

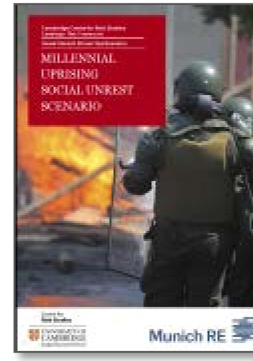


Geopolitical Conflict
Emerging Risk Scenario

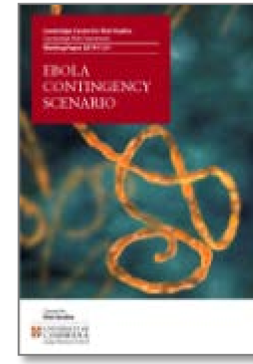
Pandemic
Emerging Risk Scenario



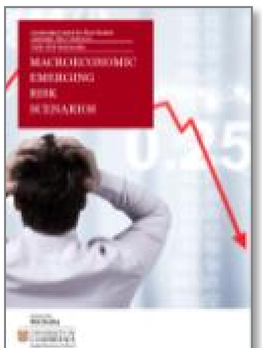
Cyber Catastrophe
Emerging Risk Scenario



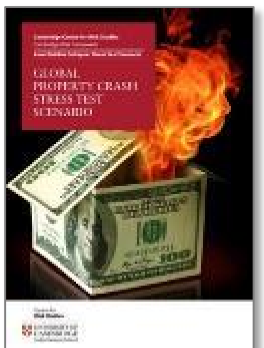
Social Unrest
Emerging Risk Scenario



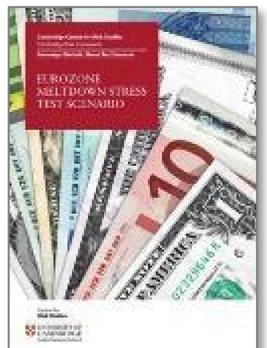
Ebola
Emerging Risk Scenario



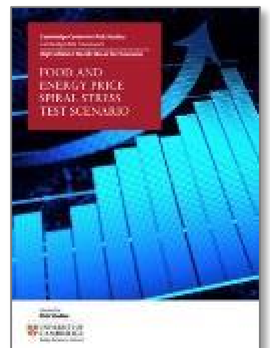
Financial Catastrophes



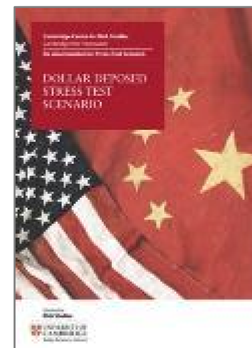
Global Property Crash
Financial Risk Scenario



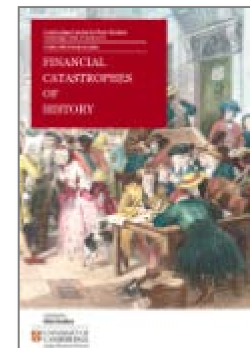
Eurozone Meltdown
Financial Risk Scenario



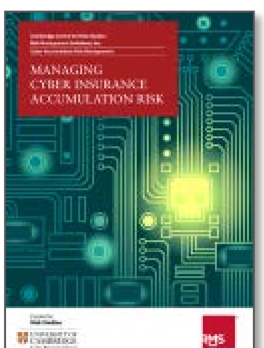
High Inflation
Financial Risk Scenario



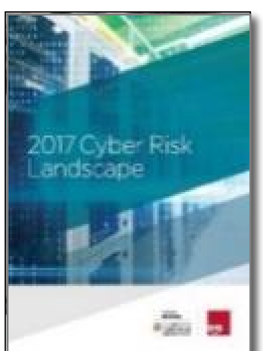
Dollar Dethroned
Financial Risk Scenario



Historical Crises
Financial Risk

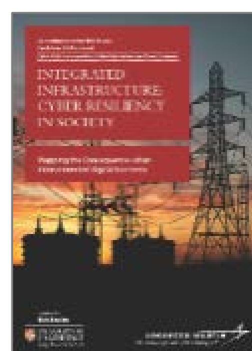


Cyber Accumulation
Insurance Risk Report

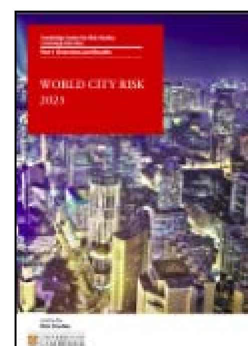


Cyber Risk 2017
Report

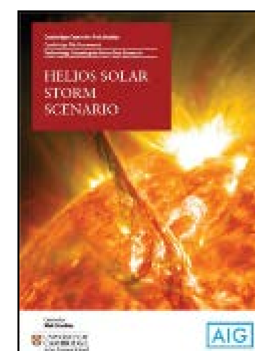
Business Blackout
Lloyds Emerging Risk Report



Infrastructure
Cyber Attack UK



World City Risk 2025
Lloyds Co-Branded Report



Solar Storm
Emerging Risk Scenario

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The Potential for Multi-Line Insurance Clash from Solar Storm Events

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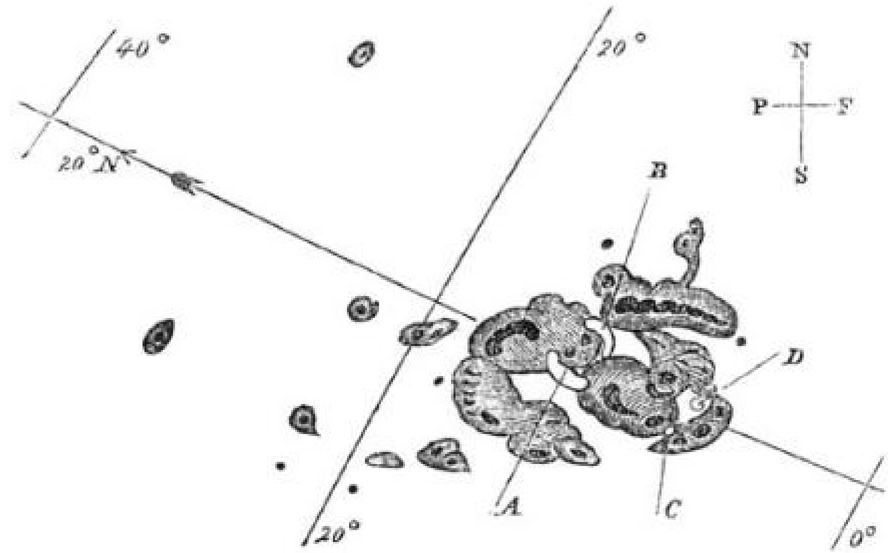
Simon Ruffle
Director of Research & Innovation
Cambridge Centre for Risk Studies

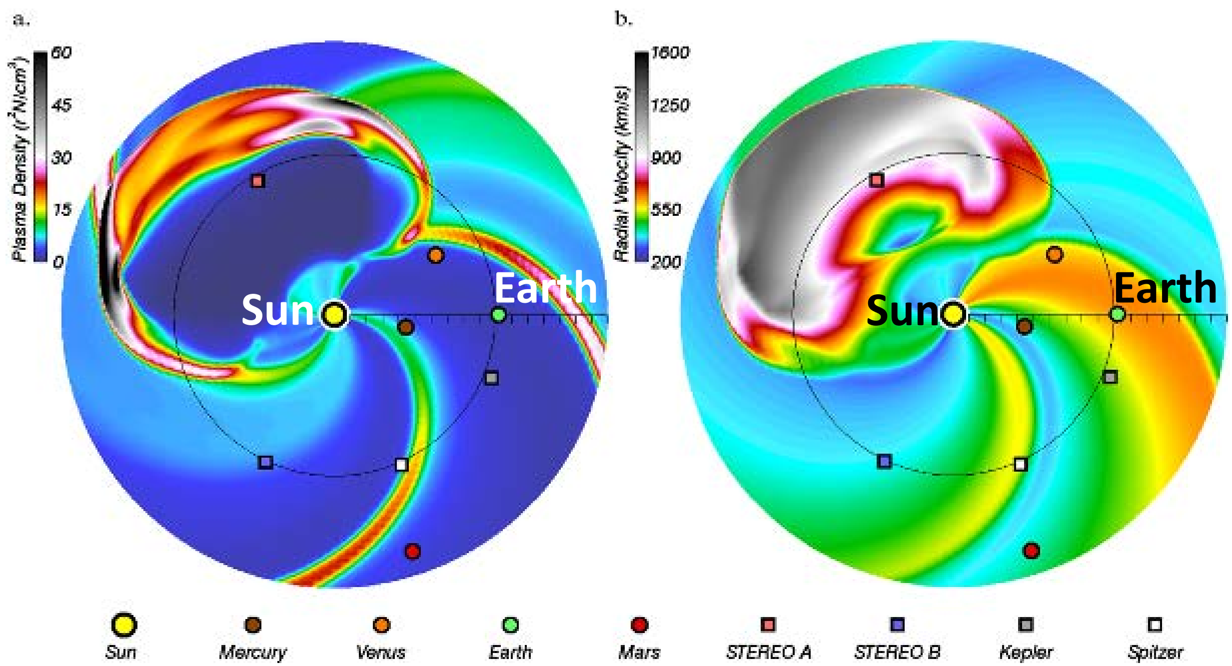
The 1859 Carrington Event

- September 1–2, 1859
- Identified as the largest solar storm on record
- Auroras were seen around the world
- As far south as the Caribbean
- Injuries to telegraph operators from electric shocks



Sunspots of 1 September 1859 as sketched by Richard Carrington

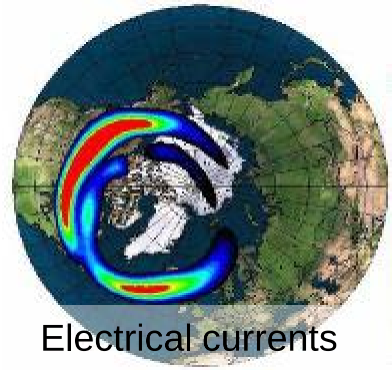
23rd July 2012 Coronal Mass Ejection

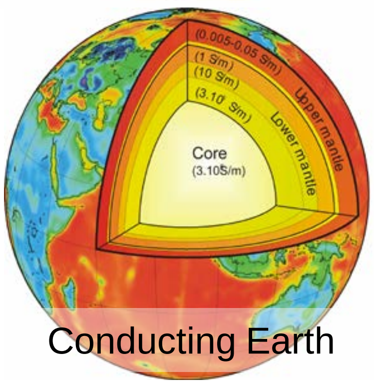


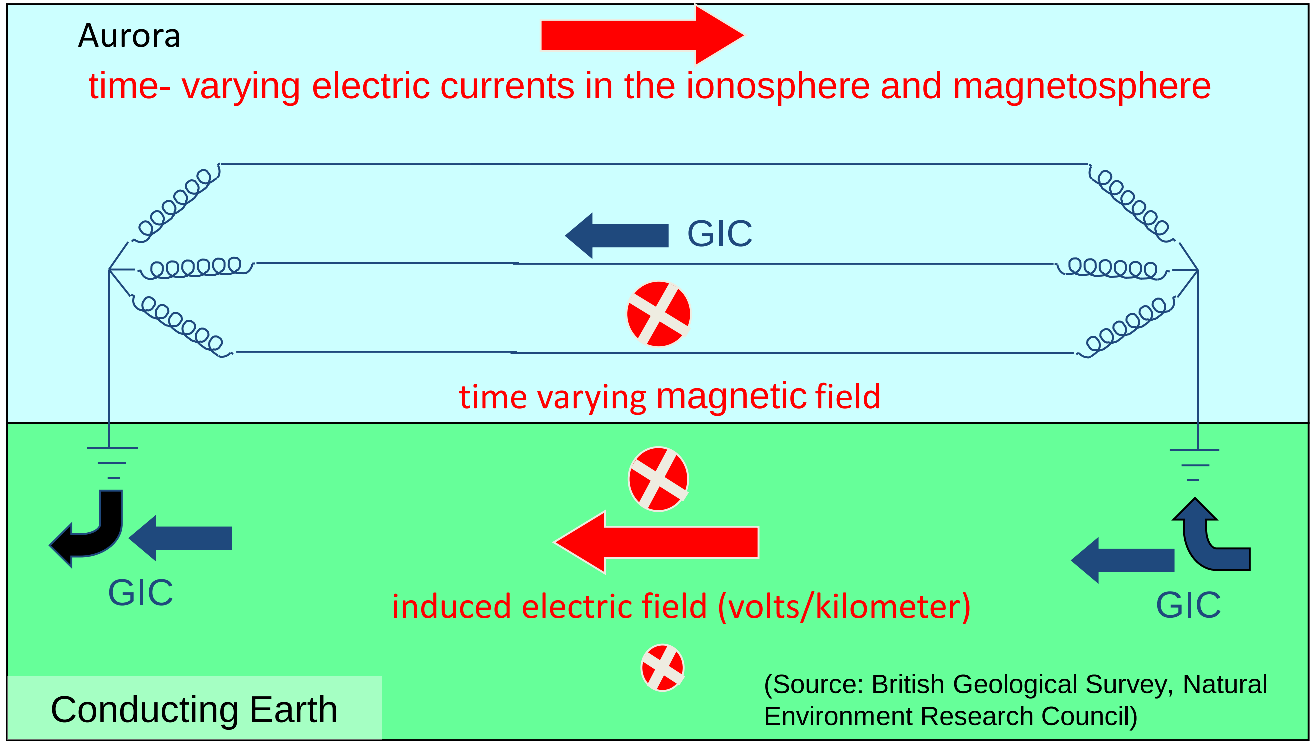
(Source: Baker et all., 2013)

- On **23 July 2012**, a CME occurred that was well measured by spacecraft, but **missed the Earth**.
- Observations of the properties of the CME indicate that it was **larger than the most extreme event witnessed in the modern era**.
- The effect on the Earth's magnetic field would have been larger than the 1859 Carrington event, and significantly larger than the 1989 'Quebec' storm.
- Propagation speeds were ~2500 km/s, and the CME would have taken 19 hours to arrive in the vicinity of the Earth.

Why Does Space Weather Cause Grid Problems?



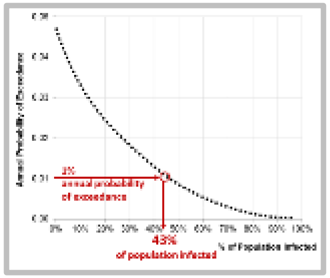




- Geomagnetically induced currents (GIC) cause
  - Half-cycle saturation of transformers, voltage harmonics, overheating, increased reactive power demand, and/or drop in system voltage.
  - Leading to transformer burn-out (in rare big storms) or shortened transformer lifetimes (due to many smaller storms).

EHV Transformers are Vulnerable, and Big

Scenario Development Process

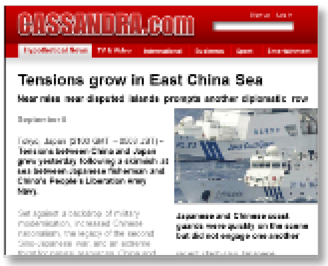


Historical Context

A justification and context for a 1% annual probability of occurrence worldwide

Timeline & Footprint

Sequencing of events in time
and space in hypothetical scenario



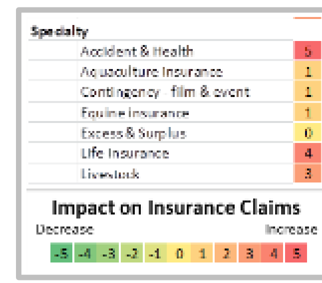
CASSANDRA.com

Tensions grow in East China Sea

Japanese and Chinese coast guards were quickly on the scene but did not engage one another

Narrative

Detailed description of events
3-4 variants of key assumptions for sensitivity testing



Specialty	
Accident & Health	5
Aquaculture Insurance	1
Contingency - film & event	1
Equine insurance	1
Excess & Surplus	0
Life Insurance	4
Livestock	3

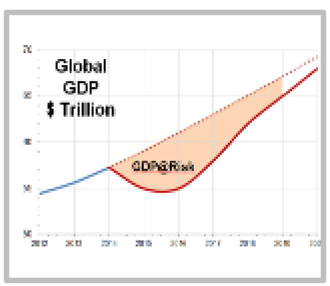
Impact on Insurance Claims

Decrease Increase

-5	-4	-3	-2	-1	0	1	2	3	4	5

Loss Assessment

Metrics of underwriting loss across many
different lines of insurance business



Macroeconomic Consequences

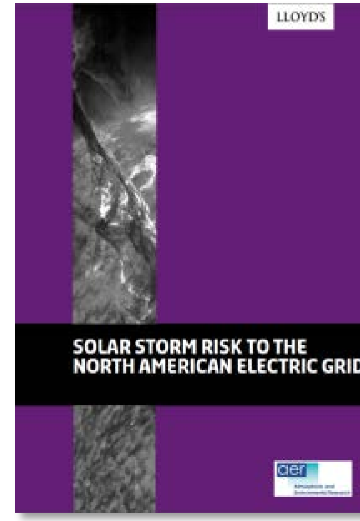
Quantification of effects on
Industry sectors and the global economy

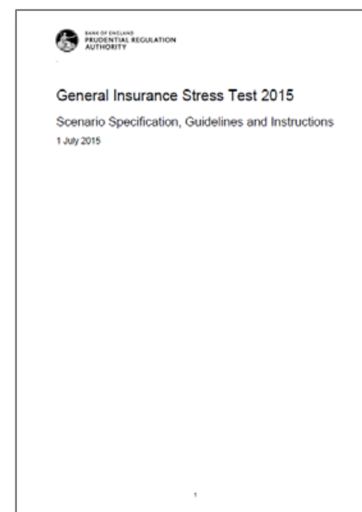
Insurance Industry Impact

Total loss estimation of scenario
for the insurance industry

Context from the Regulators

- Lloyd's Report: Solar Storm Risk to the North American Electric Grid
  - Proposes 1 in 150 year Carrington-level scenario where EHV transformers are destroyed resulting in extended outage.
  - US population at risk 20-40m, 16 day to 1-2 year duration
- PRA General Insurance Stress Test 2015
  - Proposes power transformers knocked out
  - Causing power outages in US and UK
  - At least 1 month to replace transformers



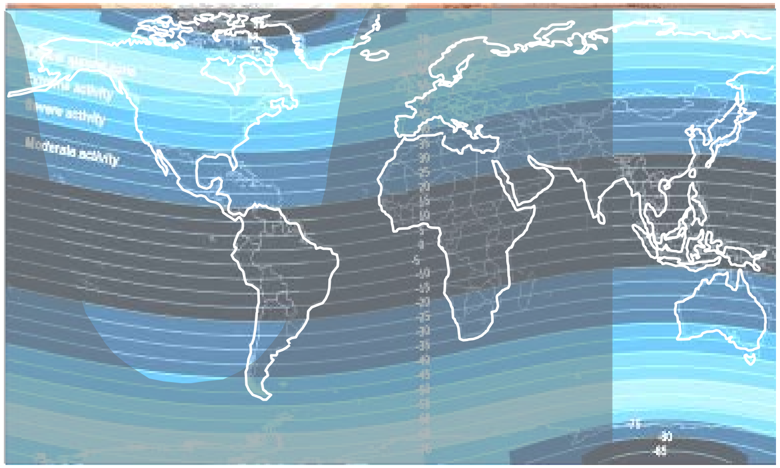

General Insurance Stress Test 2015

Scenario Specification, Guidelines and Instructions

1 July 2015

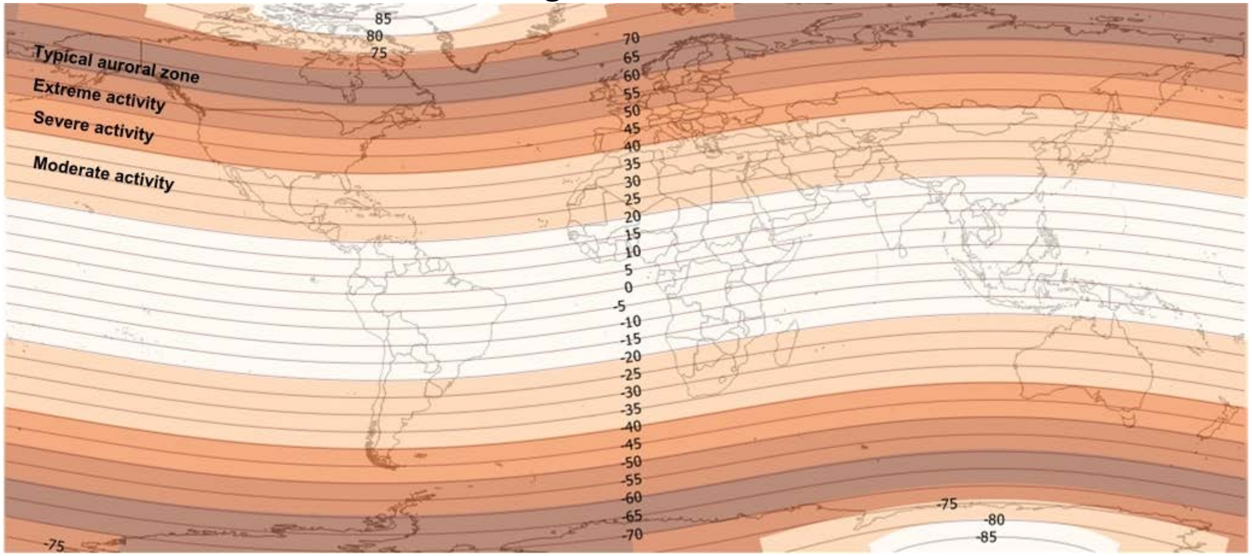
Helios Solar Storm Hypothetical Catastrophe Event

- 3 scenario variants (S1, S2, X1)
- Solar storm causes charged particles to be deposited directly above North America
- GIC intensifications in US take place down to 20° magnetic latitude
- 6% of EHV transformers in US power grid are damaged
- Damage to 132 EHV transformers (11 severe)
- Damage to satellites
- 28% of US population suffer initial outage
- Produces a power outage across United States, taking 6-12 months to fully restore
- Total shock for US $ Bn: $474bn - $2,693bn
- US Insurance Industry Loss: $55bn – $338bn.



CME Arrives at Earth

- Satellite systems provide 30-60 minutes warning of incoming CME
  - The CME bombards Earth's magnetosphere, forcing a reconfiguration between the southward-directed interplanetary magnetic field and Earth's geomagnetic field
- The second CME reaches Earth in only 20 hours
  - Consequently billions of tonnes of gas containing charged particles intensify the shock compression
  - Particles are accelerated along the magnetotail, back towards Earth being deposited in the auroral ionosphere and magnetosphere on the night side of the Earth, directly above North America
  - Dst measurements = ~ -1000nT
  - dB/dt measurements = ~ 5,000nT/m at 50° magnetic latitude

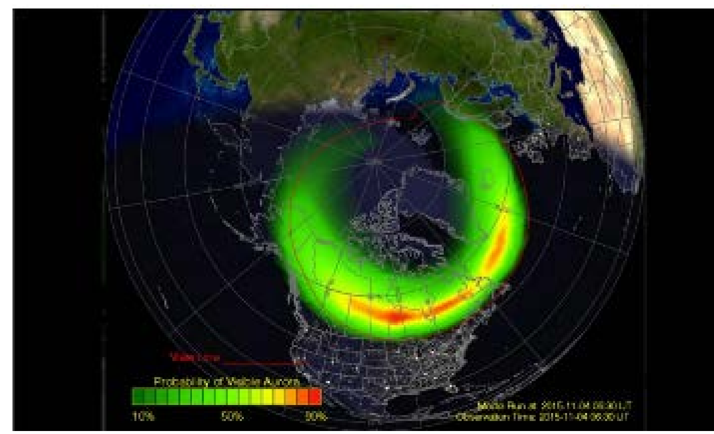


Notes: The contour lines on this map were generated using the World Magnetic Model (WMM) 2015 shape file from NOAA (Chulliat, 2014).

Geomagnetic Storm on Earth

- Auroral oval forced equatorward by 15° magnetic latitude
- Numerous substorms take place every few hours on the dawn-to-dusk side of the Earth due to the highly dynamic nature of the auroral electrojet roughly 100km above ground
- Geomagentic effects
  - Rapid change in the magnetic field rate-of-change down to 50° magnetic latitude
  - Ring current intensifications take place down to 20° magnetic latitude

(Source: Svein-Magne Tunli, https://commons.Wikimedia.org)

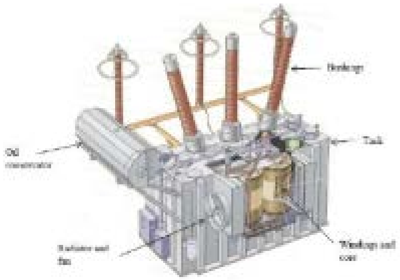


(Source: Space Weather Prediction Centre, National Oceanic and Atmospheric Administration, www.swpc.noaa.gov/)

EHV Transformers Damaged

- Due to intense electrojet and ring current activity key electricity network assets are placed under significant strain
- Extra High Voltage (EHV) transformers are at risk
- Due to lack of adequate warning utility operators do not have time to fully implement emergency procedures
  - Some EHV transformers automatically trip off and others have to be manually shut off
  - Grid instability ensues causing a complete voltage collapse
  - In some cases, degradation to windings and insulation cause failure within 48 hours
- Total US EHV transformers damage distribution

EHV Transformer



S1	D0 Not affected	D1 Tripped off	D2 Minor damage	D3 Major damage	D4 Destroyed
No. of transformers with spare	159	53	6	0	0
No. of transformers without spare	1,432	559	115	11	0
Total no. of transformers damaged	1,595	612	121	11	0
S2 and X1	**D0**	**D1**	**D2**	**D3**	**D4**
No. of transformers with spare	118	67	22	3	0
No. of transformers without spare	1,006	703	313	74	5
Total no. of transformers damaged	1,152	770	335	77	5

Image Source:
DOE. Large Power Transformers and the US Electric Grid. April 2014 Update. Page 5.

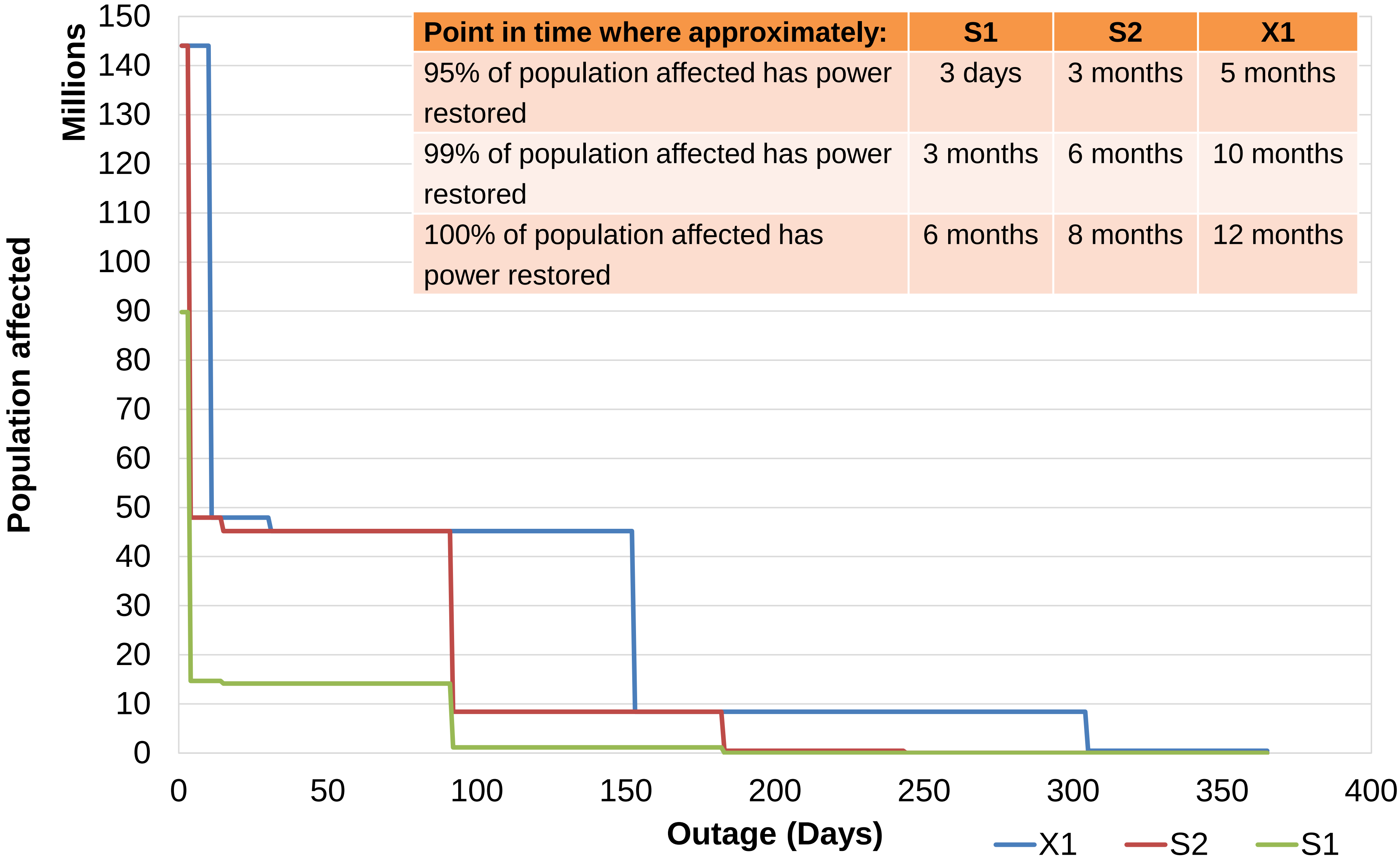
Extended Power Restoration

- Tripped off transformers can be brought back on-line quickly
- Minor and major damaged transformers are transported to a workshop for repair
- If a spare is available it can be brought in from a storage facility within 14 days
- Manufacturing Concerns
  - Custom built and designed
  - Average lead time is 5 to 21 months
- Transportation Concerns
  - Rail transport requires special Schnabel railcars due to weight
  - Road transport requires Goldhofer vehicle and road permits/plans
- Restoration Times (days) for damaged EHV transformers

S1 and S2	**D0** Not affected	**D1** Tripped off	**D2** Minor damage	**D3** Major damage	**D4** Destroyed
Outage for transformers with spare (days)	0	3	14	14	14
Outage for transformers without spare (days)	0	3	91	182	243
X1	D0	D1	D2	D3	D4
Outage for transformers with spare (days)	0	10	30	30	30
Outage for transformers without spare (days)	0	10	152	304	365

(Source: T&D World Magazine, tdworld.com)

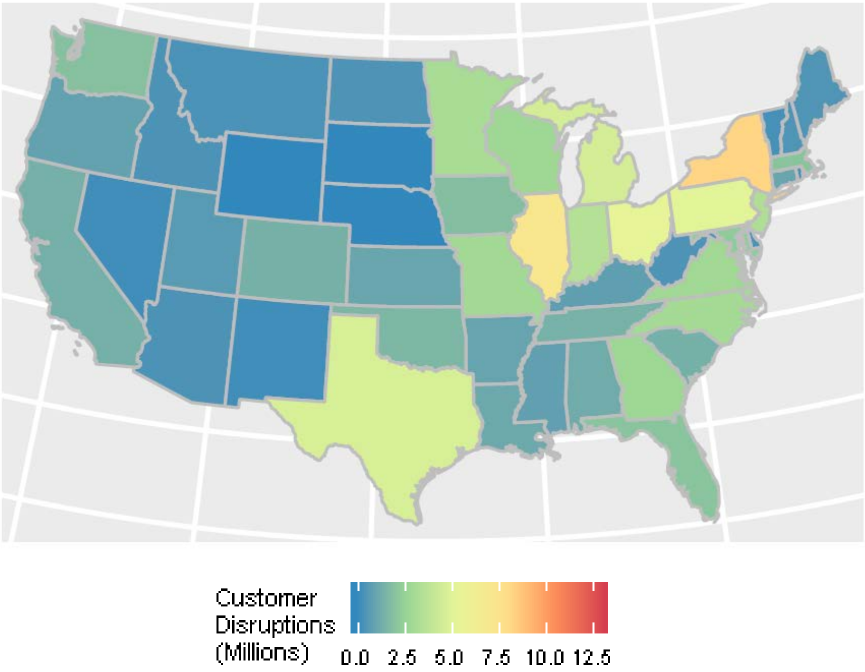
US Power Restoration Curves



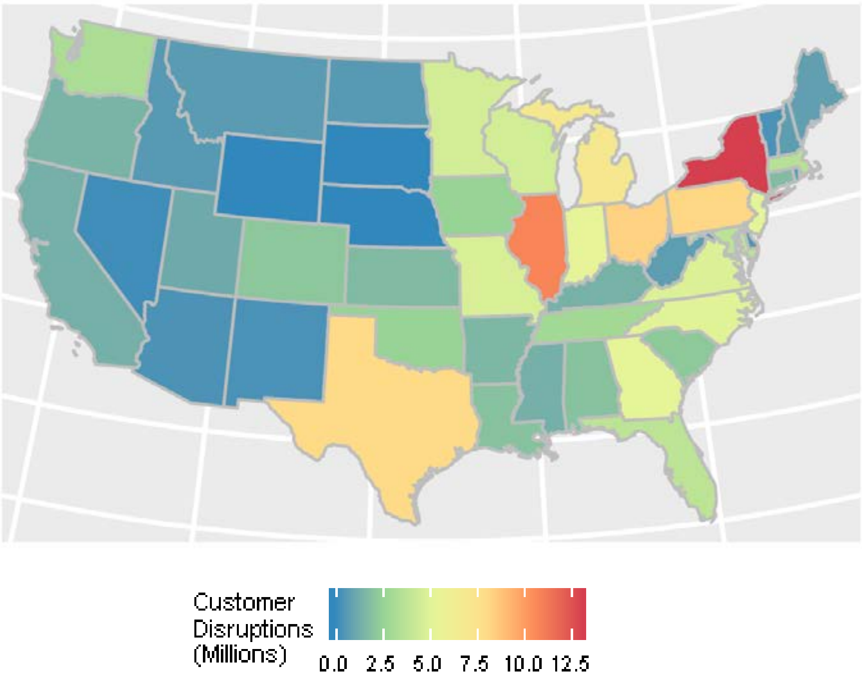
Point in time where approximately:	S1	S2	X1
95% of population affected has power restored	3 days	3 months	5 months
99% of population affected has power restored	3 months	6 months	10 months
100% of population affected has power restored	6 months	8 months	12 months

Customer Disruptions

S1 - Day 1 Total Customer Disruptions



S2/X1 - Day 1 Total Customer Disruptions



Methodology

Scenario Variants

S1

S2

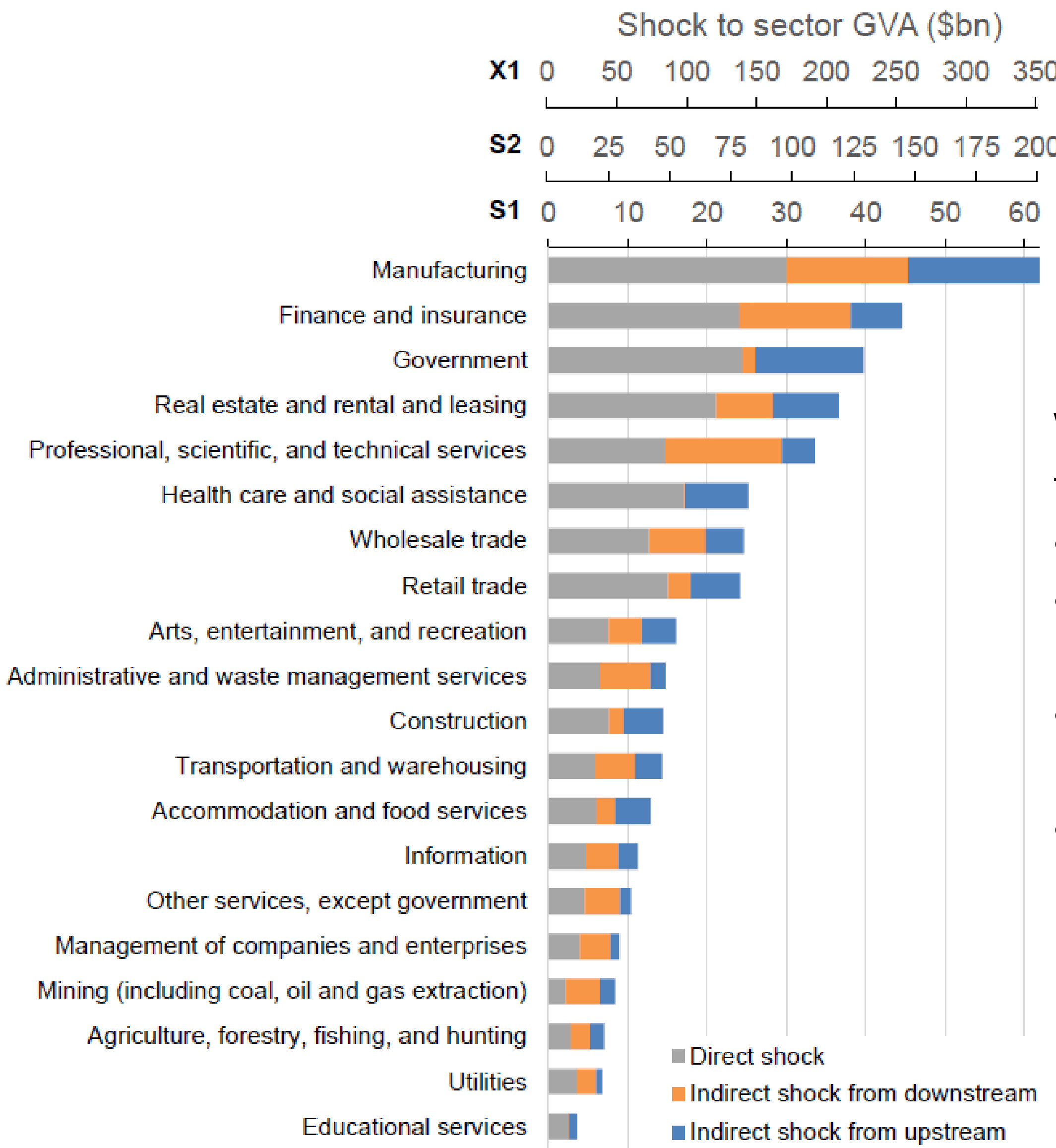
X1

Method 1
State-level Multi-criteria Risk Matrix

Method 2
Calculation of Direct Costs to Economic Sectors

Method 3
Estimation of Indirect Costs to Domestic and International Supply Chains

US Sectoral Supply Chain Impacts



What causes some sectors to be more affected?

- Industrial clustering
- Overall economic output (GVA/GDP)
- Interdependence on other economic sectors
- Length of supply chains

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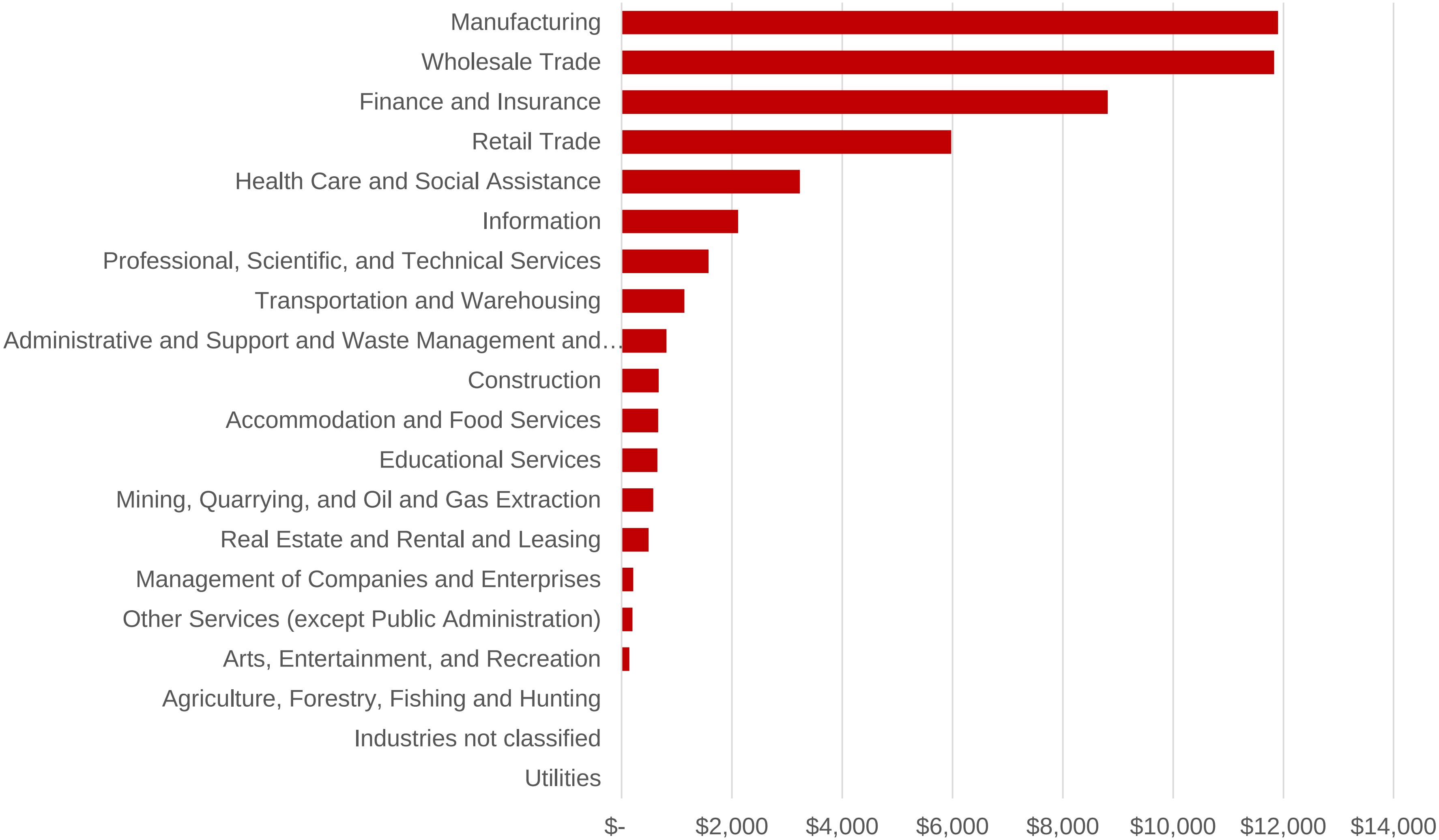
US Insurance Loss Estimate

Claimant Type		Coverage	$ millions
Power Transmission Companies	1	Property Damage (EHV transformers)	466
		Incident Response Costs	29
		Fines – FERC/NERC	4
		Directors and Officers Liability	600
Power Generation Companies		Property Damage (generator step-up transformers)	84
		Business Interruption	423
		Incident Response Costs	4
		Fines – FERC/NERC	4
		Directors and Officers Liability	95
Companies that loss power	2	Perishable contents	1,079
	3	Contingent business interruption – service interruption/utility interruption/suppliers extension	50,983
Satellite	4	Property damage (satellites)	218
Homeowners	5	Household contents	449
Speciality	6	Event cancellation	603
		Total	**$55,040**

For variant S1, $ millions

Insurance Loss by Sector



Sectoral share of $50 Billion of Contingent Business Interruption Losses from Service Interruption cover S1 variant only

Insurance Industry Loss Estimates for Solar Storm Scenario

Scenario Variant	Outage Duration	Total Direct and Indirect, US only, $ Bn	US Insurance Industry Loss Estimate, $ Bn	Insurance Loss as a % of economic loss
S1	6 months	$474	$55	13%
S2	8 months	$1,532	$173	13%
X1	12 months	$2,693	$334	14%

For context:

- Total insurance catastrophe losses 2015: $85 Bn
- Hurricane Katrina 2005: $80 Bn
- Tohoku Earthquake Japan 2011: $38 Bn
- Superstorm Sandy 2012: $37 Bn
- Hurricane Andrew 1992: $28 Bn
- 9/11 WTC 2001: $26 Bn

[2016 $ value]

Modelled insurance industry loss from

- Erebos Lloyd's Business Blackout: $21-$71 Bn
  - (Hypothetical cyber attack on power grid causing power outage in US Northeast)

Conclusions

- Solar Storm events on this scale are real and emergent
  - The available science now confirms this as a real threat
  - There is however a lot more still science still needed to understand likelihoods and severities
- These are rare but potentially catastrophic events
- The lack of a historical catalogue of catastrophic events is because the systems they damage are a recent artefact
  - This causes a clear awareness problem
  - It may take a major catastrophic event before the threat is fully recognized
- Solar Storms are potentially more disruptive today than ever before
  - We are rapidly growing our power infrastructure
  - We have an increasing reliance on power continuity for our economy
- Collectively we can manage the risk, mitigate it through investments in engineering and space observation, and improve our preparedness
- Insurers, financial services companies, and businesses need appropriate scenarios to explore their risk management
- We offer this study as a first step in building the awareness and tools needed to manage this risk

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Natural Catastrophes and their Potential Impact on Financial Markets

Dr. Andrew Coburn
Director of Advisory Board, Cambridge Centre for Risk Studies
SVP, RMS

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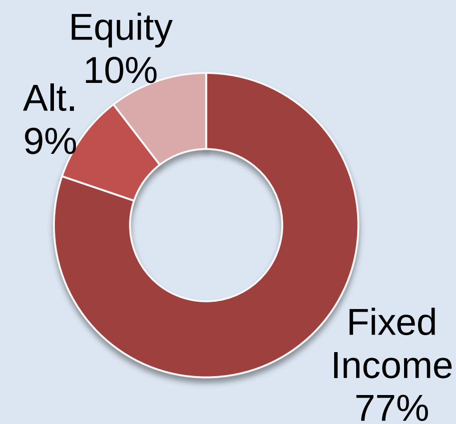
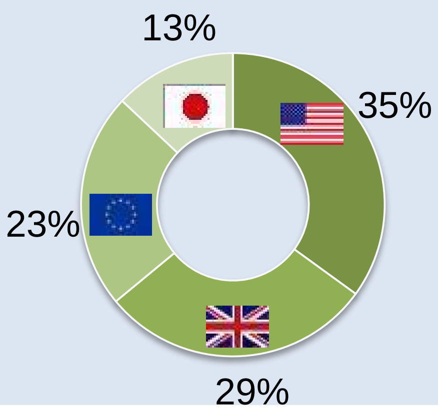
Insurers and Market Risk

- Insurers maintain large investment portfolios that are structured to pay future expected claims
  - Portfolios are structured to mirror geography and durations of exposure
- In the Great Financial Crisis of 2008/9, insurer's investment assets devalued by an average of 25%
  - Some insurers reported asset losses of 50%
- Investment devaluations reduce insurer's incomes
  - Typically 20% of income comes from investment returns
- Market risk analysis is required by regulators
  - Correlation between underwriting risk and market risk is assumed to be minimal

High Quality, Fixed Income Investment Portfolio



Market Asset Mix

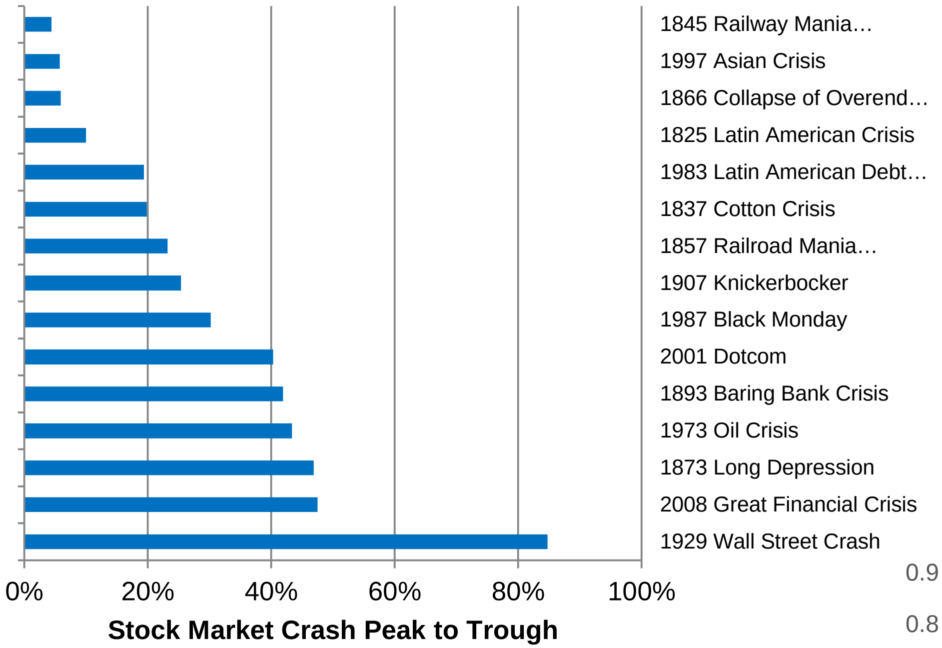


NatCats and Market Risk

- It is generally assumed that NatCats are not correlated with Market Risk
- This is not an unreasonable assumption..:
  - Analysis of the historical catalog of NatCat events and stock market indices shows poor correlation
  - Largest NatCat to date, HU Katrina, caused $150 Bn economic loss. S&P500 rallied 3 pts, lost 2.4% over 38 days
  - On an average day, NYSE trading volume is $169 Billion
  - Which is less than 1% of the equity trading value of NYSE at $18.5 Trillion
- How big would a cat event have to be to move the stock market?

Historical Stock Market Crashes

US Stock Market Crashes
Worst events last 200 years



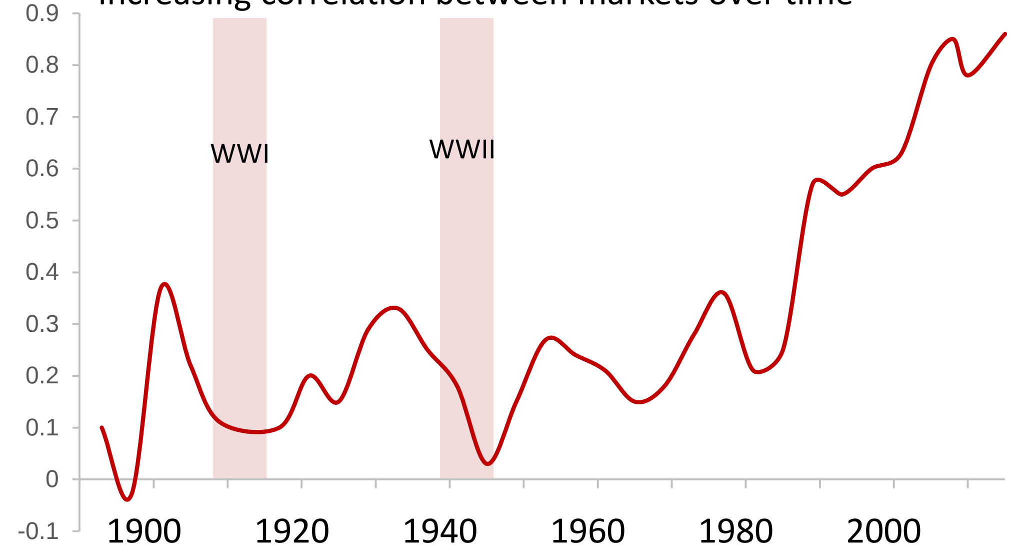
Observed, last 200 years

Crashes Greater Than	Number of Crises	Average Interval (Yrs)
10%	12	16
20%	9	21
40%	6	32
50%	1	190

Current world according to market equity capitalization

Source: Mapping Worlds; Bloomberg

Increasing correlation between markets over time



Source: Quinn & Voth, 'A Century of Global Equity Market Correlations'

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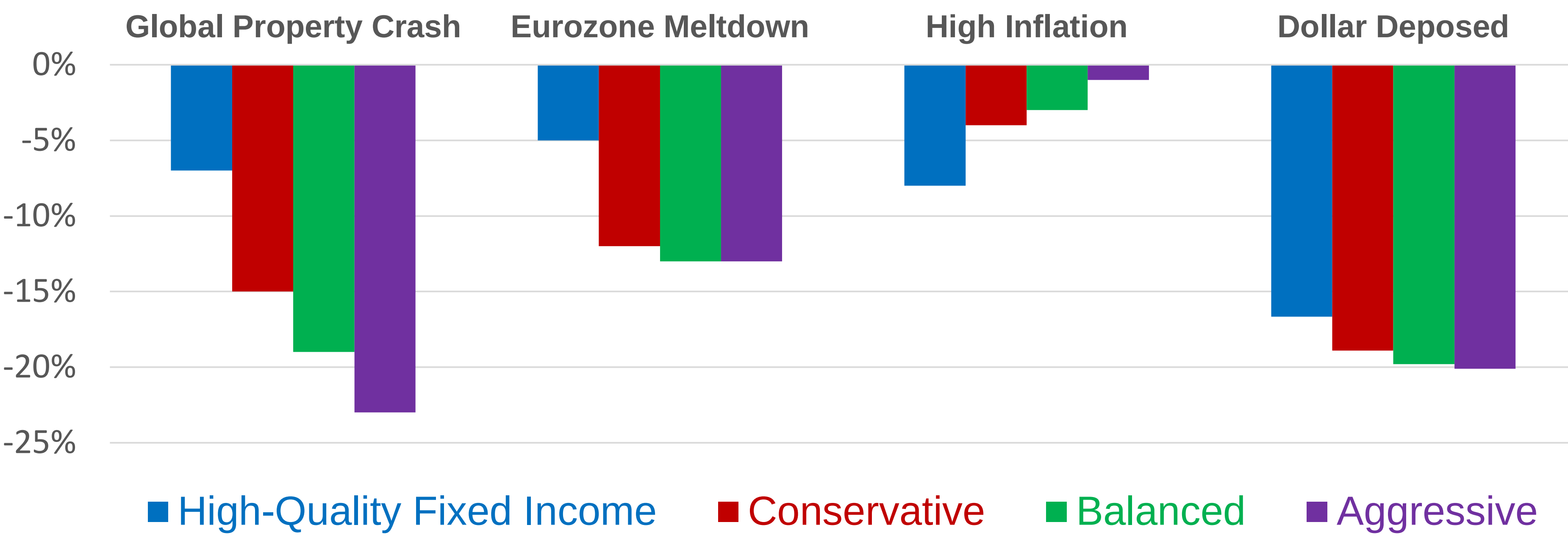
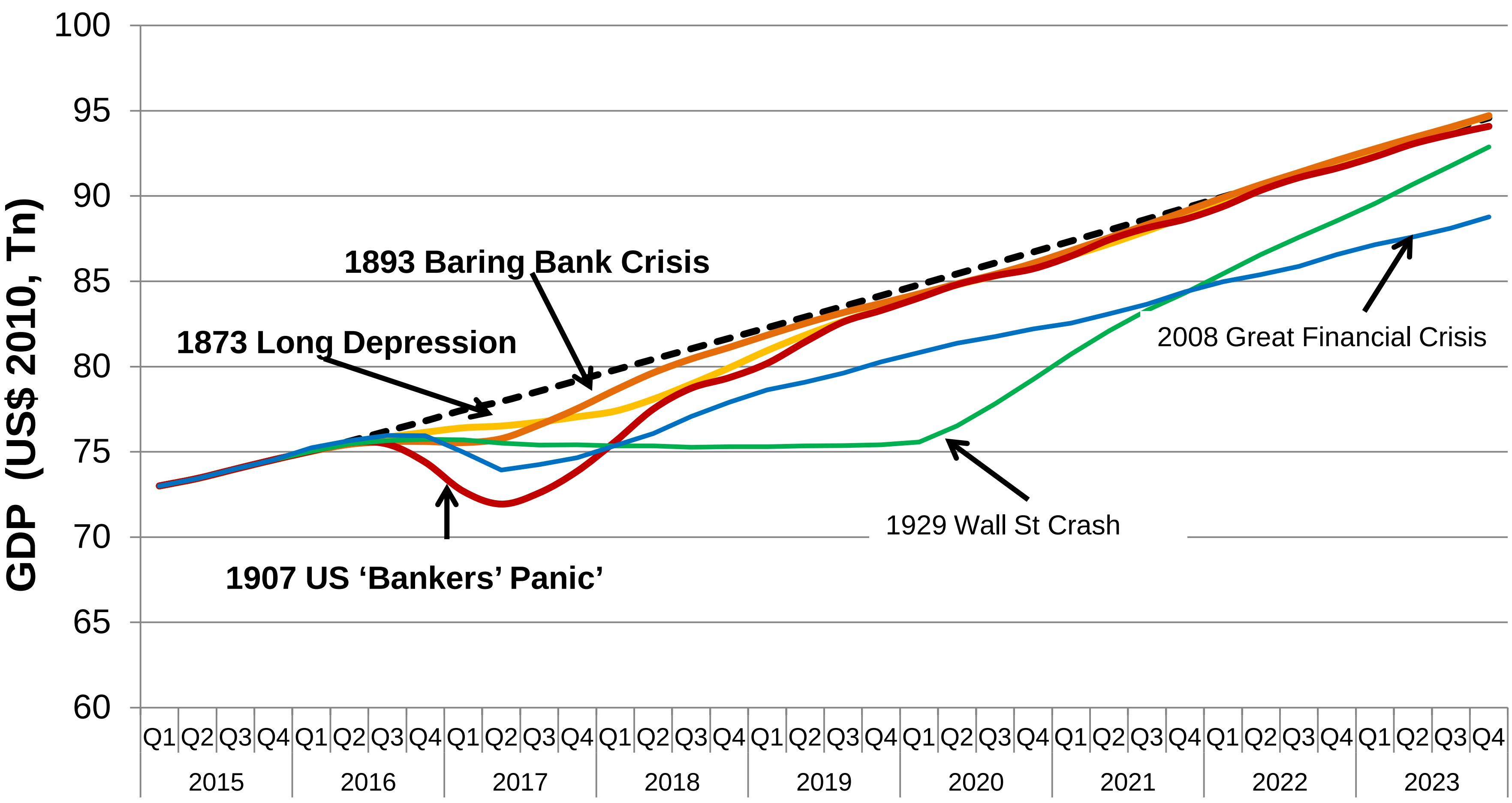
Analysis of Financial Crises on Insurance Portfolios



S1 variant of each scenario

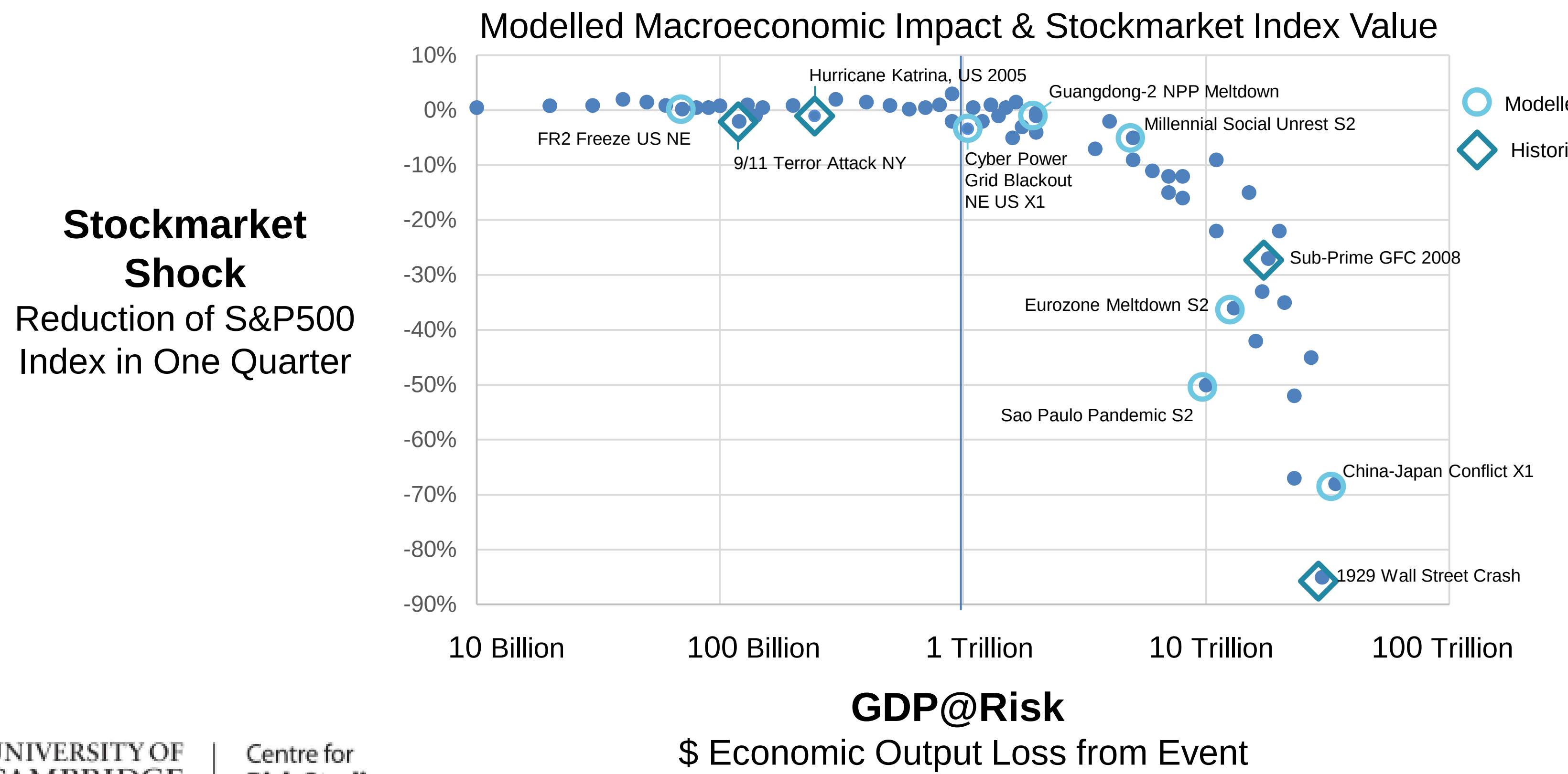
Duration of Recessions Following Financial Crisis



- Historical crises (proportion of output lost) overlaid on a 2016 projection of global economic growth

Events that Trigger Stock Market Devaluation

- The economy is relatively robust to minor and localized shocks
- A shock that destroys **a trillion dollars or more** of economic output is sufficiently large to trigger significant stockmarket equity devaluations
  - It becomes systemic and impacts connections and wider scale relationships
- Could a NatCat cause a Trillion Dollar loss?



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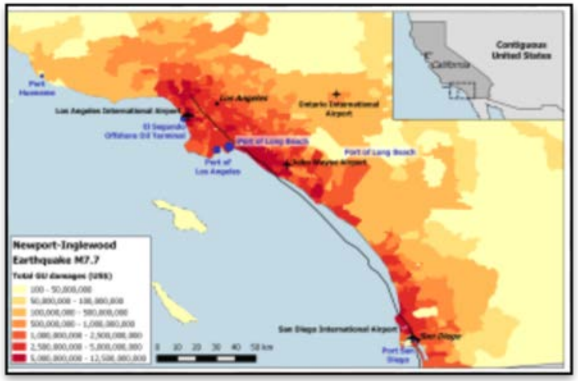
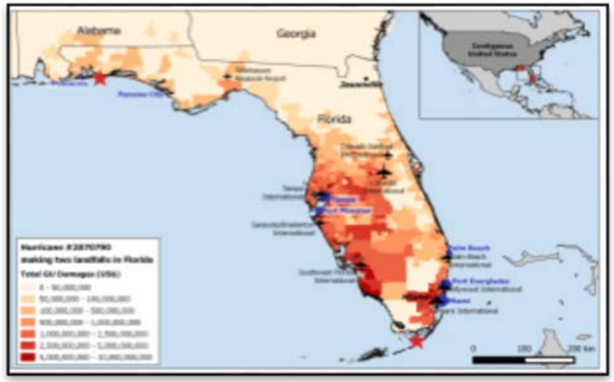
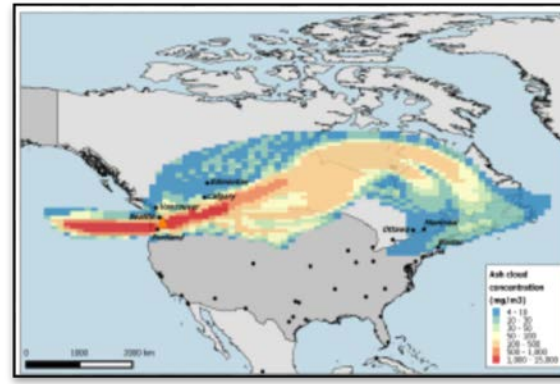
Six 'Trillion Dollar NatCat' Events



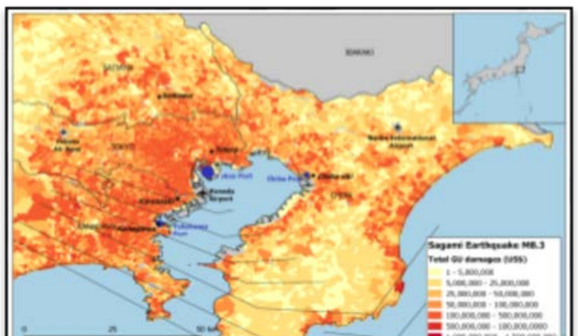
Earthquake M7.7 Los Angeles
GU Loss: $863 Bn
Global GDP Loss: $3.6 Trillion
RP: 1,100 yrs



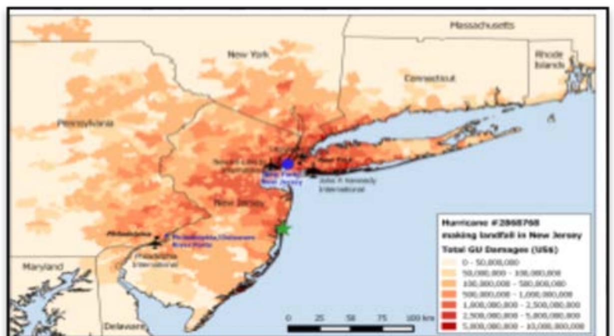
Hurricane CAT 4 Florida
GU Loss: $1,350 Bn
Global GDP Loss: $2.4 Trillion
RP: 1,200 yrs



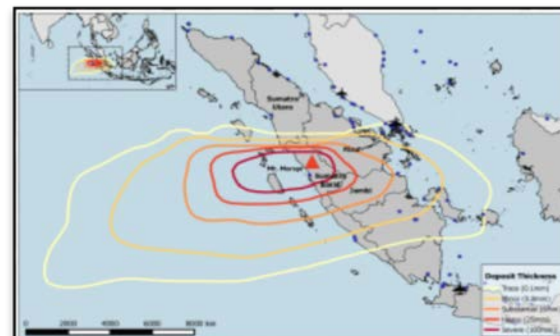
Volcano VEI VII Mt Rainer, Seattle
GU Loss: $1,100 Bn
Global GDP Loss: $6.3 Trillion
RP: 3,000 yrs



Earthquake M8.3 Tokyo, Japan
GU Loss: $1,368 Bn
Global GDP Loss: $1.6 Trillion
RP: 1,400 yrs



Hurricane CAT 4 New Jersey
GU Loss: $1,150 Bn
Global GDP Loss: $3.6 Trillion
RP: 1,150 yrs



Volcano VEI VII Mt Marapi, Indonesia
GU Loss: $493 Bn
GDP Loss: $2.5 Trillion
RP: 750 yrs

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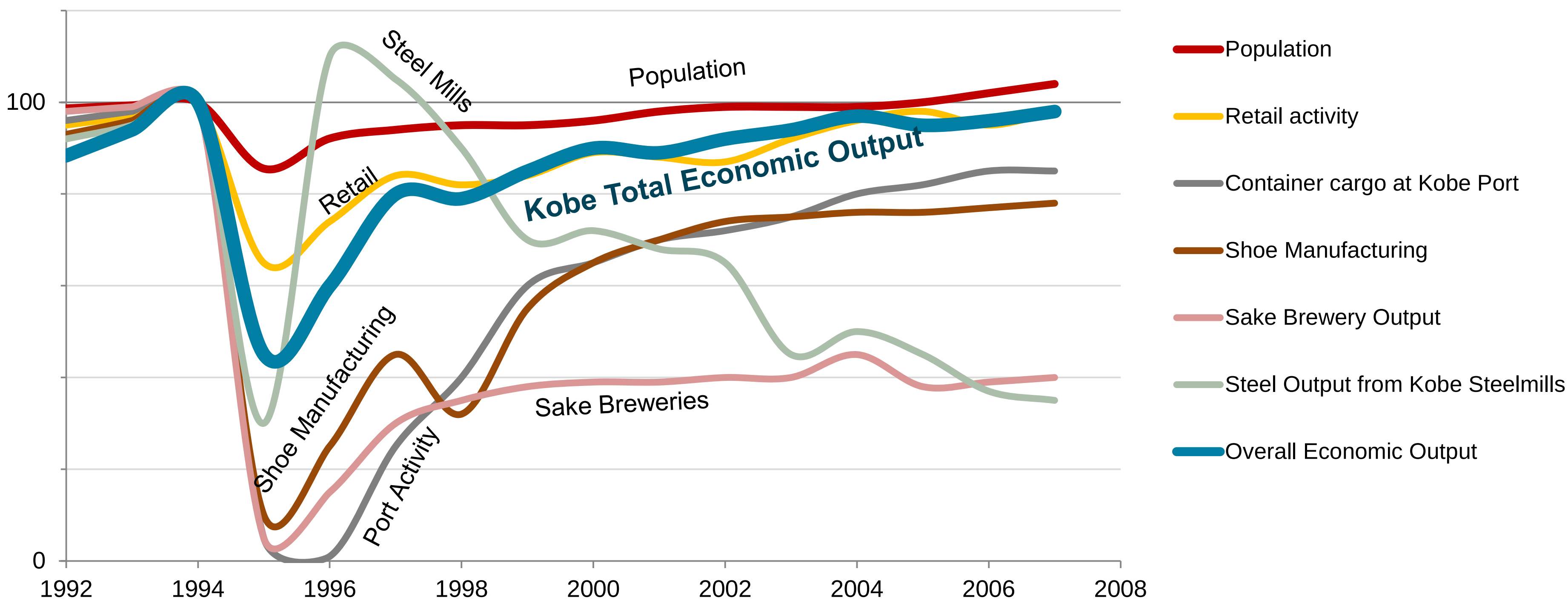
Economic Impact of Natural Catastrophes

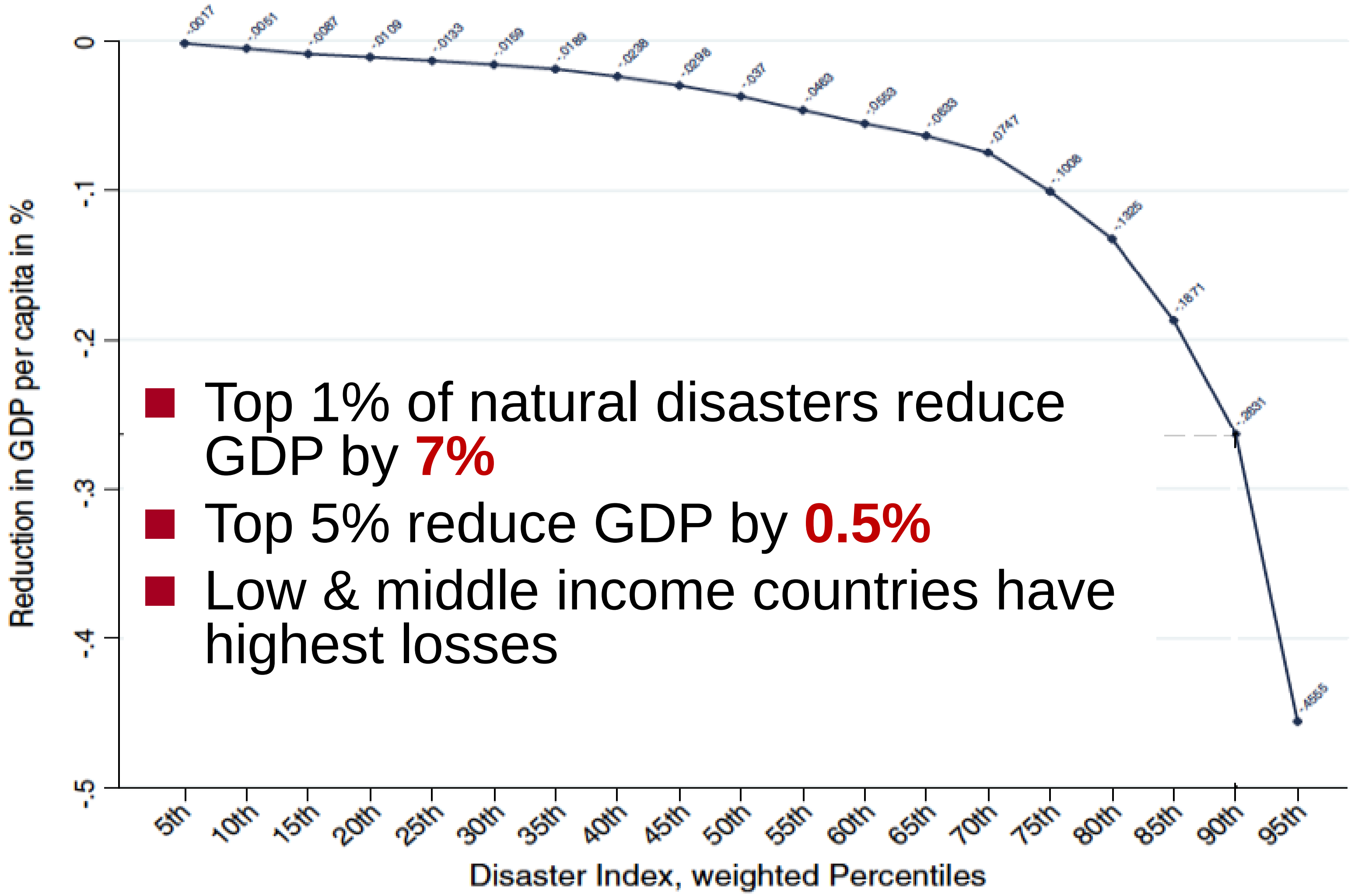
- Destruction of physical assets and infrastructure – the ‘means of production’ – depletes stock and results in reduced economic output
- ‘Supply shock’ is compounded by ‘demand shock’: reduction in purchasing goods and discretionary expenditure
- Injection of economic stimulus by government can offset some of the impact and hasten recovery
  - Some economists suggest that post-catastrophe investment stimulus can be ‘expansionary’
    - They propose that a destructive catastrophe can be beneficial to the economy overall
    - However, this assumes that external assets are unused. This view is losing credibility.
- Other parallel research at CCRS is exploring economic ‘resilience’ to improve disaster recovery speed

Impact of 1995 Earthquake on Economy of Kobe, Japan



- Great Hanshin earthquake January 17, 1995, Magnitude 7.3
- Death toll 6,400; Direct damage costs $100 billion
- The port of Kobe, one of the world's busiest, was destroyed
- Kobe Steel Ltd, major steel maker, heavily damaged
- 80% of shoe factories damaged
- 50% of the region's sake breweries put out of action
- Kobe’s economic output halved in 1995, reducing Japan’s total industrial output by 2.6 percent

Historical Impacts of NatCats on GDP



- Top 1% of natural disasters reduce GDP by **7%**
- Top 5% reduce GDP by **0.5%**
- Low & middle income countries have highest losses

Growth effects of natural disasters as a function of disaster intensity
Fig. 2. from Felbermayr & Groshcl (2014)

Analysis of Economic Loss in a Catastrophe

Supply Shock

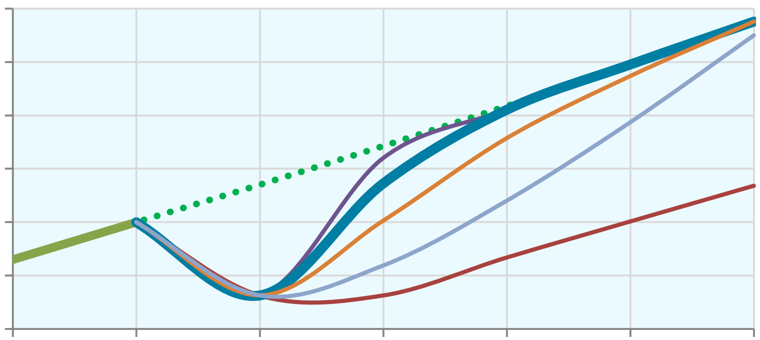
Destruction of Physical Assets

Disruption of Labour Availability

Flight of Capital

Inability to Export

Government Recovery Stimulus



Catastronomics Model

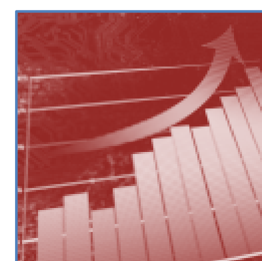
Demand Shock

Consumer Confidence

Shortage of Private Capital

Share Price Reduction

Inability to Import



Inflation: increased cost of inputs

Taxonomy of Macroeconomic Models

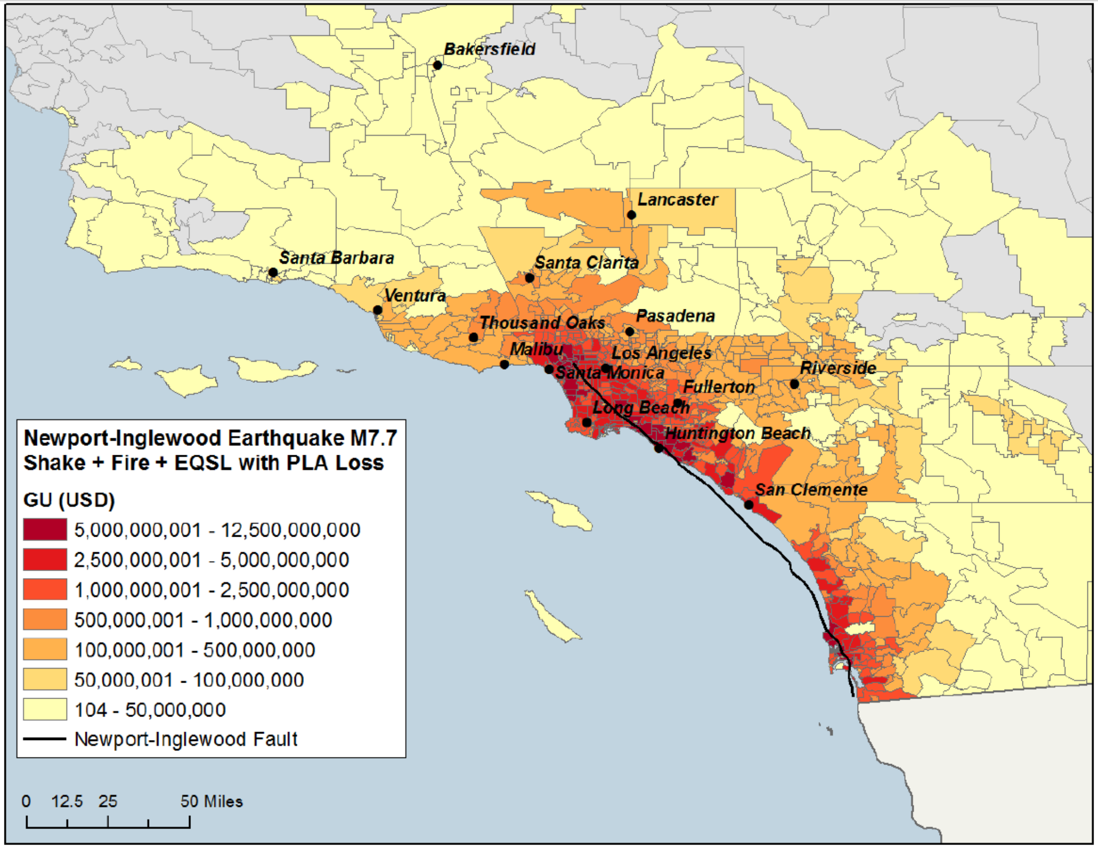
Visual models	derived from mathematical models	e.g. supply and demand curves
Mathematical models	systems of equations, abstract, assumptions	e.g. neo-classical growth models
Empirical models	based on historical data, econometrics	e.g. estimation of elasticities
Simulation models	must use computers, interaction of numerous variables	e.g agent based modelling
all other models	combine different aspects from each model	e.g. complexity models, network models

M7.7 Earthquake, Los Angeles

Newport-Inglewood Earthquake

Los Angeles, US

- RMS 2011 US FFEQ ILC
- Name: CA Newport-Inglewood Flt – All Seg FM2 c
- Maximum Magnitude: 7.7
- Event ID: 20077557
- Source ID: 1461
- Commercial Property Insured Loss: All Lines, Shake + Fire, Insured Ground Up: **$169.2 Bn**



Capital Stock Destruction	**Amount (Billion US$)**
Physical	
Building PD, contents, business interruption	
Residential	372.4
Commercial	476.5
Human	
Total Casualties: 71,251	
Workers' Compensation	14.2
Total Capital Stock Lost	**863.1**
Total Value in Footprint:	4,606.5
% of Value Lost	18.7%

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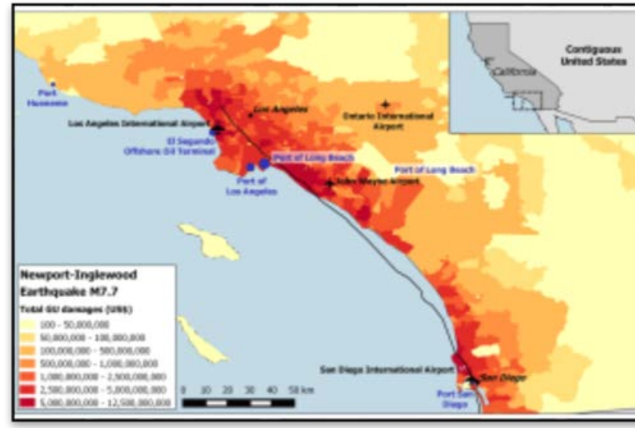
Impact of a Trillion Dollar NatCat on the Economy

- Unprecedented NatCat Impact
- Massive loss to infrastructure as well as property
- Insurance loss would impact many lines of business
  - Potential for massive litigation activity, post-event
- Recovery from Los Angeles earthquake takes five years.
- Population outmigration from disaster region
  - Some major companies relocate their headquarters
- Manufacturing output from within region drops
- Service activities greatly reduced
- Personal consumption in Southern California dips 89% in year following quake
- Several ports damaged and closed for 6 months
- Airports damaged and closed for 3 months
- National import and exports reduced by up to 8% during the first six months of recovery
- US national output falls by 11%
- US government implements stimulus package
  - Major LA Reconstruction Bond issued
  - Treasury raises yields on bonds
- Global stocks rebound quickly
  - Companies with major exposure to region see stock prices downgraded
- Economic growth rates are spurred in the second year
- US economy returns to pre-disaster levels within 18 months

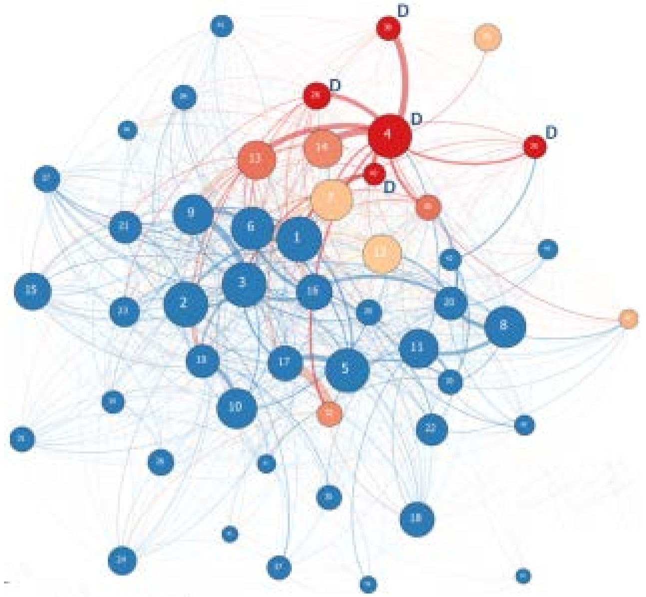


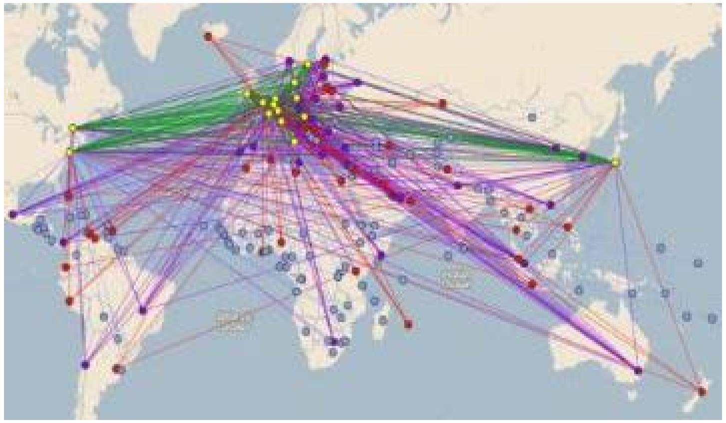
Earthquake M7.7 Los Angeles

List of major hubs damaged in LA disaster zone	
Airports in California, US	Passengers per yr
Los Angeles International	34,314,197
San Diego International	9,333,152
John Wayne Airport	4,584,147
Ontario International	2,037,346
Total US airports affected	50,268,842
Total US enplanement (2016)	759,987,683
Proportion of US air traffic affected	6.6%
Seaports in California, US	**Vessel calls pr yr**
Port of Long Beach	159,070,439
Port of Los Angeles	114,320,388
El Segundo Offshore Oil Terminal	27,904,402
Port San Diego	5,285,314
Port Hueneme	5,374,104
Total US seaports affected	**311,954,647**
Total US port calls capacity (2016)	3,418,774,062
Proportion of US port traffic affected	9.1%

Contagion and Amplication

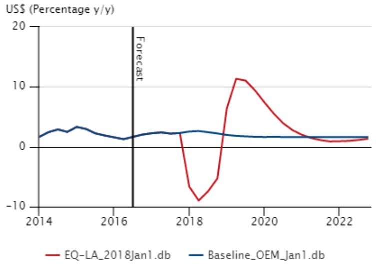
- The loss of economic output from the catastrophe is larger than the lost value from physical damage
- The US economy loses $1.89 Trillion in output over 5 years, from an event that destroys $863 Bn of property (2X)
- International trading relationships also suffer
  - UK's economy loses $120 Bn
  - Germany's economy loses $90 Bn
  - Japan's economy loses $60 Bn
  - Non-US economies lose $191 Bn



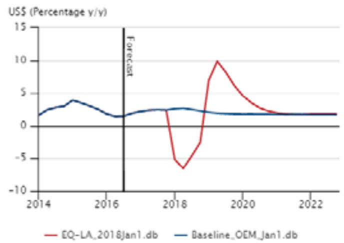


Model Outputs: Domestic Impacts (EQ-LA)

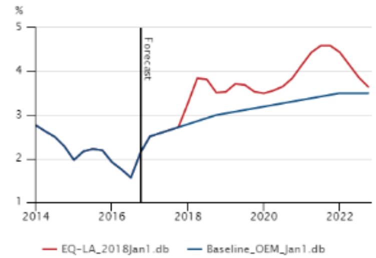
GDP



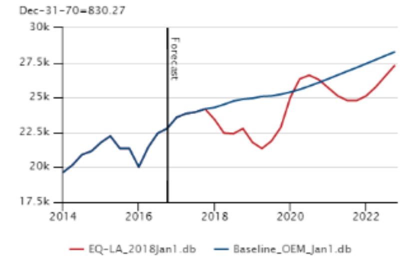
Domestic demand



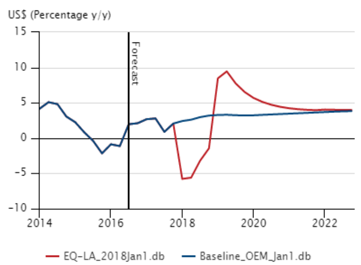
Bond yields



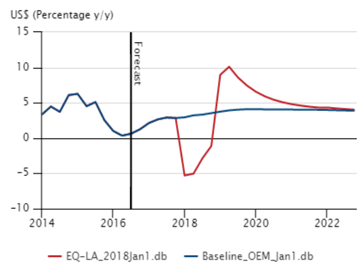
Equity prices



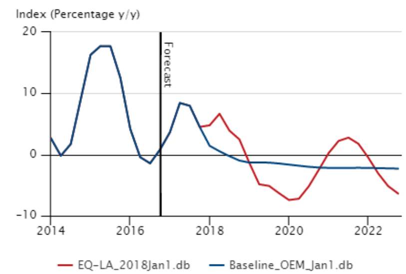
Exports



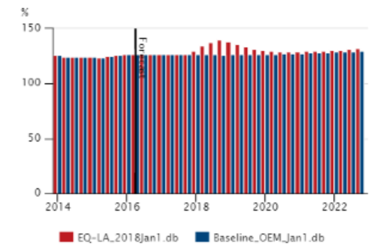
Imports



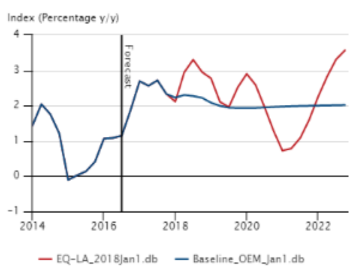
Effective exchange rate



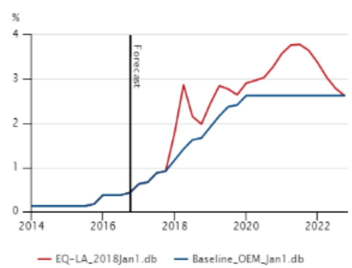
Government debt (% of GDP)



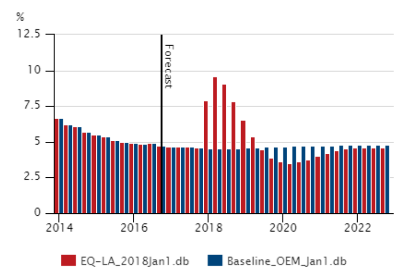
CPI



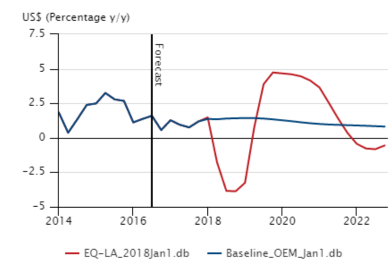
Central Bank policy rate



Unemployment rate



Real earnings vs CPI



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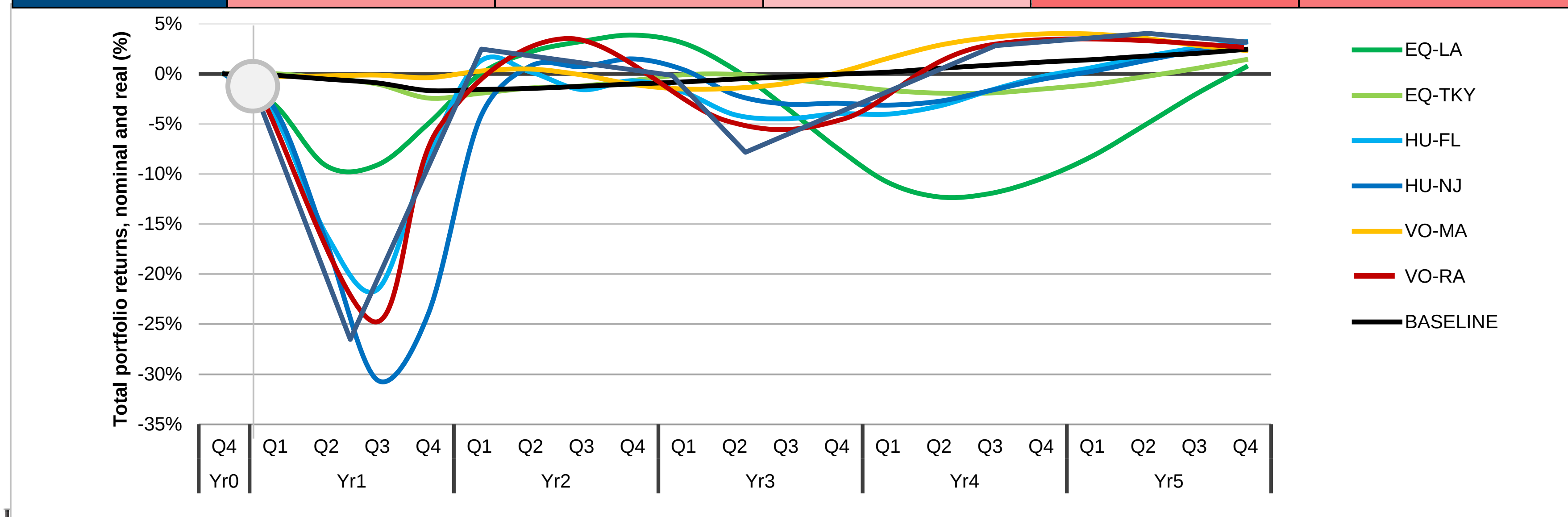
Investment Portfolio Impact of Extreme NatCat Events

High Quality Fixed Income Portfolio

	Germany (DAX)	Japan (TOPIX)	UK (FTSE All-Share)	US (Wilshire 5000)	World (Dow Jones Global Index)
Baseline	1%	3%	2%	0%	1%
EQ-LA	-6%	-3%	0%	-16%	-12%
EQ-TKY	-2%	-14%	-1%	-3%	-3%
HU-FL	-17%	-14%	-8%	-30%	-26%
HU-NJ	-25%	-22%	-15%	-40%	-36%
VO-MA	-3%	-1%	-1%	-4%	-4%
VO-RA	-33%	-30%	-19%	-48%	-43%



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Economic Analysis of Trillion Dollar NatCat Scenarios

GDP@Risk

LOCATION	Baseline 5-yr GDP (US$ Tn)	GDP@Risk (US$ trillion)					
		EQ-LA	EQ-TKY	HU-FL	HU-NJ	VO-MA	VO-RA
Germany	19.76	0.09 (0.46%)	0.04 (0.20%)	0.12 (0.61%)	0.12 (0.61%)	0.05 (0.25%)	0.12 (0.61%)
Japan	31.02	0.06 (0.19%)	0.90 (2.90%)	0.11 (0.35%)	0.10 (0.32%)	0.09 (0.29%)	0.21 (0.68%)
UK	14.64	0.12 (0.82%)	0.08 (0.55%)	0.05 (0.34%)	0.17 (1.16%)	0.07 (0.48%)	0.20 (1.37%)
US	91.45	1.89 (2.07%)	0.28 (0.31%)	0.28 (0.31%)	2.38 (2.60%)	0.39 (0.43%)	3.39 (3.71%)
WORLD	**428.51**	**3.81 (0.89%)**	**1.89 (0.44%)**	**2.35 (0.55%)**	**3.59 (0.84%)**	**2.51 (0.59%)**	**7.63 (1.78%)**

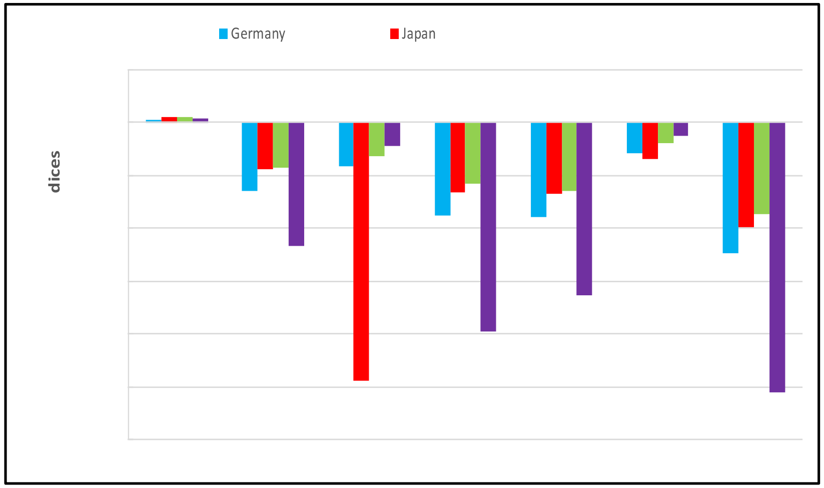
Maximum Growth Rates (Quarterly)

	Baseline	EQ-LA	EQ-TKY	HU-FL	HU-NJ	VO-MA	VO-RA
Germany	0.6%	0.2%	0.4%	-0.1%	-0.1%	0.5%	-0.6%
Japan	-0.9%	-0.4%	-10.7%	-0.3%	-0.4%	-0.4%	-0.9%
UK	1.2%	0.1%	0.7%	-0.4%	-0.4%	0.6%	-1.0%
US	1.5%	-9.0%	1.0%	-14.9%	-12.0%	1.3%	-18.6%
WORLD	2.4%	-0.7%	1.6%	-2.3%	-1.6%	1.8%	-3.4%

Bond Markets

	Baseline	EQ-LA	EQ-TKY	HU-FL	HU-NJ	VO-MA	VO-RA
Germany	AAA	AAA	AAA	AAA	AAA	AAA	AAA
Japan	A	A	BBB	A	A	A	BBB
UK	AA	AA	AA	AA	AA	AA	AA
US	AAA	A	AA	A	A	AA	BBB

Equity Markets



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OEM VARIABLES		DOMESTIC IMPACTS	INTERNATIONAL SPILL OVERS				
		General trends	General trends	Variants			
				Extreme deflation	*Non-US originating shock*	*For Germany & Eurozone*	*Volcano scenario*
GDP related	GDP	-1	-1	-1	-1	-1	-1
	Consumer Spending	-1	-1	-1	-1	-1	-1
	Fixed Investment	0	-1	-1	-1	-1	-1
	Government Consumption	0	0	0	0	0	0
	Domestic Demand	-1	-1	-1	-1	-1	-1
	Exports	-1	-1	-1	-1	-1	-1
	Imports	-1	-1	-1	-1	-1	-1
Labour related	Average Earnings	-1	-1	-1	-1	-1	-1
	Real Earnings	-1	-1	1	-1	-1	-1
	Productivity	-1	-1	-1	-1	-1	-1
	Unit Labour Costs	1	1	1	1	1	1
	Total employment	-1	-1	-1	-1	-1	-1
	Labour Supply	-1	0	0	0	0	0
	Unemployment Rate	1	1	1	1	1	1
Trade related	Exports of Goods	-1	-1	-1	-1	-1	-1
	Imports of Goods	-1	-1	-1	-1	-1	-1
	Exports of Services	-1	-1	-1	-1	-1	-1
	Imports of Services	-1	-1	-1	-1	-1	-1
	Visible Trade Balance (% of GDP)	1	1	1	1	1	-1
	Current Account Balance (% of GDP)	1	1	1	1	1	-1
	Government Balance (% of GDP)	-1	-1	-1	-1	-1	-1
	Government Debt (% of GDP)	1	1	1	1	1	1
Finance related	CPI Inflation	1	-1	-1	-1	-1	1
	CB Policy Rate	1	1	1	1	0	1
	Bond Yields	1	1	1	-1	1	1
	Equity Prices	-1	-1	-1	-1	-1	-1
	Effective Exchange Rate (EER)	1	1	1	1	1	1
World related	World Oil Price	-1	-1	-1	-1	-1	1
	Non-Oil Commodity Prices	-1	-1	-1	-1	-1	-1
	World Trade	-1	-1	-1	-1	-1	-1

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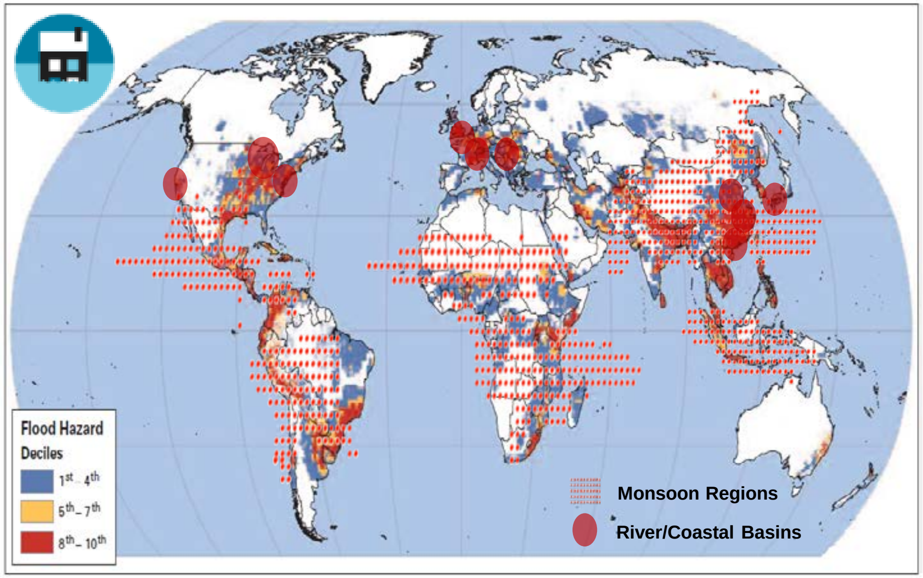
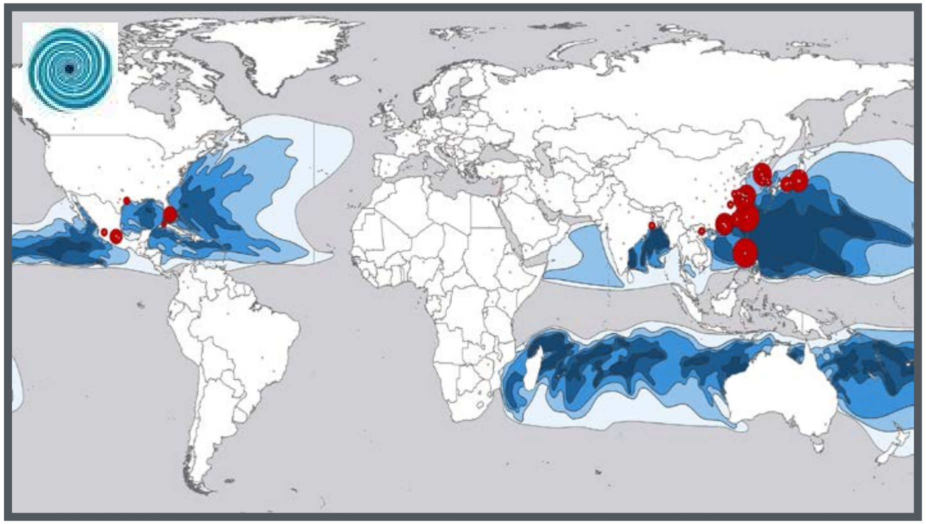
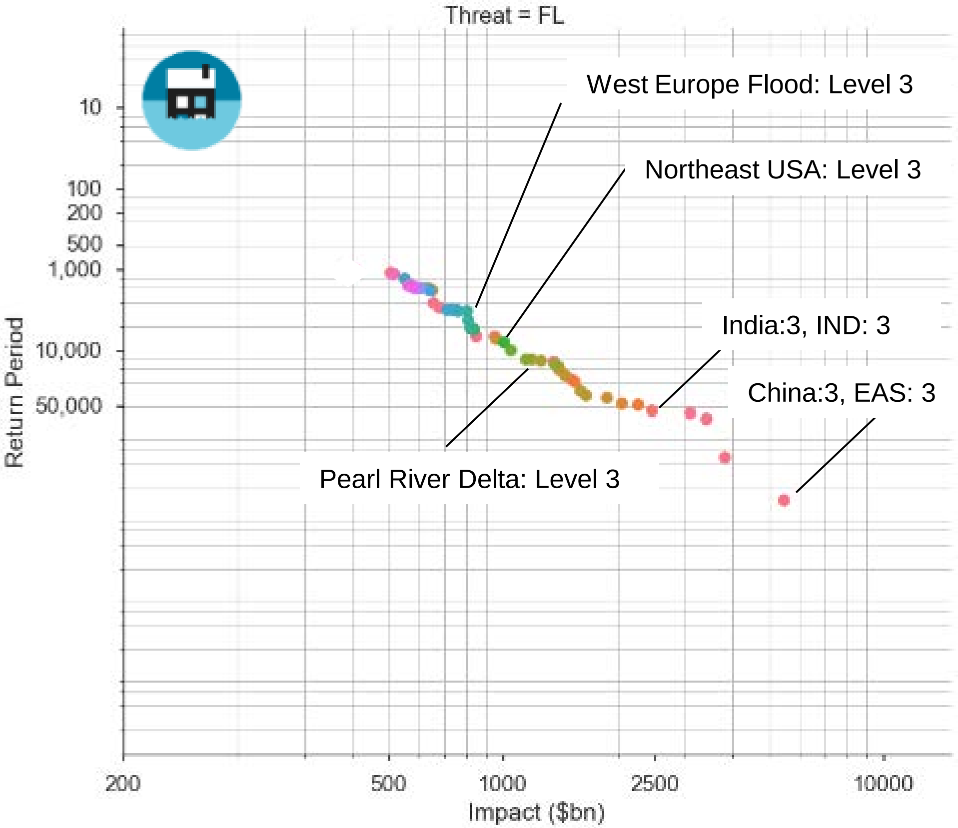
Finding the Other Trillion Dollar NatCat Events







Ongoing research to identify other potential extreme NatCat scenarios

- 60 extreme flood scenarios identified with impacts ranging from $0.5trn to $5.4trn
- Potential for multiple tropical storms to impact regions in a single season

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Impacts of Severe Natural Catastrophes on Financial Markets

- The potential impact on an insurer's investment portfolio from these extreme NatCat events is clearly significant
- Insurers with NatCat exposure in these regions would suffer a correlated loss to both underwriting and asset sides of their balance sheet
- Scenario analysis of this type can assist with correlation assumptions between market risk and underwriting risk
- These scenarios can be used as Asset + UW balance sheet stress tests
- Trillion dollar NatCats may not be as rare as generally perceived
  - record for costliest catastrophe is consistently being broken.
    - 1992 Hurricane Andrew $25 billion ($43 billion adjusting to 2017).
    - 1995, Northridge Earthquake $49 billion ($90 billion adjusting to 2017).
    - 2005, Hurricane Katrina's $150 billion ($211 billion in 2017)
  - Economic growth, interconnectivity and potential amplifiers increase future costs of catastrophes
- The next stage of research is to identify all the potential Multi-Trillion Dollar NatCats and to estimate the probability of one impacting insurers balance sheets

Publication in preparation:
Impacts of Severe Natural Catastrophes on Financial Markets

Pathfinder Webinar 11 July 2017

The Insurance Gap & Post-Catastrophe Recovery

Centre for Risk Studies
UNIVERSITY OF CAMBRIDGE
Judge Business School

Jessica Tsang
Research Assistant
Centre for Risk Studies

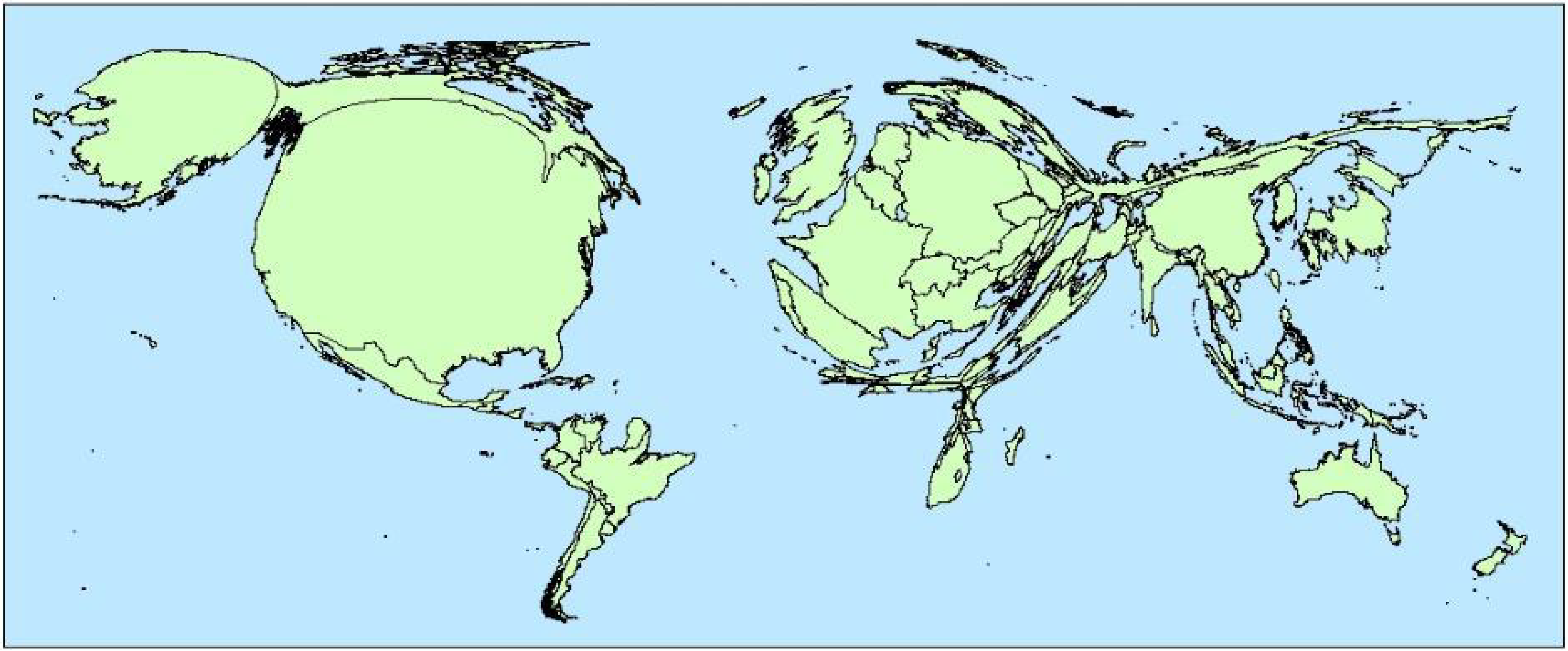
Insurance Growth and Opportunity

Cambridge Centre for Risk Studies has an ongoing project to understand:

- The dynamics of insurance growth
- Drivers (and inhibitors) of insurance uptake
- What constitutes the ‘Insurance Gap’
- Case studies of insurance and disaster recovery
- Understanding how increased insurance penetration can improve societal resilience

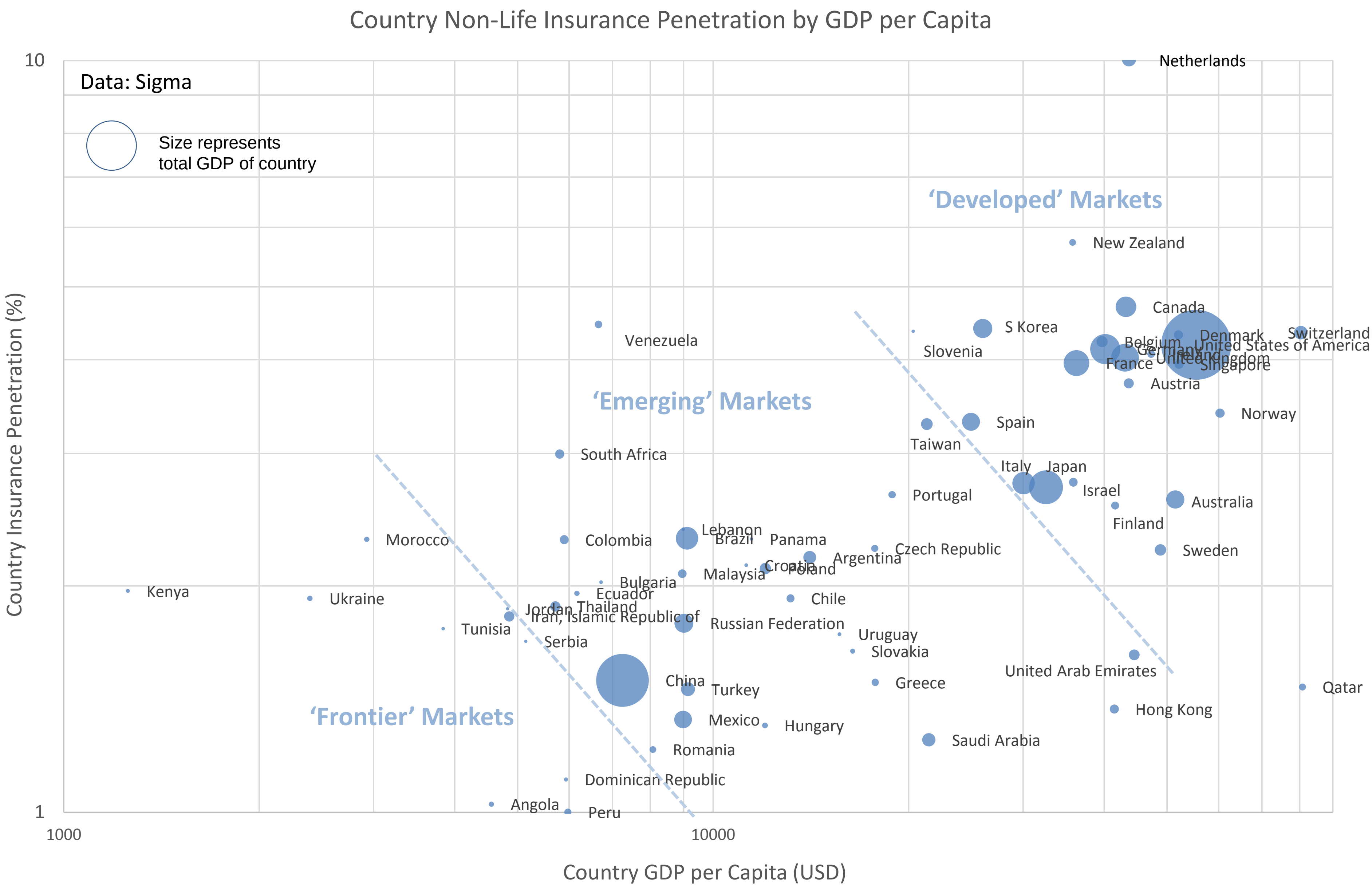
Geography of Insured Exposure

Commercial Property, Sum of Limits by Country



Cartogram: Area of country represents insured total insured exposure

Insurance Penetration by Country



Insurance Uptake

Regulation

- + Health & Safety
- + Anti-Corruption
- + Legislation

Economic Development

- + GDP growth
- + Mid-size companies
- + International trade
- - Low interest rates

+ Large Catastrophe

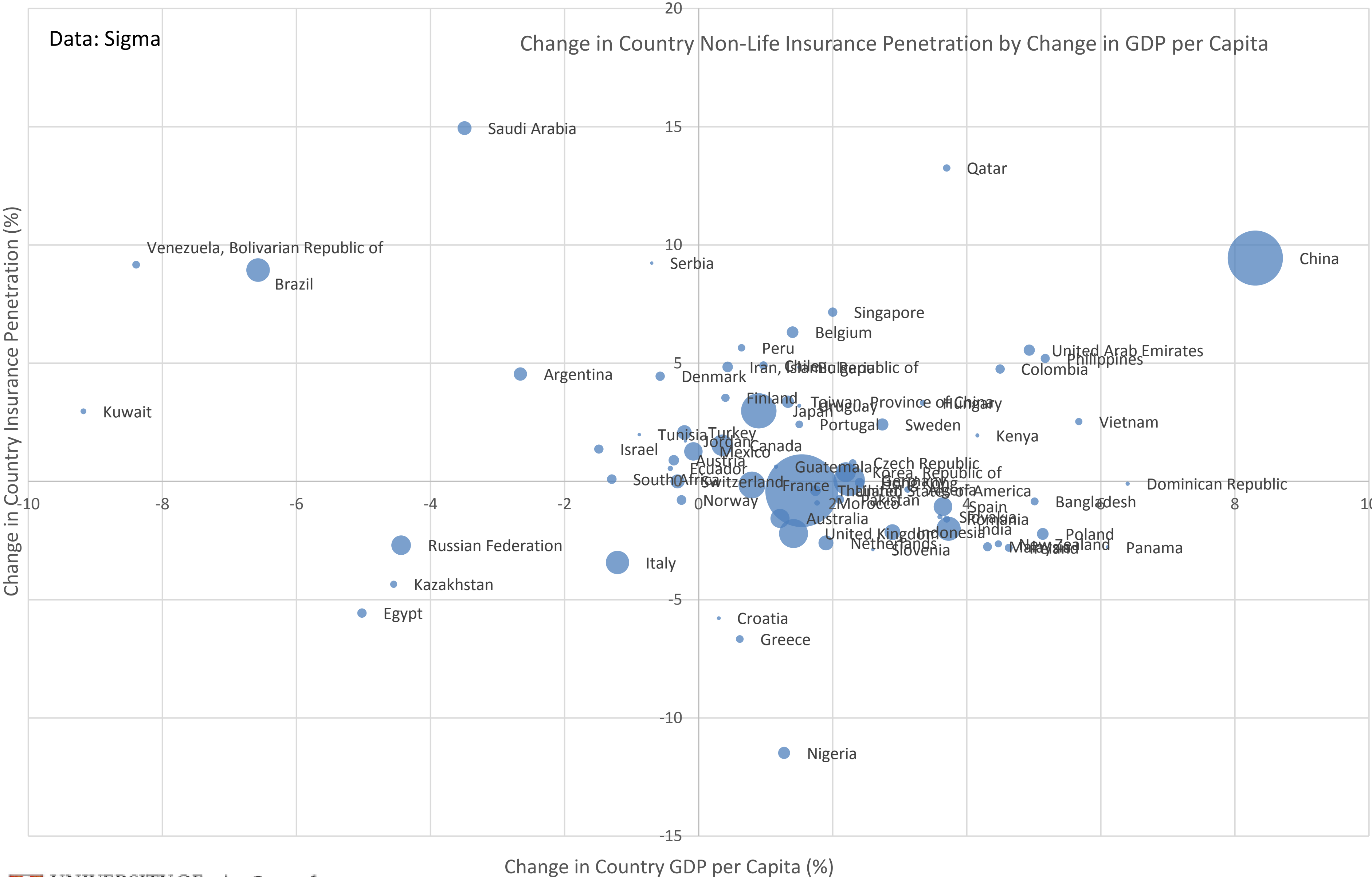
Product

- + Product innovation
- + Technology
- - Unsuitable coverage terms

Consumer

- + Risk perception
- + Education
- - High price
- - Small market size

Country Insurance Penetration Growth

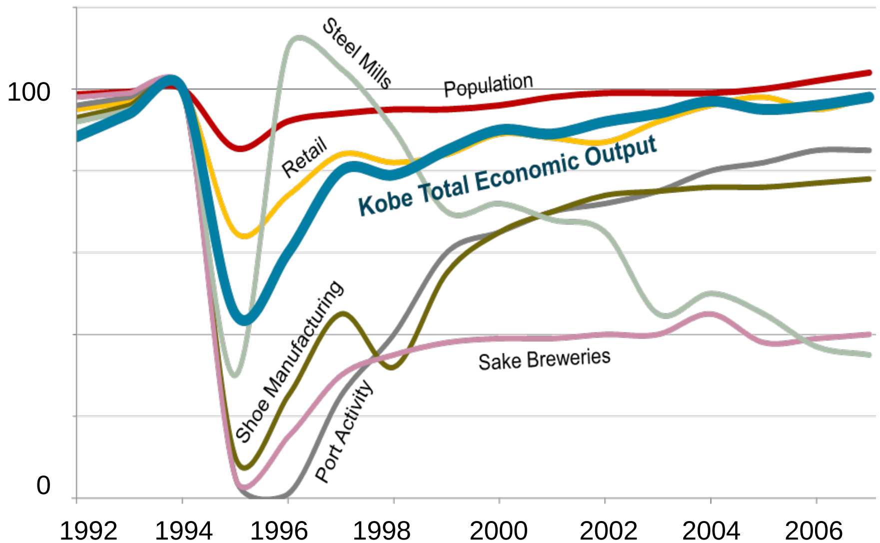


Insurance Lines & the Threats that Impact Them

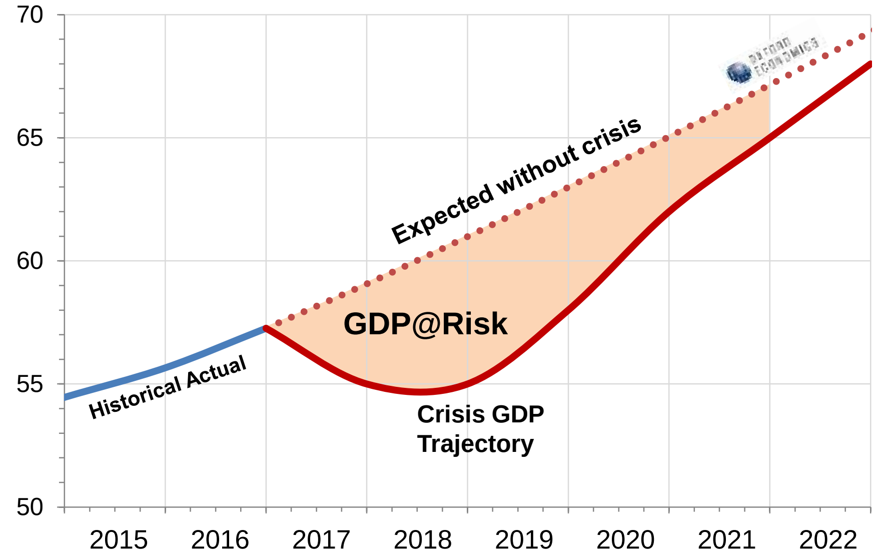
Insurance Lines	*Type of Exposure*	Financial & Economics	Geopolitics & Security	NatCat & Climate	Technology & Space	Health & Humanity
Commercial Property						
	Physical Damage		1	3	2	
	Revenue Loss / Business Interruption		1	3	2	2
	Contingent Business Interruption		1	2	3	
Commercial Political Risk / War Market						
	Physical Damage		3			
	Revenue Loss / Business Interruption		3			
	Human Injury, Illness or Death		2			
	Financial Asset Devaluation	1	2			
Casualty Liability						
	Duty of Care to 3rd Party	2	2	2	2	2
	Human Injury, Illness or Death		2	2	1	2
Liability D&O; E&O						
	Financial Asset Devaluation	2	1	1	2	2
Workers Comp						
	Human Injury, Illness or Death		3	2	1	2
Credit and Surety						
	Financial Asset Devaluation	3	2	1	1	2
Personal Accident						
	Human Injury, Illness or Death		2	2	1	2
Cyber Liability						
	Digital Asset Loss		1		3	
Life & Health						
	Human Injury, Illness or Death		1	1	2	3
Pensions & Annuities						
	Financial Asset Devaluation	3	1	1	2	1

Learning From Post-Catastrophe Recovery

Historical case study: Kobe Earthquake impacts



Calibrate GDP@Risk



Calibration of resilience factors through case studies

Research proposal:

- Impact from natural disasters
- The role of insurance in recovery

Taking steps toward:

- Impact from multi-threat disasters
- Quantification of resilience

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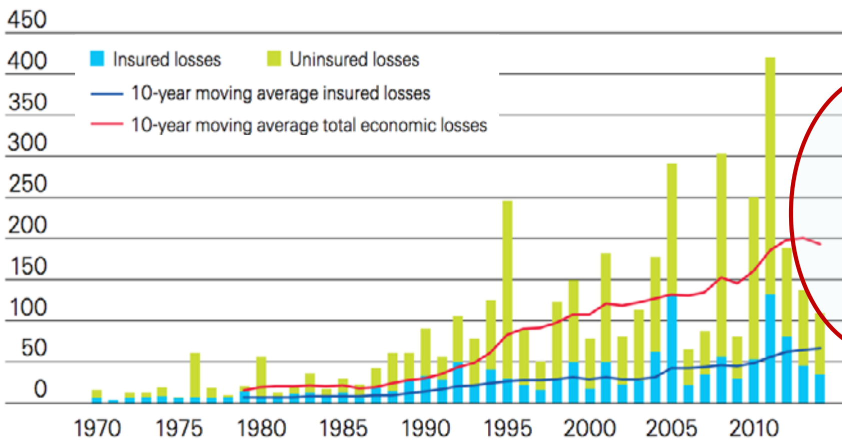
Economic Damage to Economic Loss

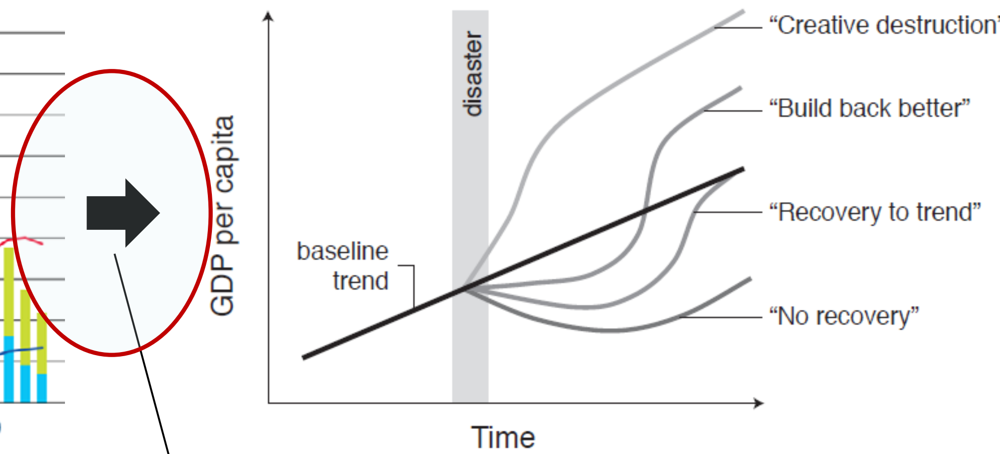
- Economic damage
  - Stock loss such as damage to property, infrastructure
  - Mostly instantaneous
  - Well-documented increasing economic damage in recent years

- Economic loss
  - Flow loss such as GDP
  - Measured post-disaster
  - Difficult to measure, difficult to isolate the cause
  - May not necessarily be a loss

Total economic and insured catastrophe damage/loss (2014 prices)



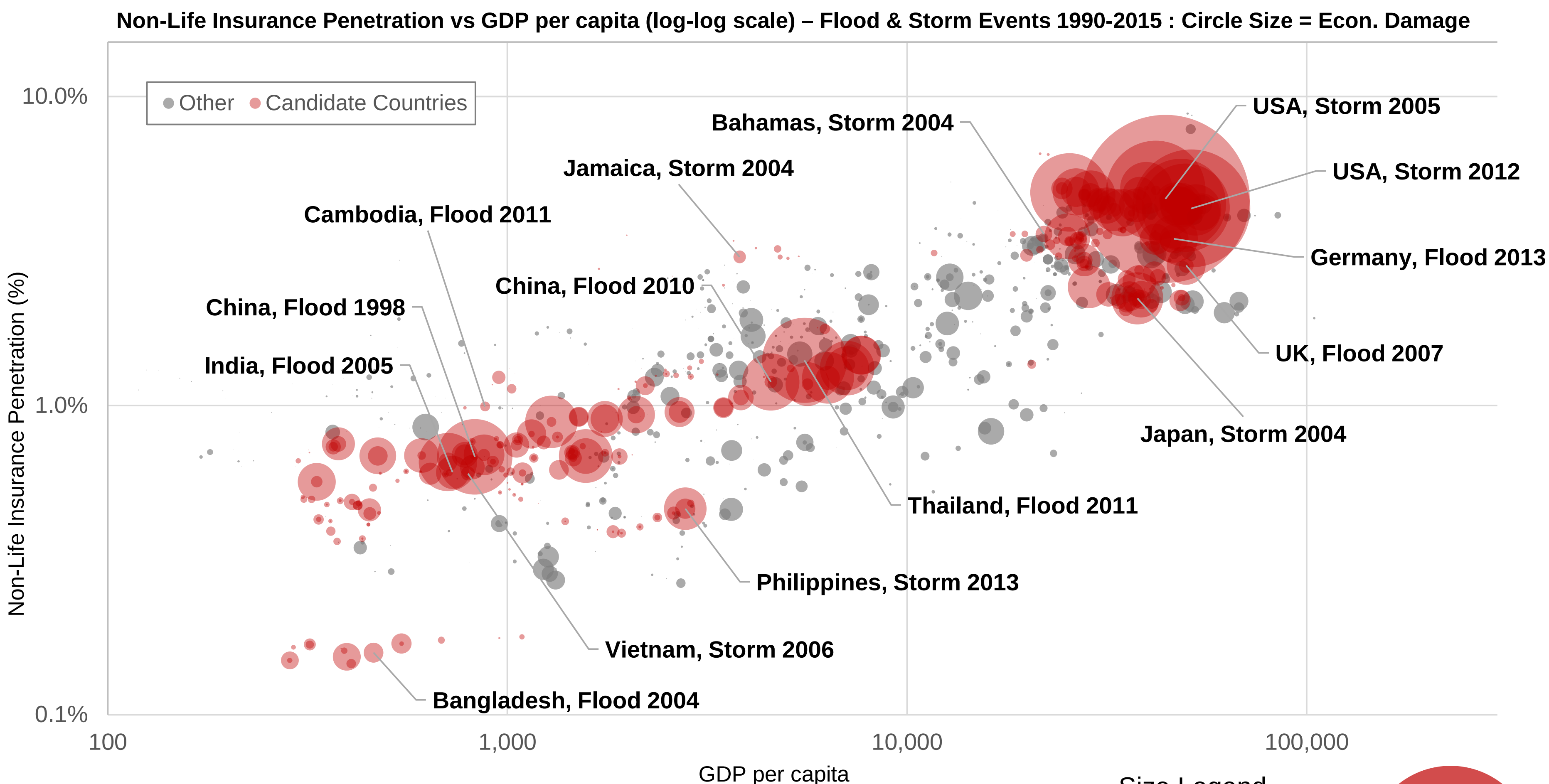
Source: Swiss Re Economic Research and Consulting and Cat Perils

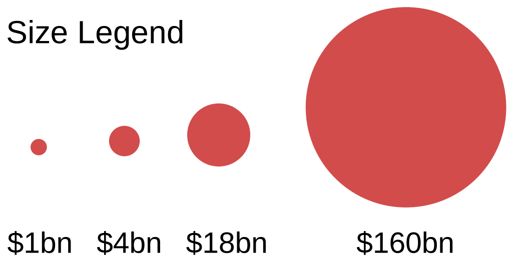


Source: Hsiang and Jina, 2014

What factors affect this function? What is the role of insurance?

Insurance, GDP, and Economic Damage 1990-2015





- Insurance penetration is positively correlated with GDP/capita (non-linear)
- Significant economic damages occur at all income and insurance levels

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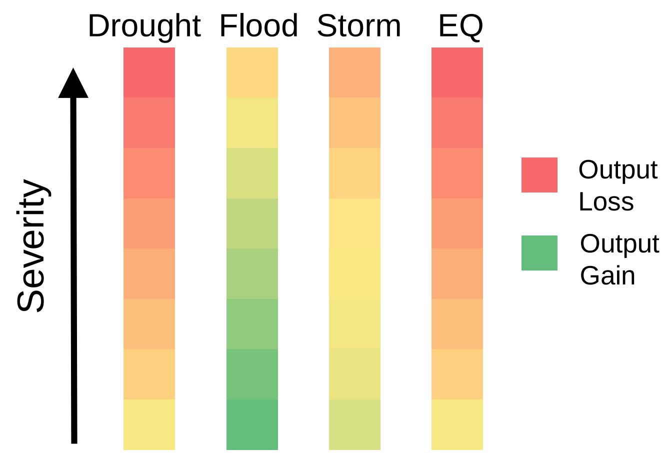
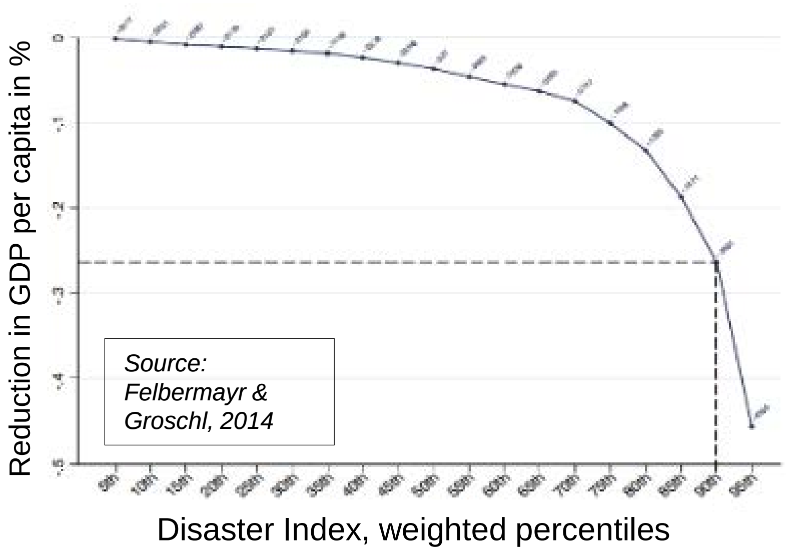
Disaster Type and Severity



Source: Based on findings from Skidmore & Toya, 2002



Impact varies by disaster type, even in direction

- Storms/earthquakes impact capital; floods/droughts impact productivity

What sectors are affected?

- Floods positively impact agricultural output, which can lead to industrial growth

What is the impact to behaviour?

- Floods and storms can often be forecasted –> preparation for known risk
- Mitigation preferences vary by income level

Impact varies by disaster severity, and only the largest seem to matter

- Non-linear relationship between disaster intensity and growth

Moderate severity impacts can be good

- *Moderate* flood GDP impact +1%; *Severe* storm GDP impact -1.1%

Very severe disasters can cause other ‘disasters’

- E.g. political revolutions

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Creative Destruction or Always Negative?

	Negative Impact	Positive Impact
Supply	▪ Destruction of productive capital, infrastructure, environment ▪ Deaths, outward migration	▪ Replacement of least productive capital ▪ Introduction of new technology
Demand	▪ Reduction in consumption and investment ▪ Outflow of population ▪ Fiscal imbalances ▪ Instability	▪ Increase in re-construction activity ▪ In-flow of population

Level, quality and timing of re-construction

Disaster type and severity

Quality of institutions

Fiscal resilience

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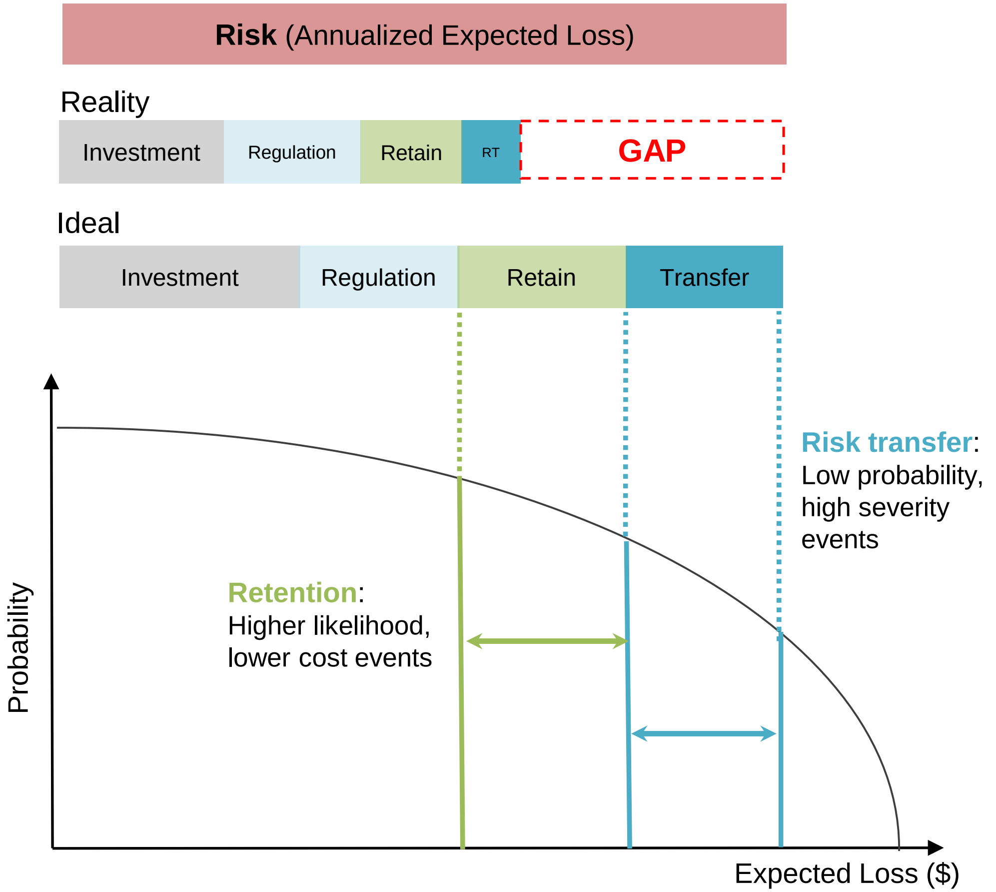
The Role of Insurance: Fiscal Capacity to Rebuild



Source: Derived from UNISDR, 2015

Meeting immediate needs

- Liquidity gap
- Ex-post disaster financing can be unreliable and slow to materialize

Meeting future needs

- Inefficient diversion of funds
- Increased debt
- Increased taxes
- Inflation

Price of stability

- Existence of insurance necessary for a stable investment environment

Insurance is not the only factor

- Quality of institutions
- Strong financial sector & regulation

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Proposed Case Studies

Category: Asia – Monsoons & Typhoons

Southeast Asia – High occurrence of typhoons

- Vietnam – 2006 (Typhoon Xangsane and Typhoon Chanchu)
- Philippines – 2013 (Typhoon Haiyan)

Indian Sub-continent – Monsoon Riverine flooding

- Bangladesh – floods 2004
- India – floods 2005

Southeast Asia - Monsoon Riverine Flooding

- Cambodia - 2011
- Thailand - 2011

China – large economy with high frequency of disasters

- China - flood 1998, 2010

Category: High income countries

United States – high income economy with large and frequent disasters

- US - storm 2005 (Hurricane Katrina), 2012 (Hurricane Sandy)

Europe – high income economies with moderate disasters

- Germany - storm 2013
- UK - flood 2007

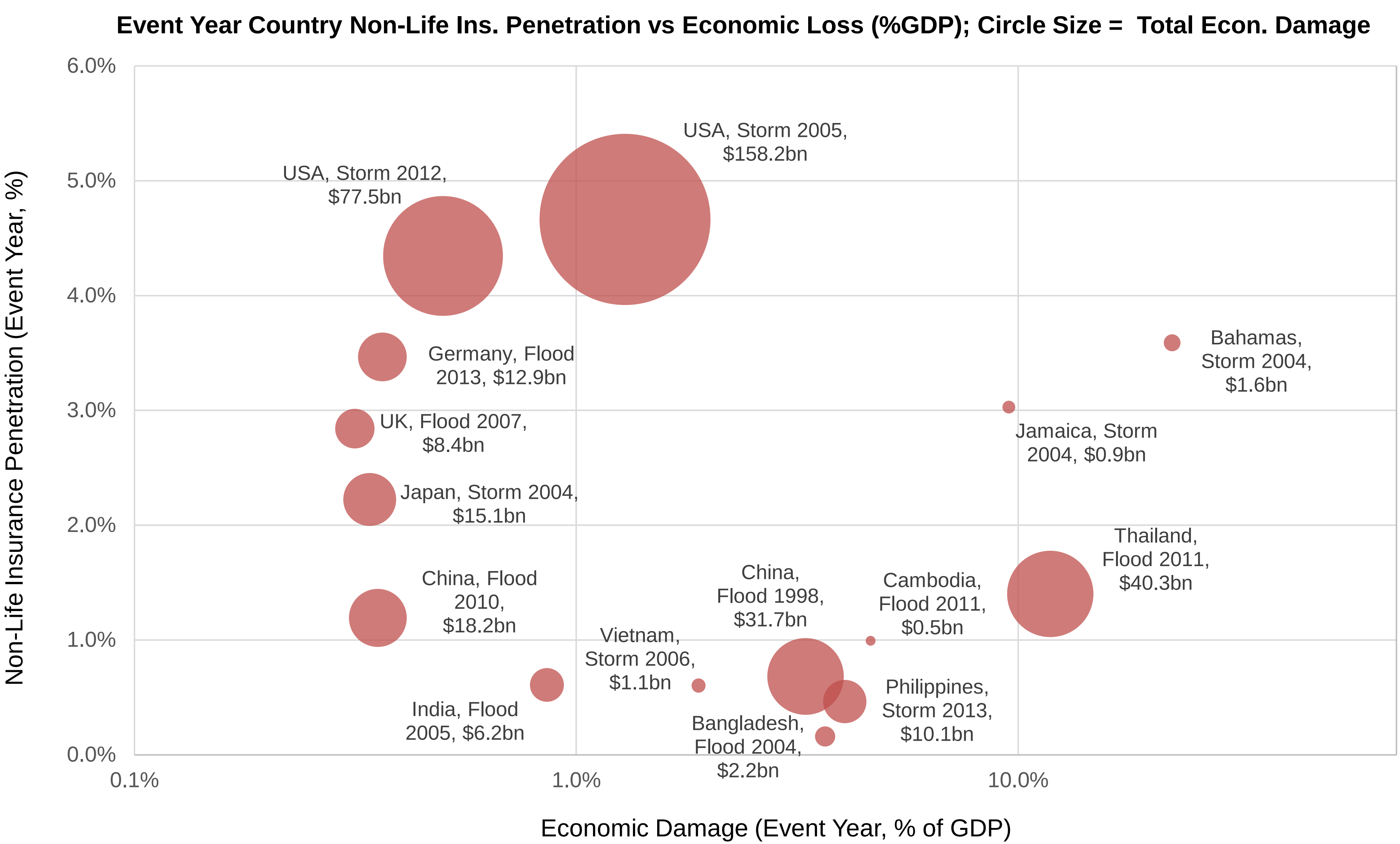
Japan – large economy with high frequency of disasters

- Japan – storm 2004

Caribbean – middle income economies with large and frequent disasters

- Bahamas, Jamaica - storm 2004 (Hurricane Frances, Jean, Ivan)

Event Analysis: Insurance Penetration Range



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Proposal for Upcoming Year's Research

Overall Objective: Determine the impact of insurance as a factor of resilience

Over upcoming year: Case Study Comparisons

- Comparison of variety of income levels (and insurance penetration):
    - Bangladesh riverine flooding vs Germany riverine flooding
    - US hurricane season vs. South-east Asia typhoon season
- Comparison between events in different years and regions
    - US hurricane: Hurricane Sandy 2012 vs Hurricane Katrina 2005
    - Bangladesh: 1998 floods vs. 2004 floods

- Analyse local level sector data and resultant impacts to macro-economy
- Timing of insurance payments compared to timing of recovery
- Impact of alternative financing mechanisms

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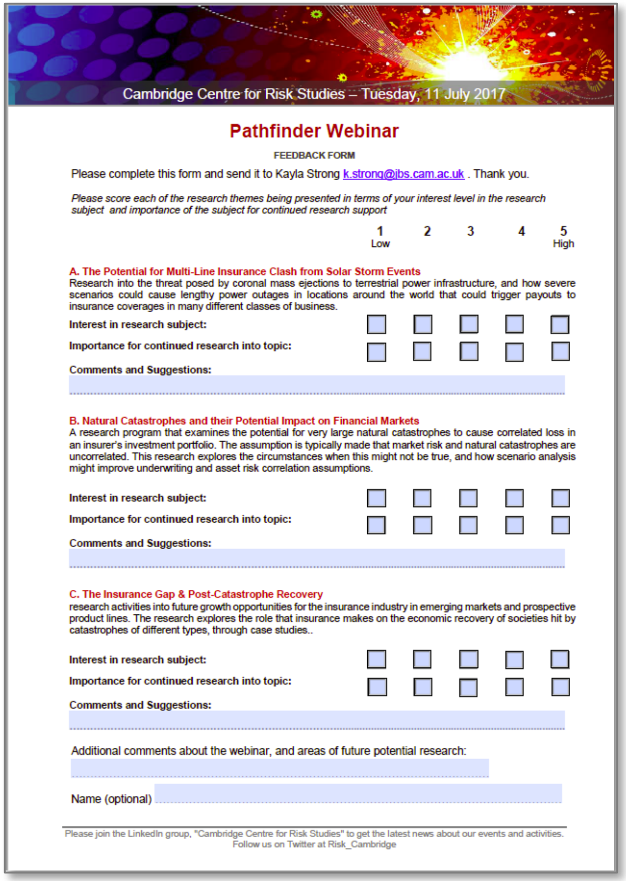
The Cambridge Centre for Risk Studies
Pathfinder Webinar

We value your feedback on this event.

Please complete the feedback form and return Kayla Strong at K.strong@jbs.cam.ac.uk

We look forward to keeping you updated on our research activities!

Thank you!



Cambridge Centre for Risk Studies – Tuesday, 11 July 2017

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FEEDBACK FORM

Please complete this form and send it to Kayla Strong k.strong@jbs.cam.ac.uk . Thank you.

Please score each of the research themes being presented in terms of your interest level in the research subject and importance of the subject for continued research support

	1 Low	2	3	4	5 High

A. The Potential for Multi-Line Insurance Clash from Solar Storm Events
Research into the threat posed by coronal mass ejections to terrestrial power infrastructure, and how severe scenarios could cause lengthy power outages in locations around the world that could trigger payouts to insurance coverages in many different classes of business.

Interest in research subject:

Importance for continued research into topic:

Comments and Suggestions:

B. Natural Catastrophes and their Potential Impact on Financial Markets
A research program that examines the potential for very large natural catastrophes to cause correlated loss in an insurer's investment portfolio. The assumption is typically made that market risk and natural catastrophes are uncorrelated. This research explores the circumstances when this might not be true, and how scenario analysis might improve underwriting and asset risk correlation assumptions.

Interest in research subject:

Importance for continued research into topic:

Comments and Suggestions:

C. The Insurance Gap & Post-Catastrophe Recovery
research activities into future growth opportunities for the insurance industry in emerging markets and prospective product lines. The research explores the role that insurance makes on the economic recovery of societies hit by catastrophes of different types, through case studies..

Interest in research subject:

Importance for continued research into topic:

Comments and Suggestions:

Additional comments about the webinar, and areas of future potential research:

Name (optional)

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