Cambridge Centre for Risk Studies

Research Showcase 22 June 2015

CATASTRONOMICS: THE ECONOMICS OF CATASTROPHES

Dr Scott Kelly

Senior Research Associate

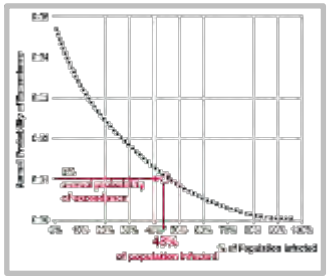
Centre for Risk Studies

Centre for **Risk Studies**

UNIVERSITY OF CAMBRIDGE
Judge Business School

CJBS 25

Cambridge Stress Test Scenarios



Context

A justification and context for a 1% annual probability of occurrence worldwide based on historical precedents and expert opinion

Timeline & Footprint

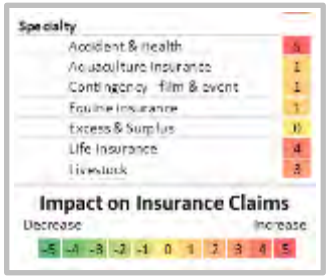
Sequencing of events in time and space in hypothetical scenario

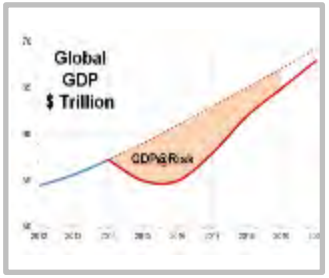
Narrative

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

Loss Assessment

Metrics of underwriting loss across many different lines of insurance business



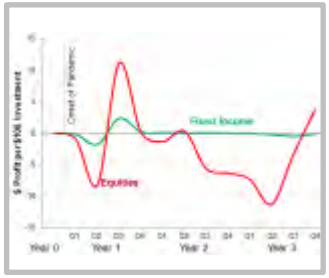


Macroeconomic Consequences

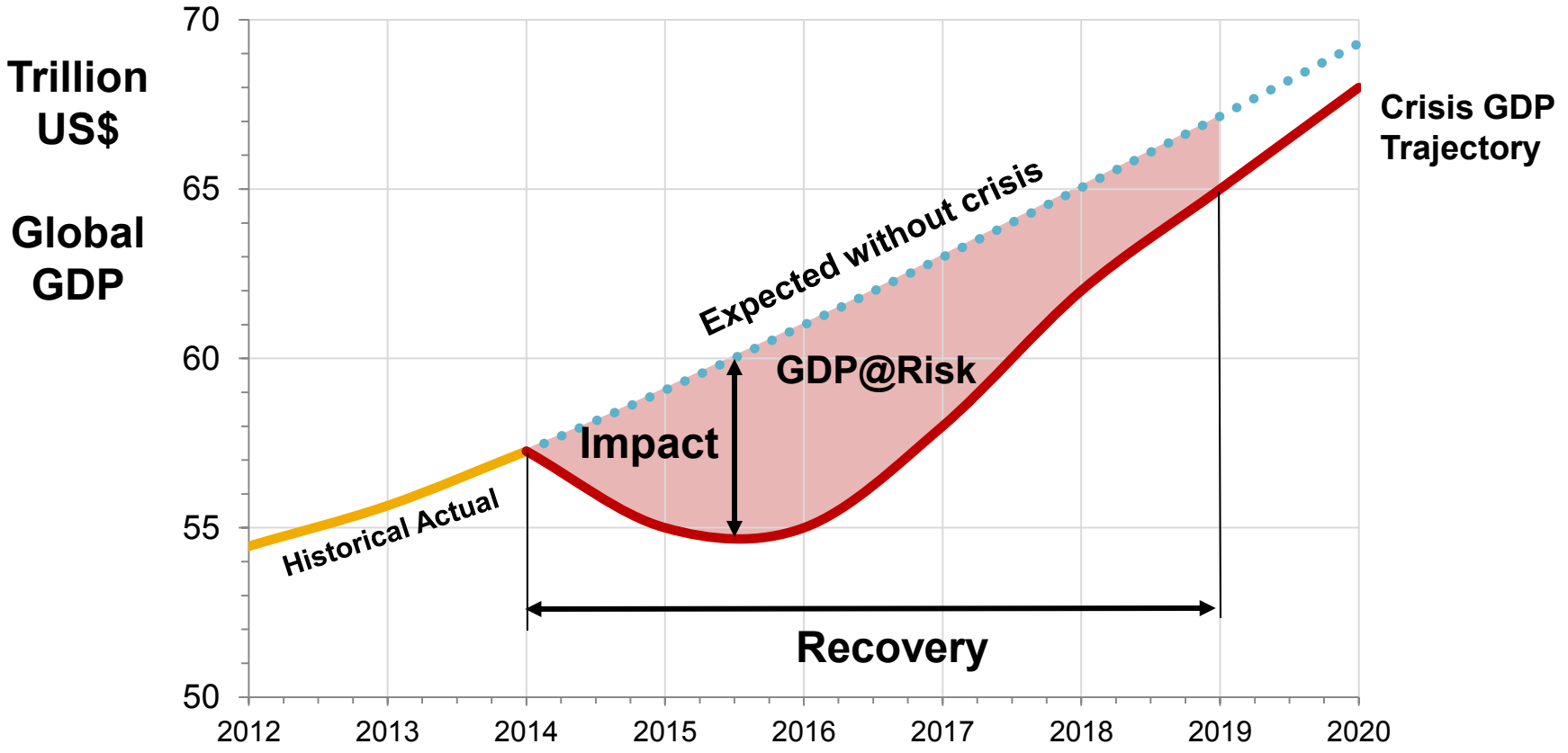
Quantification of effects on many variables in the global economy

Investment Portfolio Impact

Returns and performance over time of a range of investment assets

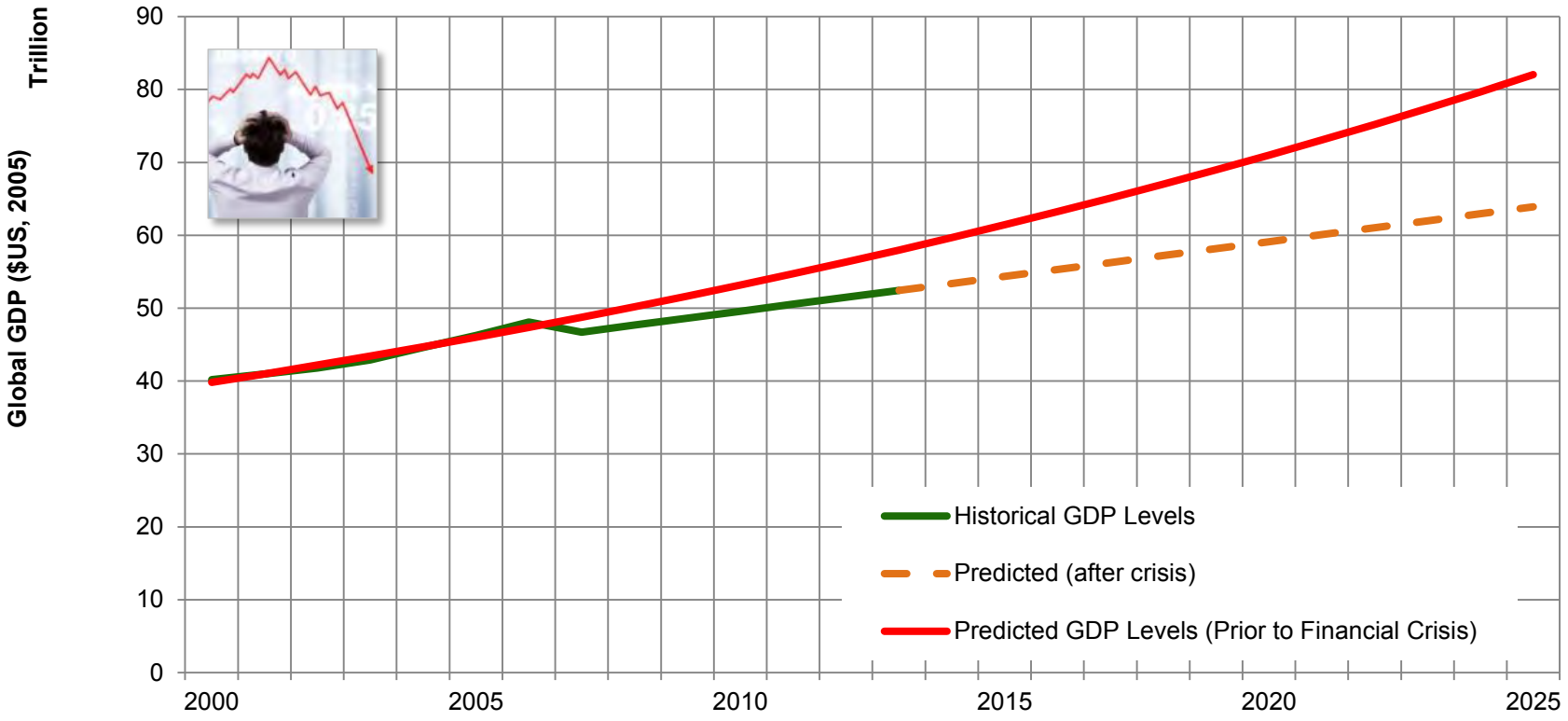


Estimating GDP@Risk



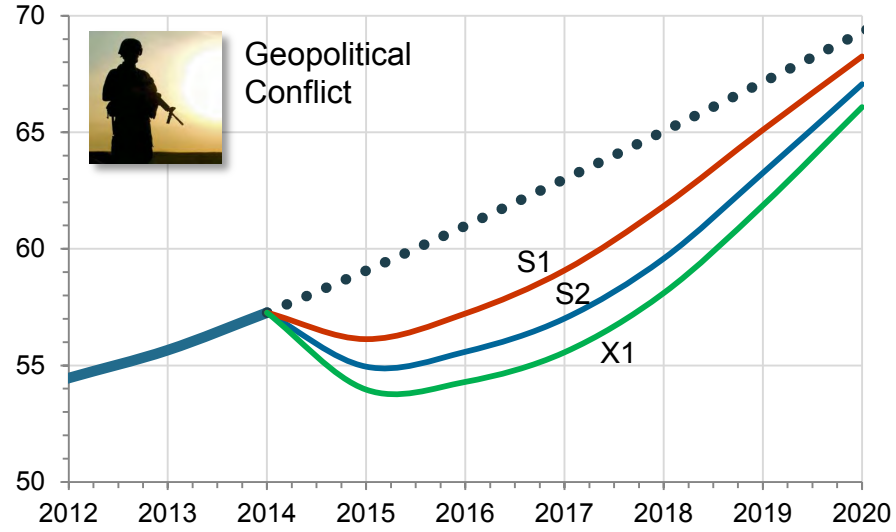
GDP@Risk: Cumulative first five year loss of global GDP, relative to expected, resulting from a catastrophe or crisis

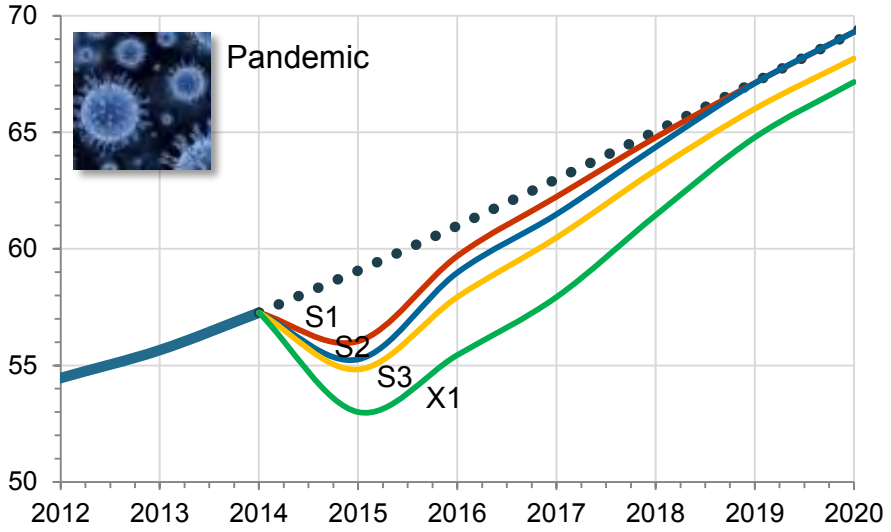
2007-12 Great Financial Crisis

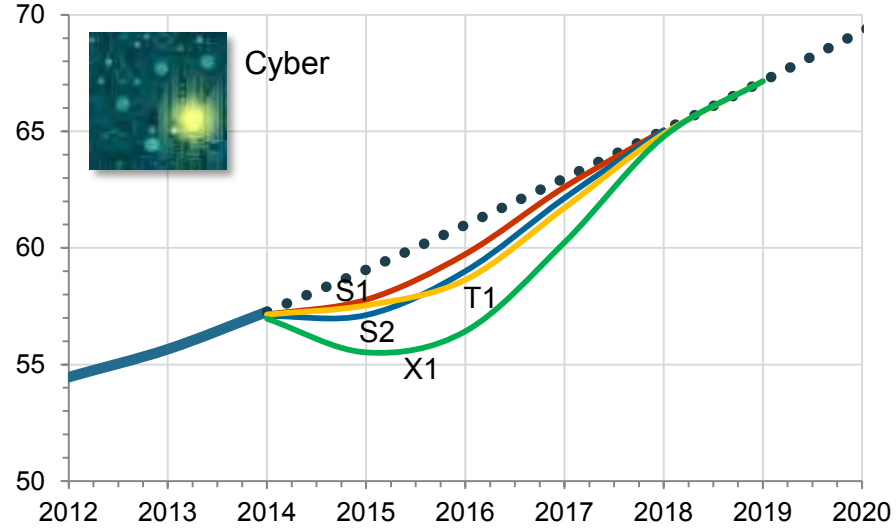


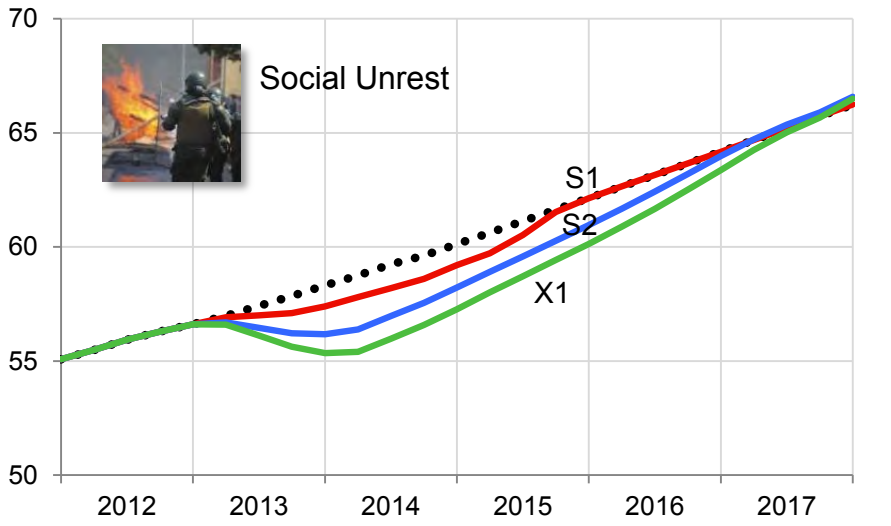
GDP@Risk: 20 Trillion ($US, 2010)
GDP@RR: 6.82%

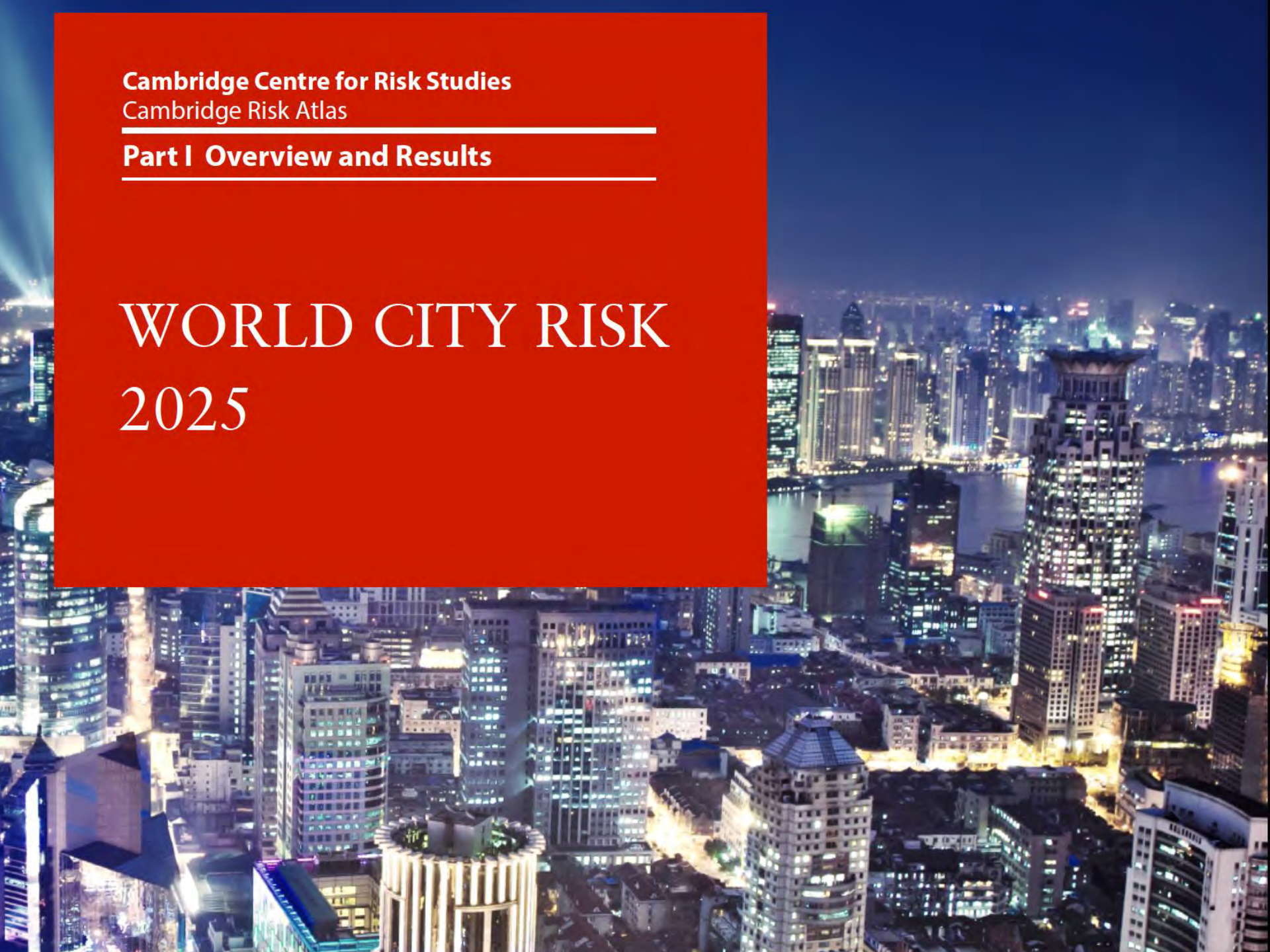
Scenarios and Their Variants: Shape of Impacts









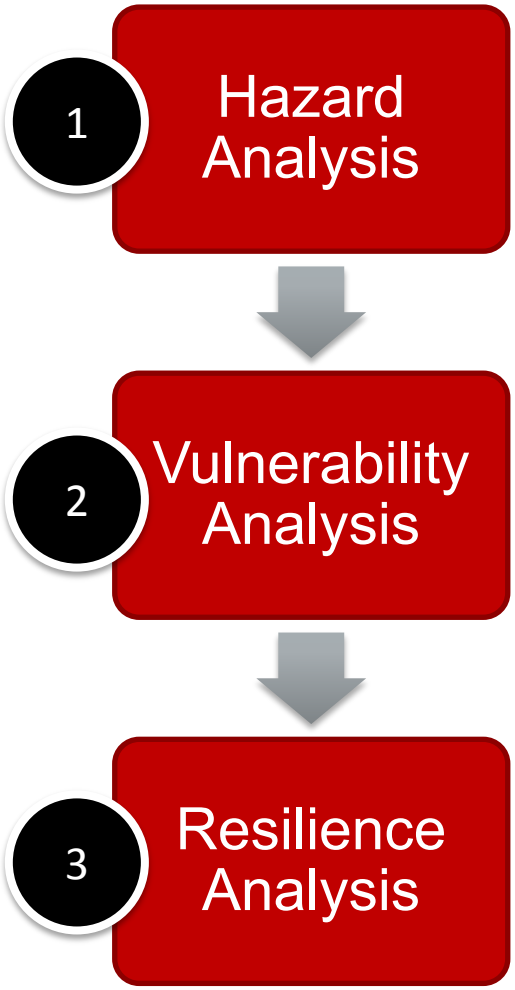


Cambridge Centre for Risk Studies
Cambridge Risk Atlas

Part I Overview and Results

WORLD CITY RISK 2025

Estimating the Economic Risk of Catastrophes



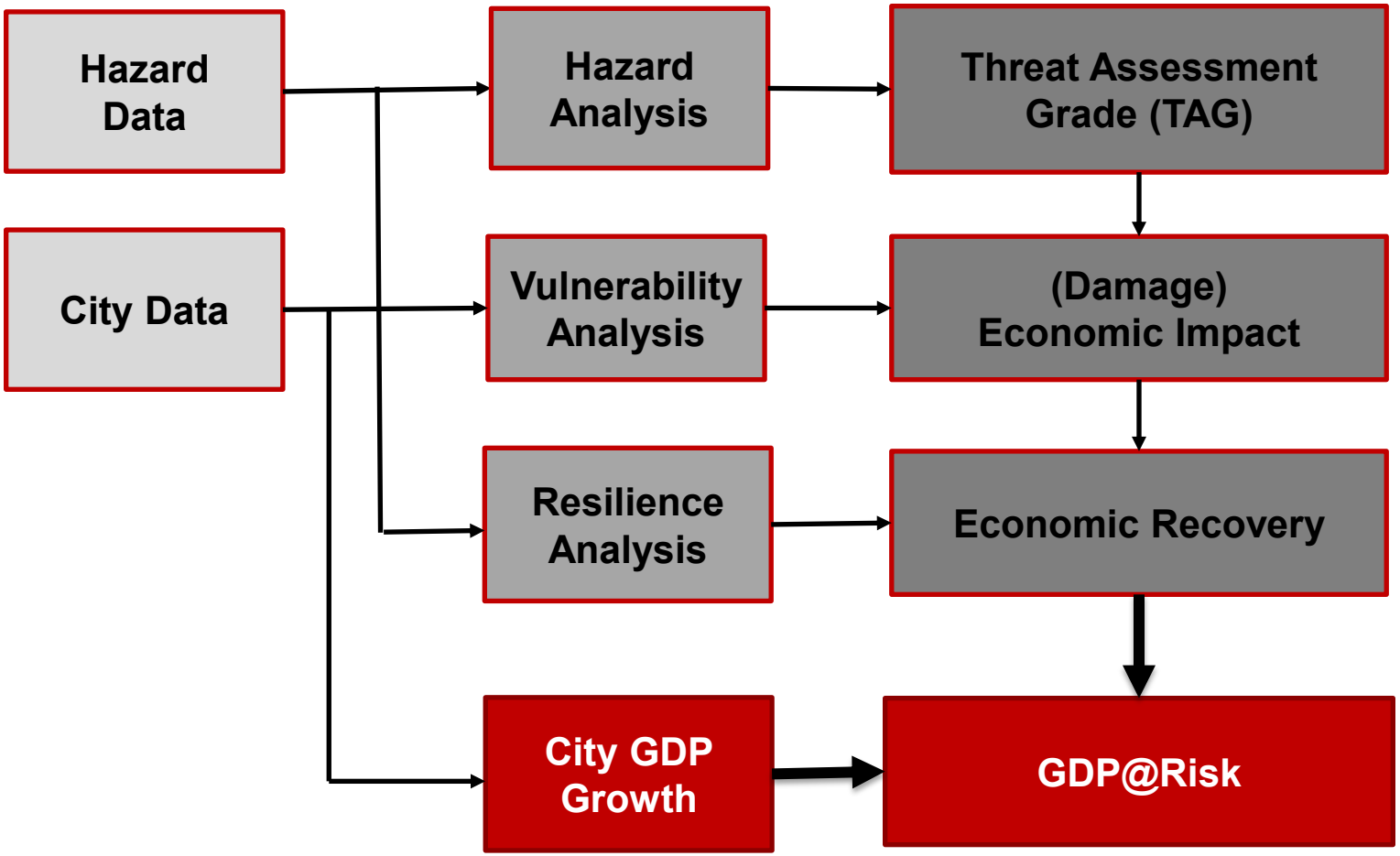
- What is the magnitude of the hazard?
- What is its probability and return period?

- How exposed are assets and infrastructure?
- What is the fragility of assets and infrastructure?

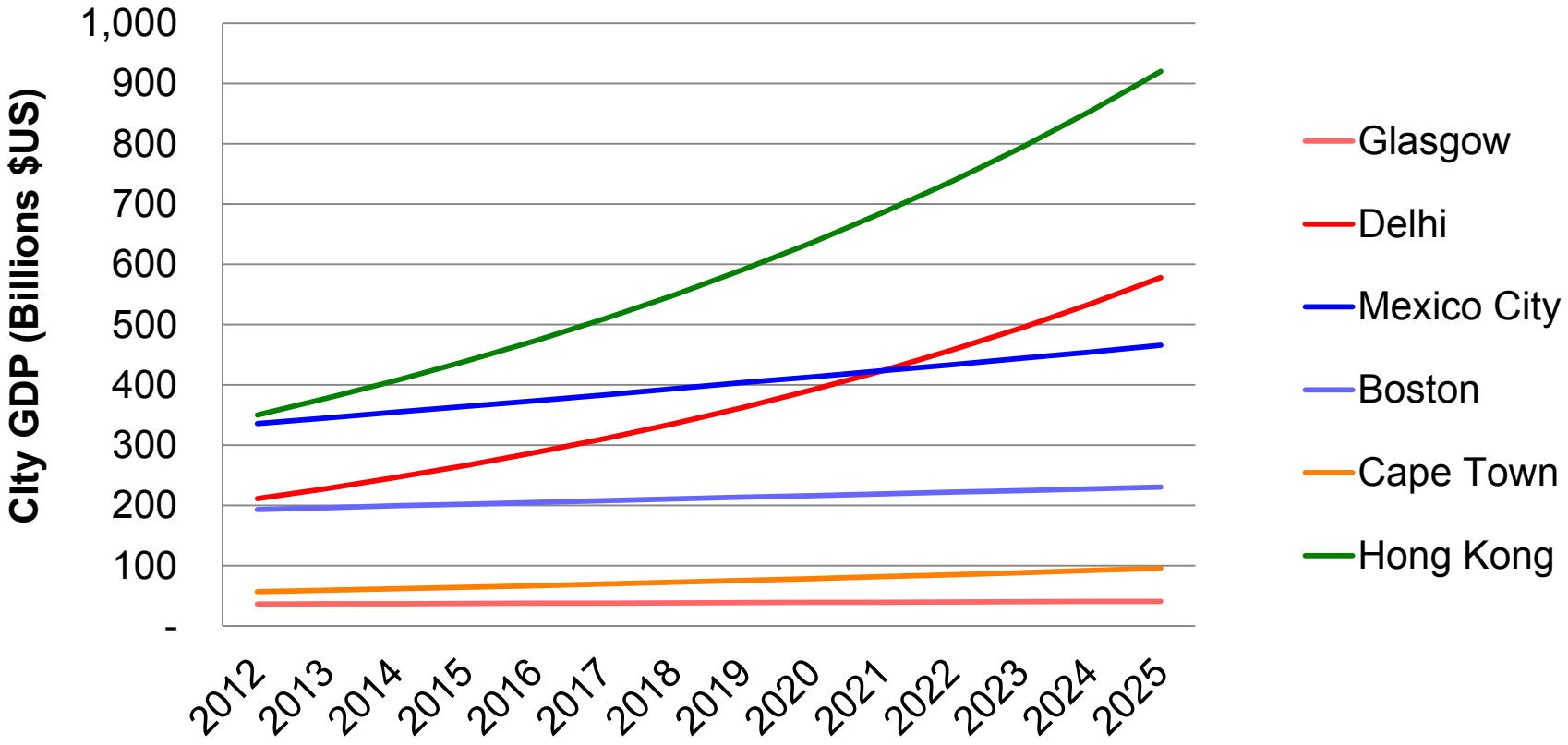
- How prepared are we to respond after a disaster?
- How quickly can we return to normal?

(V. Meyer, 2013)

GDP@Risk Estimation Process

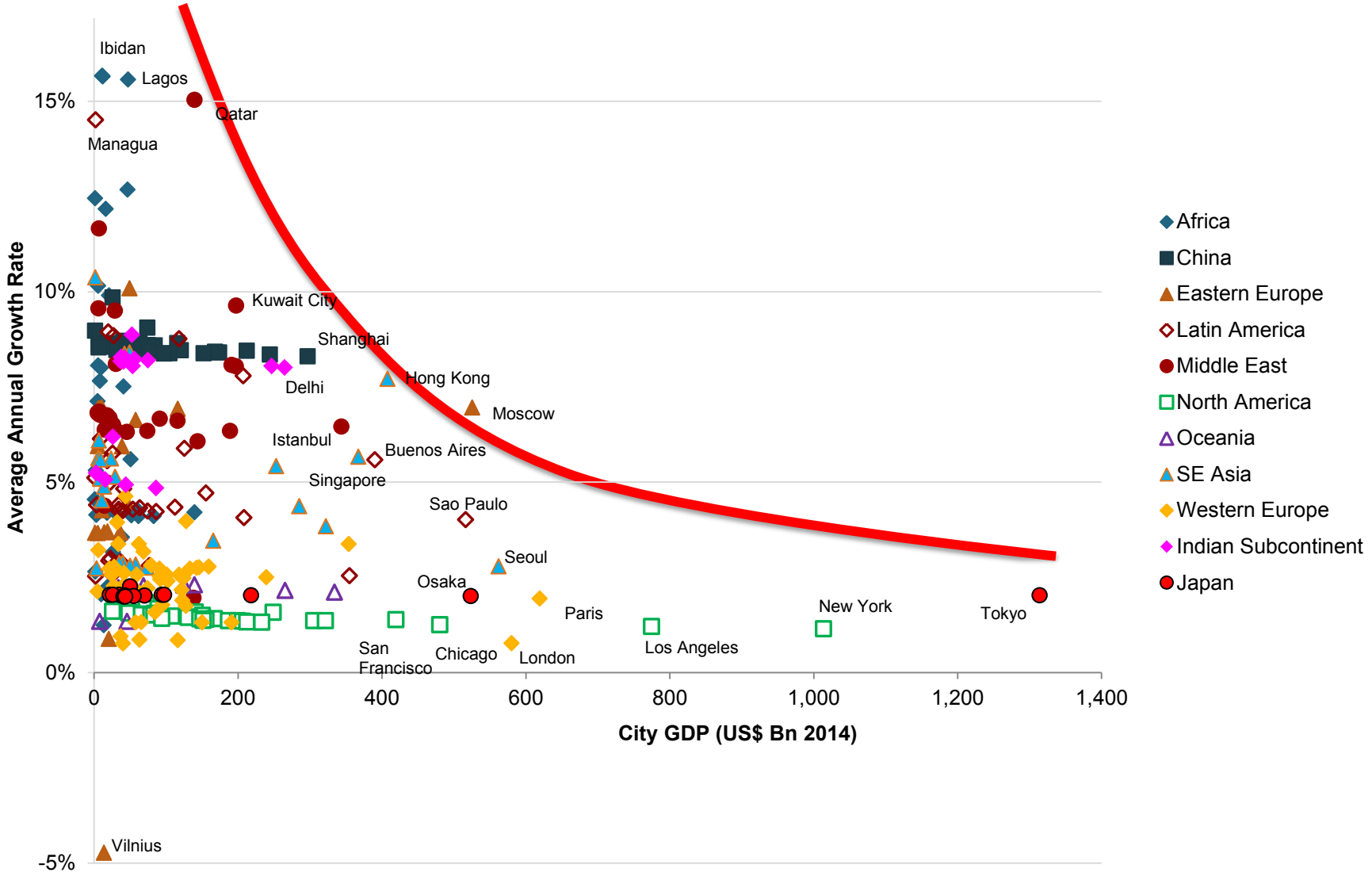


City GDP Projections



- GDP projections derived for each of 300 cities
- These draw on studies from McKinsey, Brookings Institute, OECD
- Projections take account of future GDP projections and future demographic change by city.

GDP and Growth



Overview of Threat Models

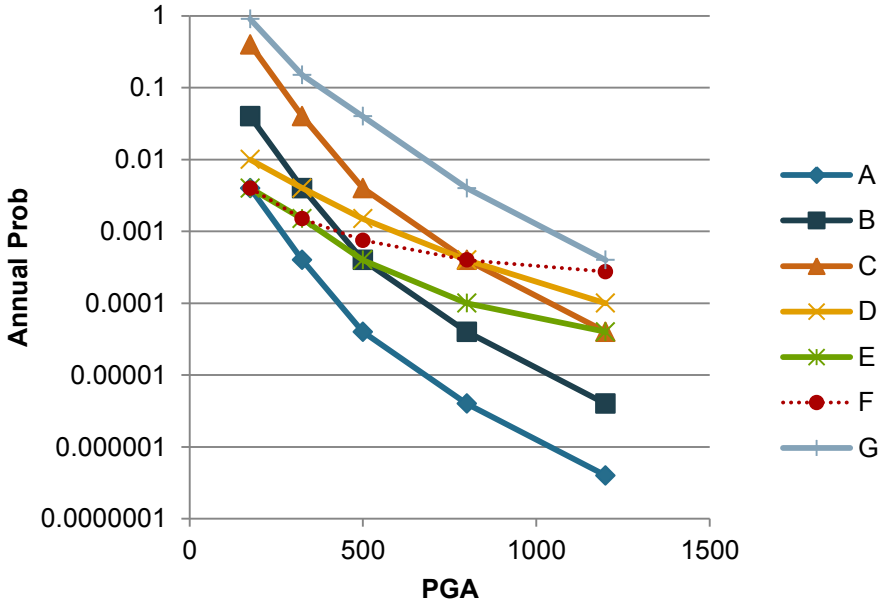
		ID	Threat	Phase	Hazard Map	Severity Scale	Cause	Projection	Uncertainty
Natural Catastrophe & Climate									
	1.1	EQ	**Earthquake**	1	United States Geological Survey; GSHAP	Ms (Surface-wave Magnitude)	Natural	Constant	Low
	1.2	VE	**Volcanic Eruption**	1	Smithsonian Institute of Volcanology	VEI (Volcanic Explosiivity Index)	Natural	Constant	Medium
	1.3	HU	**Tropical Windstorm**	2	EM-DAT; Pacific Research Center; Munich Re	Saffir-Simpson CAT Hurricane Scale	Natural	CC Trend	Low
	1.4	WS	**Temperate Windstorm**	2	EM-DAT Windstorm Database	Beaufort Wind Scale	Natural	CC Trend	Low
	1.5	FL	**Flood**	1&2	UNEP/DEWA/GRID-Europe Flood Risk Rating	Depth and velocity of flood water	Natural	CC Trend	Low
	1.7	TS	**Tsunami**	2	NOAA NCDC Historical Tsunami Database	Run-up height	Natural	CC Trend	Medium
	1.8	DR	**Drought**	2	US National Center for Atmospheric Research	Palmer Drought Severity Scale	Natural	CC Trend	Medium
	1.10	FR	**Freeze**	2	Global Climate Zoning Map	Degree-Days below 0C	Natural	CC Trend	Medium
	1.11	HW	**Heatwave**	2	Global Climate Zoning Map	Degree-Days Above 32C	Natural	CC Trend	Medium
Financial, Trade & Business									
	2.1	MC	**Market Crash**	1	IMF Banking Network Core-Periphery Designation	S&P500 Index reduction	Man-Made	Dynamic	High
	2.2	SD	**Sovereign Default**	1	S&P National Credit Ratings	% Devaluation of national currency	Man-Made	Dynamic	Medium
	2.3	OP	**Oil Price Shock**	2	UN imported oil intensity of GDP output	% increase in oil price (Brent Crude)	Man-Made	Dynamic	Medium
Political, Crime & Security									
	3.1	IW	**Interstate War**	1	Cytora Interstate Conflict Scenario Set	War Magnitude Scale	Man-Made	Dynamic	High
	3.2	SP	**Separatism**	1	Encyclopedia of Modern Separatist Movements	Civil War Intensity (deaths)	Man-Made	Dynamic	Medium
	3.3	TR	**Terrorism**	1	IEP START Global Terrorism Index	Terrorism Severity Scale	Man-Made	Dynamic	Medium
	3.4	SU	**Social Unrest**	2	Cytora Social Unrest Event Index	Social Unrest Severity Scale		Dynamic	Medium
Technology & Space									
	4.1	PO	**Power Outage**	2	Nation Master Electrical Outage Report	City-Days of Outage	Man-Made	Constant	Medium
	4.2	CY	**Cyber Catastrophe**	1	McAfee International Cyber Risk Report	Cyber Magnitude & Revenue@Risk	Man-Made	Dynamic	High
	4.3	SS	**Solar Storm**	2	US National Oceanic and Atmospheric Administration	US NOAA Space Weather Scale	Natural	Constant	High
	4.4	NP	**Nuclear Meltdown**	2	World Nuclear Association Information Library	Intntl Nuclear Events Scale (INES)	Man-Made	Constant	Low
Health & Environmental									
	5.1	HE	**Human Epidemic**	1	Emerging Infectious Diseases, Institute of Zoology	US CDC Pandemic Severity Index	Natural	Dynamic	Medium
	5.2	PE	**Plant Epidemic**	2	Wallingford Distribution Maps of Plant Diseases	Staple Crop (Wheat) Price Index	Natural	Dynamic	Medium

Hazard Analysis - TAGs

Data and Science → Geographical Mapping → Frequency Severity → Define Three Scenarios → TAG Cities

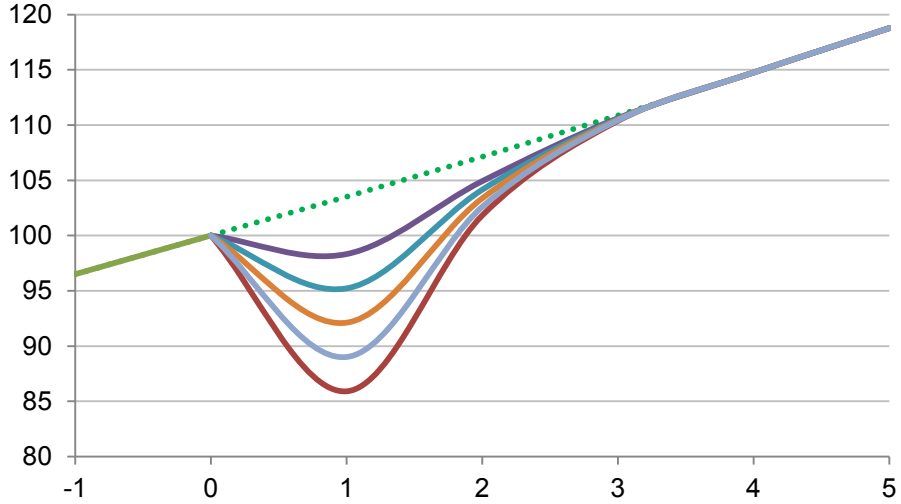
Quake Map Banding of City					PGA 2500		
					250-400	400-600	600-1000
					VII	VIII	XI
PGA 250					0.0004	0.0004	0.0004
	MidRange	MMI equiv	Annual Frequency				
100-250	175	VI	0.004		**A**	**E**	**F**
250-400	325	VII	0.004			**B**	**D**
400-600	500	VIII	0.004				**C**
600-1000	800	XI	0.004				**G**

		Annual Probs						
	PGA	A	B	C	D	E	F	G
VI	175	0.004	0.04	0.4	0.01	0.004	0.004	0.9
VII	325	0.0004	0.004	0.04	0.004	0.0015	0.0015	0.15
VIII	500	0.00004	0.0004	0.004	0.0015	0.0004	0.00075	0.04
XI	800	0.000004	0.00004	0.0004	0.0004	0.0001	0.0004	0.004
XI	1200	0.0000004	0.000004	0.00004	0.0001	0.00004	0.000275	0.0004



City Vulnerability Analysis

	Small	Medium	Large
1 Very Strong	97.0%	95.0%	80.0%
2 Strong	95.0%	85.0%	70.0%
3 Moderate	90.0%	75.0%	60.0%
4 Weak	80.0%	68.0%	50.0%
5 Very Weak	75.0%	50.0%	40.0%

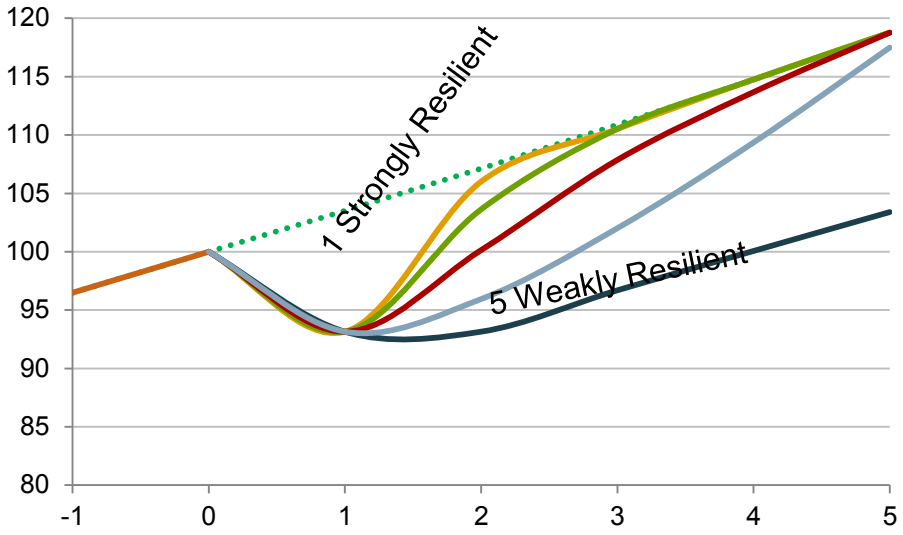


- **Physical vulnerability** includes assessment of the quality of buildings and compliance to construction codes.
- **Flood vulnerability** considers water damage loss by economic sector
- **Cyber vulnerability** considers the reliance on IT and its criticality for the city's economic output
- **Financial vulnerability** considers connectivity and impact from a financial crisis
- **Pandemic vulnerability** includes healthcare index assessment by World Health Organization

City Resilience Analysis

Recovery Period

	Small	Medium	Large
1 Very Strong	3	3	3
2 Strong	3	3	3
3 Moderate	3	4	6
4 Weak	4	4	7
5 Very Weak	4	5	8



- The speed of recovery of the city is influenced by its social and economic resilience, and physical capacity to respond
- We have developed a resilience classification (1-5) for cities based on four factors
  - Governance; Social coherence; Economic strength; Infrastructure systems
- Recovery is calibrated from precedent studies of economic recovery after disaster

Analysis of Economic Loss

- The GDP estimates include:
  - Supply Shock
    - Destruction of physical infrastructure (conditions of production)
    - Disruption to labour (lower productivity)
    - Capital flight (lower investment)
    - Loss of ability to supply export markets (global contagion)
  - Demand Shock
    - Public morale and confidence
    - Equity markets
    - Change in demand for imports
  - Government emergency response stimuli
  - Inflation and increased cost of inputs

Vulnerability (Earthquake)

Resilience	Example cities
1 – Very Strong	New York, San Diago, Tokyo, Dublin, Helsinki, Singapore, Santiago
2 – Strong	Berlin, Paris, Leeds, Rome, Montreal, Adelaide, Madrid, Amsterdam
3 – Moderate	Beijing, SauPaulo, Seol, Ankara, Izmir, Warsaw, Buenos Aires
4 – Weak	Moscow, Delhi, Cape Town, Durban, Bangkok, Lahore, Ho Chi Minh
5 – Very weak	Douala, Abidjan, Accra, Pyongyang, Dakar, Lusaka, Harare

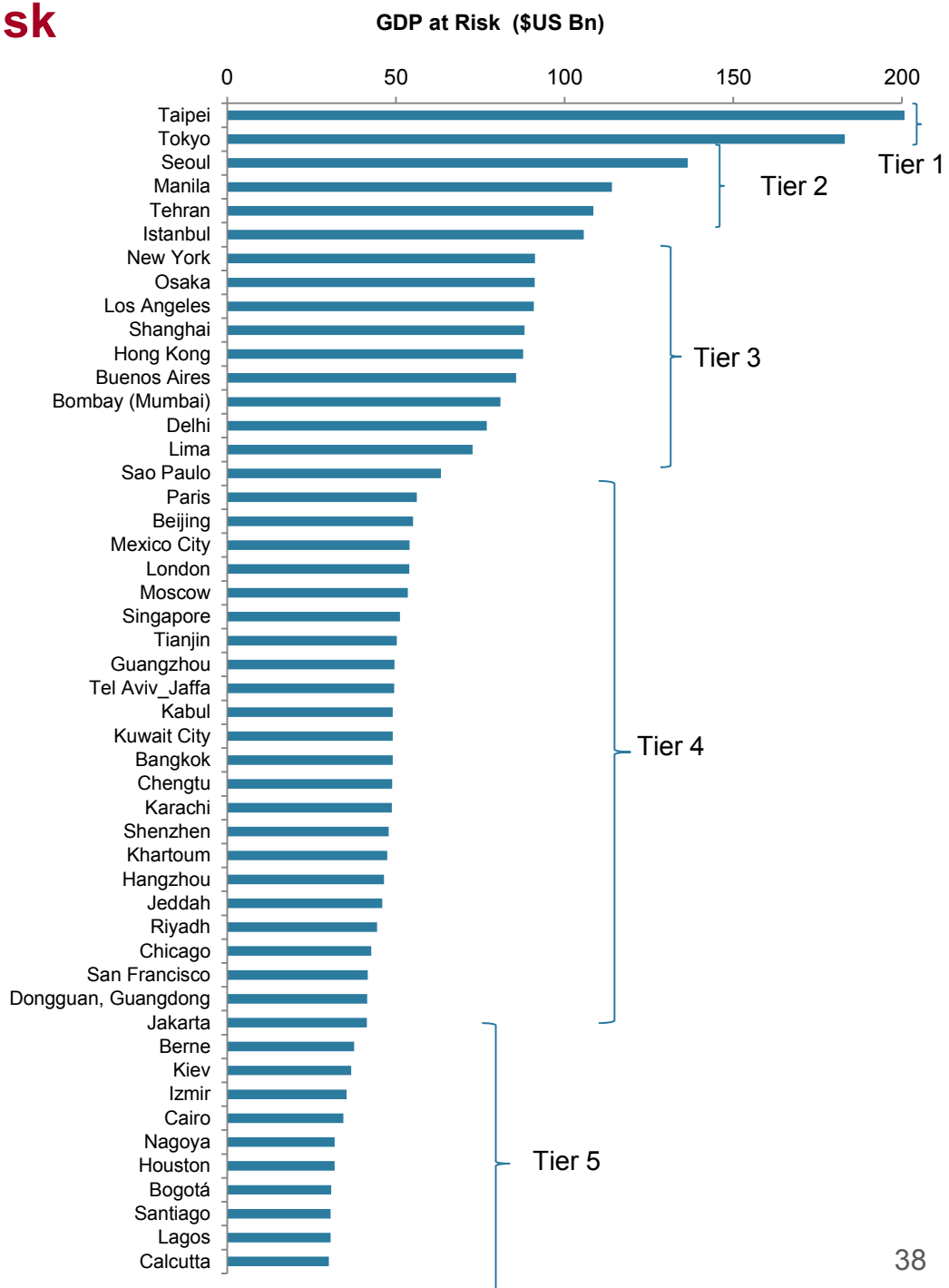
Resilience (Earthquake)

Resilience	Example countries
1 – Very Strong	New Zealand, Singapore, Japan, Germany, United Kingdom
2 – Strong	Chile, Kuwait, Israel, United Arab Emirates, Taiwan
3 – Moderate	Greece, Hungary, Czech Republic, Georgia, Brazil
4 – Weak	Armenia, Morocco, Philippines, Argentina, Guatemala
5 – Very weak	Kenya, Tanzania, Ethiopia, Cote d'Ivoire, Myanmar

Top 50 Cities by GDP at Risk

($Bn 2015-2025)

Rank	City Name	GDP@Risk ($US Bn)
1	**Taipei**	201.62
2	**Tokyo**	183.07
3	Seoul	136.52
4	Manila	114.02
5	Tehran	108.50
6	Istanbul	105.65
7	New York	91.25
8	Osaka	91.11
9	Los Angeles	90.84
10	Shanghai	88.15
11	Hong Kong	87.72
12	Buenos Aires	85.60
13	Bombay (Mumbai)	80.99
14	Delhi	76.96
15	Lima	72.69
16	Sao Paulo	63.36
17	Paris	56.23
18	Beijing	55.10
19	Mexico City	54.04
20	London	53.92
21	Moscow	53.52
22	Singapore	51.18
23	Tianjin	50.24
24	Guangzhou	49.56
25	Tel Aviv_Jaffa	49.48
26	Kabul	49.05
27	Kuwait City	49.04
28	Bangkok	49.04
29	Chengtu	48.86
30	Karachi	48.79
31	Shenzhen	47.83
32	Khartoum	47.43
33	Hangzhou	46.46
34	Jeddah	45.93
36	Riyadh	44.43
37	Chicago	42.67
38	San Francisco	41.63
39	Dongguan, Guangdong	41.51
40	Jakarta	41.42
41	Berne	37.59
42	Kiev	36.73
43	Izmir	35.40
44	Cairo	34.42
45	Nagoya	31.84
46	Houston	31.83
47	Bogotá	30.77
48	Santiago	30.66
49	Lagos	30.64
50	Calcutta	30.12

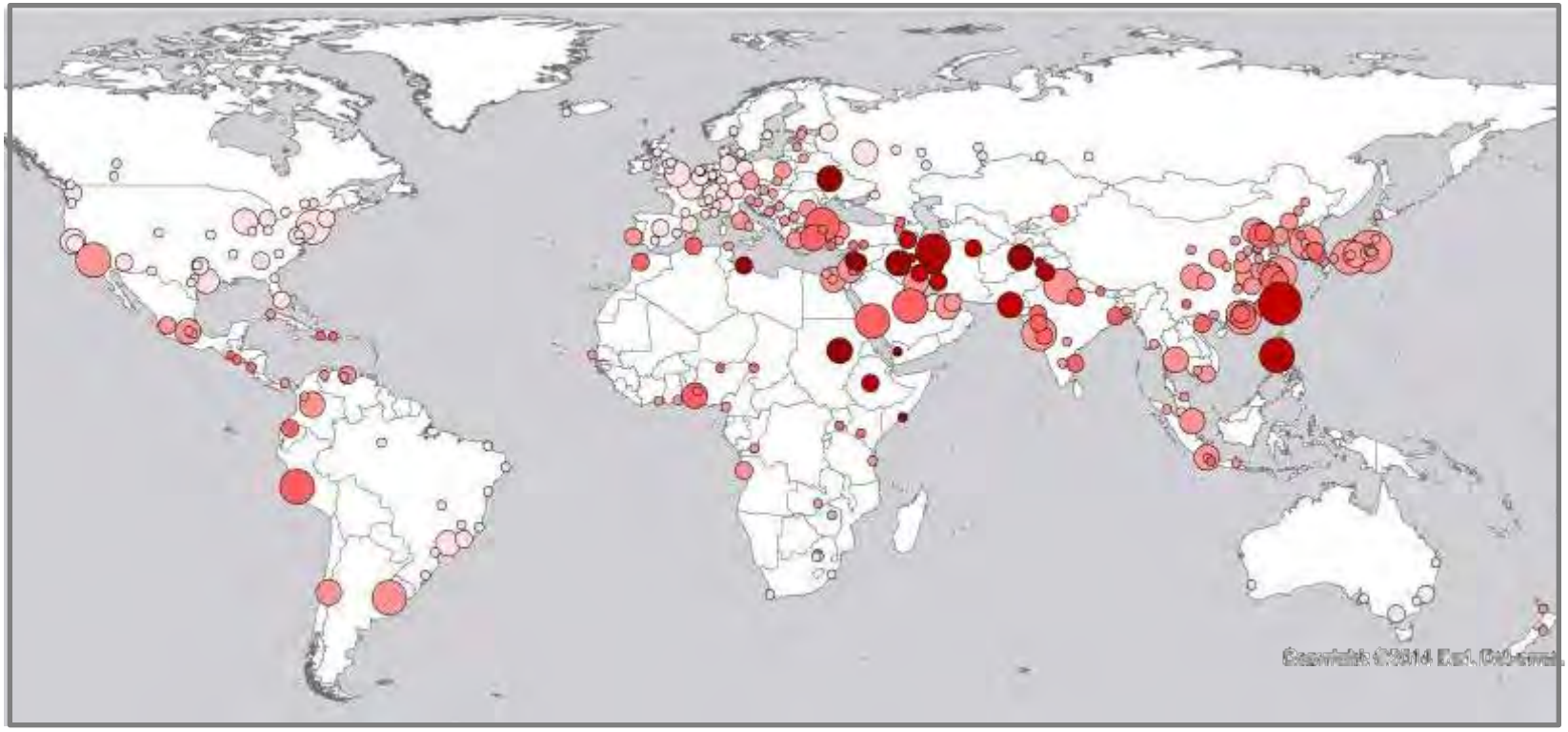


What is Driving the GDP@Risk of Highest Risk Cities?

Tiers 1 and 2

Rank [Total GDP at Risk]	1	2	3	4	5	6
CRS City ID	TWN_5155	JPN_KNT	KOR_SJK	PHL_NCR	IRN_TER	TUR_IST
City Name	**Taipei**	**Tokyo**	**Seoul**	**Manila**	**Tehran**	**Istanbul**
CRS Country ID	TWN	JPN	KOR	PHL	IRN	TUR
Country Name	Taiwan, Province of C	Japan	Korea, Republic of	Philippines	Iran, Islamic Republic	Turkey
Earthquake	14.72%	10.28%	0.00%	11.66%	31.85%	28.43%
Volcano	3.49%	4.94%	0.62%	5.09%	0.00%	0.00%
Wind Storm	40.25%	15.87%	32.73%	53.21%	0.00%	0.00%
Temperate Wind Storm	0.00%	0.00%	0.00%	0.00%	0.23%	0.00%
Flooding	5.33%	9.64%	7.20%	4.79%	2.37%	5.17%
Tsunami	0.00%	2.05%	0.00%	0.45%	0.00%	0.00%
Drought	0.39%	1.57%	4.46%	1.63%	1.73%	1.82%
Freeze	0.00%	0.72%	1.04%	0.00%	0.00%	0.00%
Heatwave	0.00%	0.36%	0.00%	0.00%	0.00%	0.21%
Market Crash	14.18%	12.51%	9.25%	4.20%	5.49%	8.07%
Sovereign Default	0.11%	0.41%	1.48%	0.63%	8.98%	10.22%
Oil Price	3.85%	11.68%	9.32%	2.09%	-3.78%	9.03%
Interstate War	10.05%	16.16%	24.12%	11.08%	37.93%	12.78%
Separatism	0.00%	0.00%	0.00%	0.00%	6.47%	5.83%
Terrorism	0.00%	0.12%	0.14%	0.67%	2.39%	1.94%
Social Unrest	0.07%	0.11%	0.07%	0.25%	0.26%	3.31%
Electrical power outage	0.61%	1.24%	0.74%	0.41%	0.58%	1.08%
Cyber	2.55%	3.33%	1.98%	0.25%	0.46%	2.18%
Solar Storm	0.30%	1.32%	0.79%	0.27%	0.31%	0.77%
Nuclear Power Plant Accident	0.28%	0.16%	0.00%	0.00%	0.00%	0.00%
Pandemic	3.52%	6.72%	5.58%	3.06%	4.32%	8.68%
Plant Epidemic	0.29%	0.81%	0.48%	0.25%	0.42%	0.47%
Total GDP at Risk ($US Bn)	**201.62**	**183.07**	**136.52**	**114.02**	**108.50**	**105.65**

Overall GDP@Risk



Cities - GDP at Risk - Total US$ (Bn)

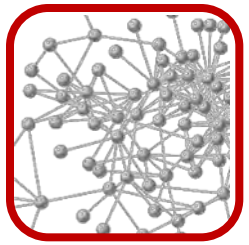
- 0.0 - 12.0
- 12.1 - 30.0
- 30.1 - 65.0
- 65.1 - 115.0
- 115.1 - 217.0

Cities - GDP at Risk - Total %

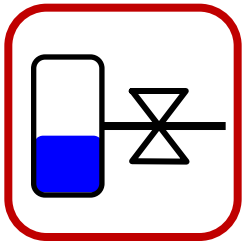
- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 6
- 6 - 12

Research Agenda for Catastronomics

Hazard, vulnerability and resilience

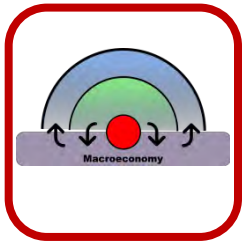


Networks of networks



Stocks and flows

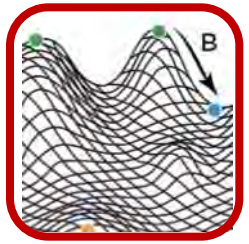
Complex dynamic feedback



Direct and indirect effects

Superstructure

Ripple and cascade phenomenon



Evolutionary dynamics

Methods and Models in Catastronomics

Scenario Analysis	Stress Testing	Counterfactual Analysis	Case Study
General Equilibrium Models	Econometric Analysis	Network Analysis	Expert Opinion and Interviews
Frequency Severity Analysis	Historical Analysis	Financial Portfolio Analysis	Integrated Assessment Models
Input-Output Analysis	Agent-Based Modelling	Systems Dynamics Models	Graphical Information Systems

The Four Stages of Model Development

- Uncertainty analysis
- Sensitivity analysis
- Expert opinion
- Model inter-comparison

- Historical data (ex post)
- Modelled data (ex ante)
- Access and retrieval
- Compare and contrast

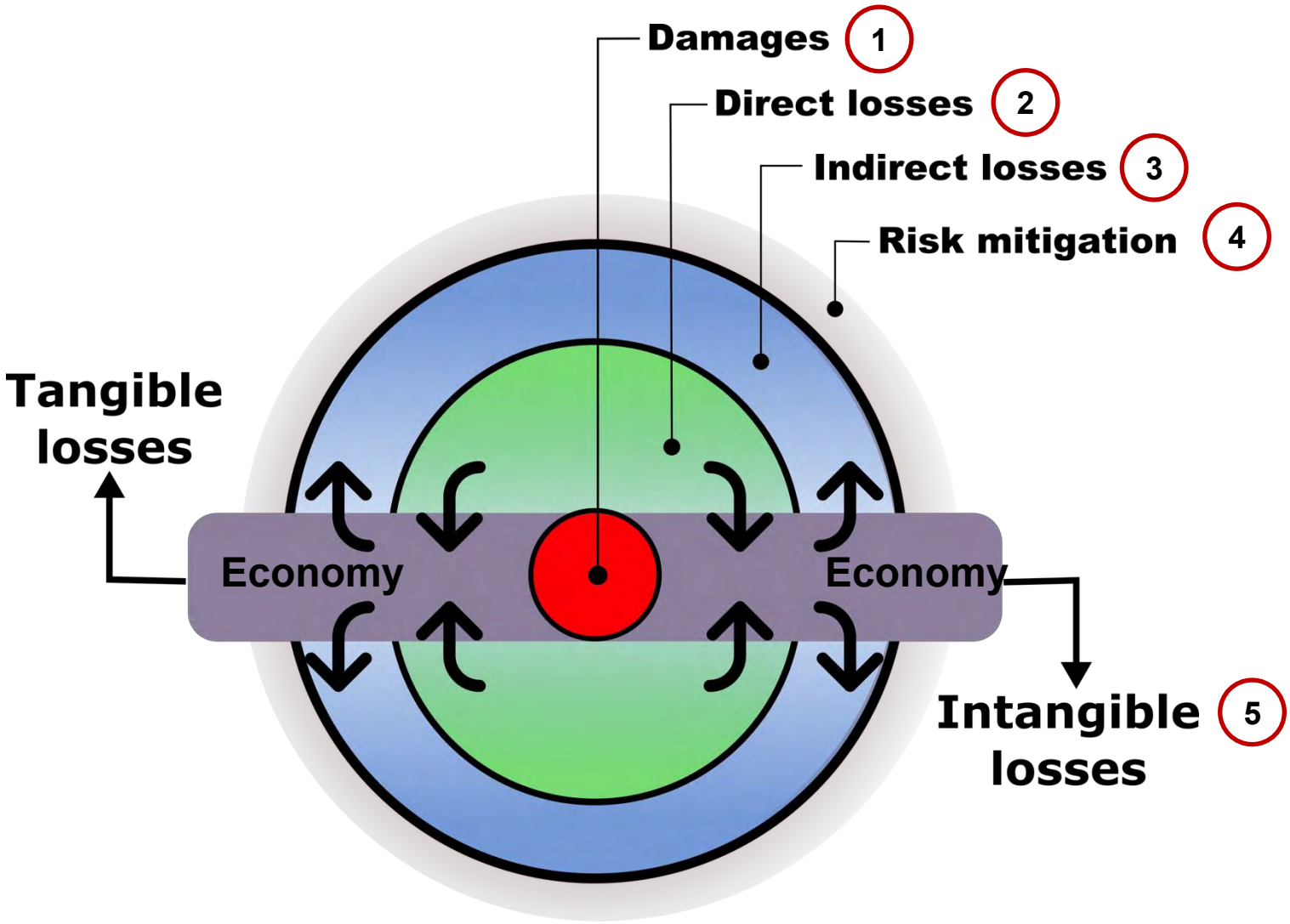
- Using latest science
- Theoretical approach
- What economic model
- Stochastic process

- Plausibility
- Target audience
- Type of output
- Visualisations

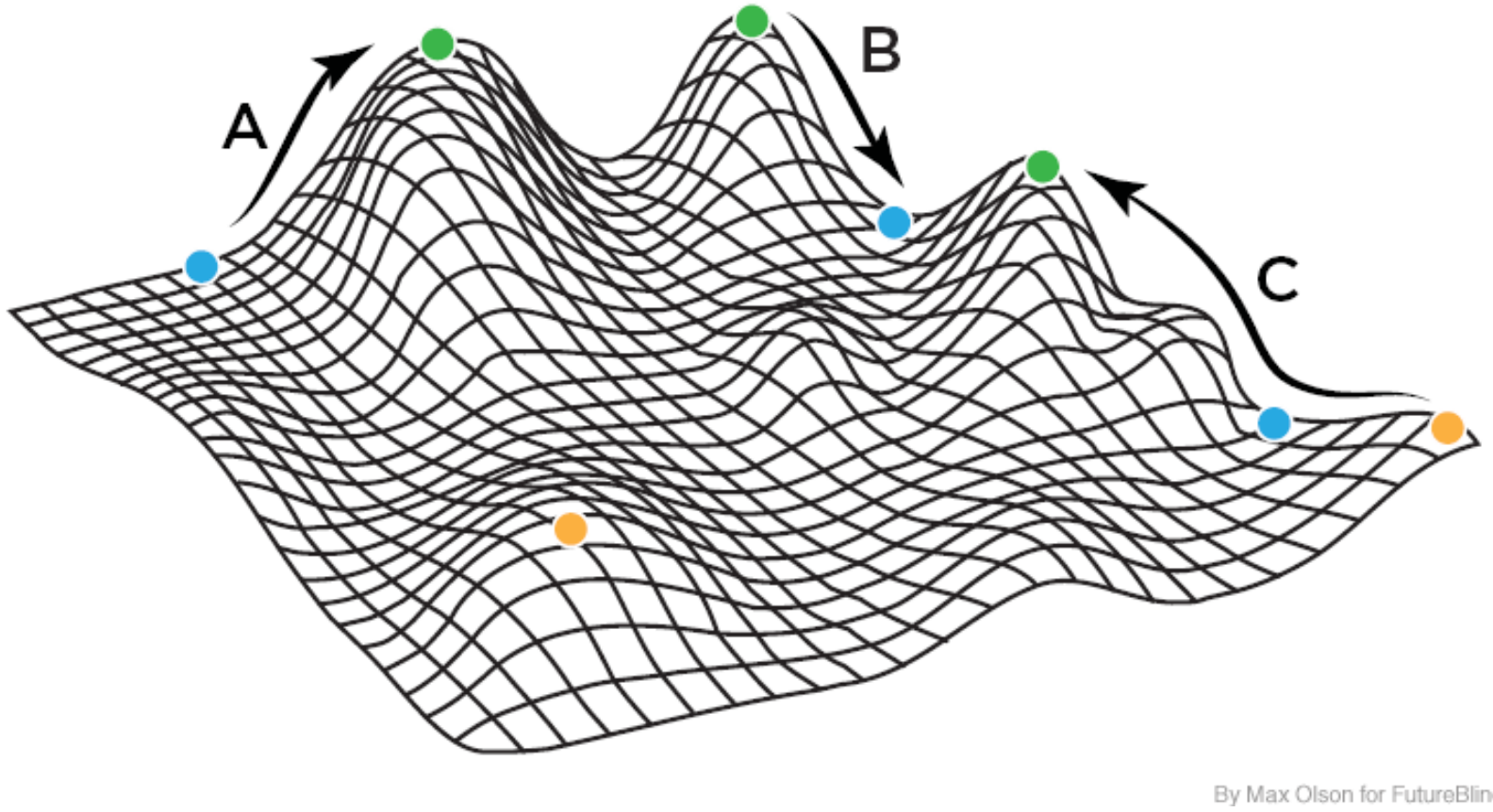
Reducing Uncertainty in Catastronomics

- **Model validation**
  - Sensitivity analysis
  - Compare predicted estimates with actuals
  - Expert knowledge
  - Model inter-comparison
  - Evaluate process of model construction
- **Better understanding of complexity**
  - Myopia - one impact, one sector
  - Dynamic processes and interventions
  - Positive and negative feedback loops
  - Improved understanding of networks and interdependency
  - No account of coinciding or cascading hazards

Estimating Economic Costs



Evolutionary Catastrophe Risk-Scape



Depiction of a fitness landscape from evolutionary biology

(Mustonen & Lässig, 2009)

Conclusions

- Catastrophes invoke highly **complex dynamic processes**
  - Interaction between complex systems ➡ emergent behaviour
  - Social and political systems very important
- Catastronomics requires an **holistic approach**
  - It is an interdisciplinary science crossing natural and social sciences
  - An integrated multi-methods approach is required
- We cannot solely depend on **historical precedence**
  - Evolutionary theory tells us that a change in environmental conditions changes the rules of competition ➡ structures, states and equilibriums
- **Bespoke models** in catastronomics are required for estimating the full economic impacts of disasters.

Final Comment:

- Catastrophes are **inherent** and **unpredictable**, but understanding the complex response of the economic system will help in the development of better **resilience management solutions**.

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Judge Business School