Lloyds City Risk Index 2015-2025
August 2014

Methodology and Usage of City Economy Risk Analysis

Centre for Risk Studies
UNIVERSITY OF CAMBRIDGE Judge Business School
LLOYD'S
Developing the City Risk Index

Andrew Coburn
Cambridge Centre for Risk Studies
Acknowledgements

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Results and outputs of this research do not imply any endorsement by Lloyd’s

Any errors and omissions are entirely those of the research team of the Cambridge Centre for Risk Studies

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Lloyd’s City Risk Index 2015-2025

301 cities
18 threats
US$4.56trn at risk

Lloyd’s City Risk Index 2015-2025 analyses the potential impact on economic output (GDP@Risk) of 301 of the world’s major cities from 18 manmade and natural threats.

Based on original research by the Cambridge Centre for Risk Studies at the University of Cambridge Judge Business School, the Index shows that governments, businesses and communities are highly exposed to systemic, catastrophic shocks and must do more to mitigate...
What’s Ground Breaking About this Study?

- This study looks at risk of economic output from catastrophes
  - Not just how catastrophes damage property
- It analyses cities as urban economic systems
  - Compiled profiles of the economies of 301 of the world’s leading cities
- We have analyzed a wide range of catastrophe threats
  - Developed assessments of likelihood of 18 threat types impacting each city
  - In some cases, pioneered analysis of previously un-modelled threats
- Developed metrics for economic consequences of catastrophe
  - GDP@Risk
- Provided a framework for thinking about this problem
  - Identifying which cities and threats are most important
Cities and Economies

- A city economy is a system

**People**

**Physical Assets**

**Utilities**

**Connections**
The world’s economy is increasingly urbanized.

For example...

London economic region has increased its share of UK output from 15% in 1960s to 45% today.
Towards the Knowledge Economy

Cities economies categorized by type

- **G: Agriculture with Industry & Service**
  - Agriculture: 39%
  - Industrial: 37%
  - Service: 24%

- **E: Industrial-Oriented Economy**
  - Agriculture: 33%
  - Industrial: 63%
  - Service: 3%

- **A: Service-Dominated Economy**
  - Agriculture: 4%
  - Industrial: 63%
  - Service: 33%

New Old

Cities economies categorized by type

- **G: Agriculture with Industry & Service**
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Earthquake

Event: Great Hanshin earthquake, 1995
Location: Kobe, Japan

Economic cost: $150bn, two-thirds in infrastructure and property damage and one-third in economic disruption.

Description: A magnitude 6.9 earthquake struck 20 kilometres from the city of Kobe, 16 kilometres below its epicentre, on 17 January 1995.

Damage: More than 6,400 people died and 15,000 were injured. Around 82 hectares of urban land was devastated by fire. The city’s subway system and stations were damaged, along with 400,000 buildings, and its supply lines interrupted by damage to regional trunk roads, monorails, railway lines and stations. Liquefaction wrecked all but six of the 187 shipping berths in Kobe’s container port.

Insight: Domestic insurers covered about $3bn, and the

“In California, take up of earthquake insurance is only about 12%. In lieu of these covers being made compulsory, the industry needs to work harder at promoting the value of and driving the take up of these products, so that disaster risk financing is in place when the ‘Big One’ happens.”
Economic development hasn’t all been smooth sailing

The 301 cities have experienced many catastrophes over the past 50 years

- Lost more than a million of their citizens to earthquakes
- Half of them have suffered a serious flood
- Suffered more than 1,000 terrorist car bombs in city centres
- Seen a third or more of their economic capital wiped out by stock market crashes 5 times
- A quarter of them have been flooded more than 5 times
- Financial crisis of their governments defaulting on sovereign debts on 50 occasions
- Experienced thousands of cyber attacks
- Had to combat the outbreak of a previously unknown disease five times
- 32 cities have had to cope with a volcanic eruption less than 100 km away
- Financial crisis of their governments defaulting on sovereign debts on 50 occasions
18 Threat Types

**Finance and Trade**
- Market crash
- Sovereign default
- Oil price shock

**Geopolitics and Society**
- Terrorism

**Natural Catastrophe and Climate**
- Earthquake
- Wind storm
- Tsunami
- Flood
- Volcanic eruption
- Drought
- Freeze
- Heatwave

**Technology and Space**
- Nuclear accident
- Power outage
- Cyber attack
- Solar storm

**Health and Humanity**
- Human pandemic
- Plant epidemic
Why are These the Threats to Worry About?

- Cambridge CRS has conducted an extensive review of potential causes of macroeconomic shocks.
- We went through 1000 years of historical records to capture historical examples of shocks to society.
- The review included:
  A. Chronological Histories
  B. Disaster Catalogues
  C. Counter-factual evidence
  D. Scientific conjecture
  E. Peer review
  F. Other Approaches
- We developed a comprehensive Taxonomy of Threats.
- This consists of 11 broad families of threat with around 50 threat types.
- The 23 threats modelled here are from this taxonomy.
- They represent the most important risks from the known threat universe.

Available for Download from Website: CambridgeRiskFramework.com
Putting them together into the City Risk Index

For each city:

- We assess the threat of all 18 threat types
  - i.e. how likely that city is to experience a number of representative scenarios of different magnitudes from that threat (3 representative scenarios)
- We model the economic consequences of each scenario for the city
  - We have modelled $301 \times 18 \times 3 = \textbf{16,254}$ scenarios
- The GDP@Risk is the ‘expected loss’ – the loss x the probability
- We combine the GDP@Risk from the various threats and cities, assuming that the events are generally independent
Technical resources to help understand this

http://cambridgeriskframework.com/wcr

Methodology Documentation

Presentations and printable risk atlas

Threat Observatory

Online interactive threat maps
Cambridge Centre for Risk Studies – Risk Briefing
6 October 2015

Compiling the Data for Analysis

Jaclyn Yeo
Cambridge Centre for Risk Studies
Modelling Threats for Every City

- Selecting the representative cities
  - Systematic review of cities at risk

- Identification of the authoritative science about each threat
  - Key data repository

- Quantification of the frequency and severity of each threat globally
  - Regional frequency and severity in many cases

- Quantification of the economic impact of each characteristic scenario on a typical city
  - Incorporating physical vulnerability and social and economic resilience of the city
  - Output in terms of ‘GDP@Risk’ – a standard metric to compare different threats

- Threat Map Data Visualisation
We picked the ‘A List’ of the world’s cities for this analysis:

- Economically most important cities of 50 largest economies
  - Top 25 cities in US (#1 economy) and top 32 cities in China (#2 economy)
  - Between 5 – 12 largest cities for rest of the top 17 economies
- Include all cities over 3m population in the world
- Consist half of the world’s capital cities
- Responsible for half of the World’s GDP today
- Contribute two-thirds of the World’s GDP in 2025
A Systematic Review of Cities at Risk

- Economic impacts of the *city-level GDP*

- In order of priority, the following resources were used to build the CityGDP database
  1. OECD
  2. Country own database estimates
  3. Brooking Institute
  5. PwC (*Cities of Opportunities* 6, 2014)
  6. Other online sources
Building the database for city-level GDP and population estimates:

<table>
<thead>
<tr>
<th>Source types</th>
<th>Primary</th>
<th>Secondary</th>
<th>Tertiary</th>
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<td>Resources</td>
<td>❖ OECD</td>
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<tr>
<td></td>
<td>❖ Countries’ own city estimates (Official records)</td>
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<td></td>
<td>❖ Brooking Institute</td>
<td>❖ McKinsey Global Institute</td>
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<td>❖ PwC</td>
<td>❖ Other online sources (E.g. Wikipedia)</td>
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<tr>
<td>Cities</td>
<td>2/3 matched with overlapping data</td>
<td>Remaining</td>
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Validation (Sense Checking)
- GDP(Country) per capita ≤ GDP(City) per capita
## Overview of Threat Models

<table>
<thead>
<tr>
<th>ID</th>
<th>Threat</th>
<th>Phase</th>
<th>Hazard Map</th>
<th>Severity Scale</th>
<th>Cause</th>
<th>Projection</th>
<th>Uncertainty</th>
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<tr>
<td>1.1</td>
<td>EQ Earthquake</td>
<td>1</td>
<td>United States Geological Survey; GSHAP</td>
<td>Ms (Surface-wave Magnitude)</td>
<td>Natural</td>
<td>Constant</td>
<td>Low</td>
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<td>1.2</td>
<td>VE Volcanic Eruption</td>
<td>1</td>
<td>Smithsonian Institute of Volcanology</td>
<td>VEI (Volcanic Explosivity Index)</td>
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<td>Constant</td>
<td>Medium</td>
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<td>1.3</td>
<td>HU Tropical Windstorm</td>
<td>2</td>
<td>EM-DAT; Pacific Research Center; Munich Re</td>
<td>Saffir-Simpson CAT Hurricane Scale</td>
<td>Natural</td>
<td>CC Trend</td>
<td>Low</td>
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<tr>
<td>1.4</td>
<td>WS Temperate Windstorm</td>
<td>2</td>
<td>EM-DAT Windstorm Database</td>
<td>Beaufort Wind Scale</td>
<td>Natural</td>
<td>CC Trend</td>
<td>Low</td>
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<td>1.5</td>
<td>FL Flood</td>
<td>1&amp;2</td>
<td>UNEP/DEWA/GRID-Europe Flood Risk Rating</td>
<td>Depth and velocity of flood water</td>
<td>Natural</td>
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<td>1.7</td>
<td>TS Tsunami</td>
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<td>NOAA NCDC Historical Tsunami Database</td>
<td>Run-up height</td>
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<td>US National Center for Atmospheric Research</td>
<td>Palmer Drought Severity Scale</td>
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<td>Global Climate Zoning Map</td>
<td>Degree-Days below 0C</td>
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<td>Global Climate Zoning Map</td>
<td>Degree-Days Above 32C</td>
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<td>Medium</td>
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<td><strong>Financial, Trade &amp; Business</strong></td>
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<td>2.1</td>
<td>MC Market Crash</td>
<td>1</td>
<td>IMF Banking Network Core-Periphery</td>
<td>S&amp;P500 Index reduction</td>
<td>Man-Made</td>
<td>Dynamic</td>
<td>High</td>
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<td>2.2</td>
<td>SD Sovereign Default</td>
<td>1</td>
<td>S&amp;P National Credit Ratings</td>
<td>% Devaluation of national currency</td>
<td>Man-Made</td>
<td>Dynamic</td>
<td>Medium</td>
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<td>2.3</td>
<td>OP Oil Price Shock</td>
<td>2</td>
<td>UN imported oil intensity of GDP output</td>
<td>% increase in oil price (Brent Crude)</td>
<td>Man-Made</td>
<td>Dynamic</td>
<td>Medium</td>
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<tr>
<td><strong>Technology &amp; Space</strong></td>
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<td></td>
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</tr>
<tr>
<td>4.1</td>
<td>PO Power Outage</td>
<td>2</td>
<td>Nation Master Electrical Outage Report</td>
<td>City-Days of Outage</td>
<td>Man-Made</td>
<td>Constant</td>
<td>Medium</td>
</tr>
<tr>
<td>4.2</td>
<td>CY Cyber Catastrophe</td>
<td>1</td>
<td>McAfee International Cyber Risk Report</td>
<td>Cyber Magnitude &amp; Revenue@Risk</td>
<td>Man-Made</td>
<td>Dynamic</td>
<td>High</td>
</tr>
<tr>
<td>4.3</td>
<td>SS Solar Storm</td>
<td>2</td>
<td>US National Oceanic and Atmospheric Administration</td>
<td>US NOAA Space Weather Scale</td>
<td>Natural</td>
<td>Constant</td>
<td>High</td>
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<td>4.4</td>
<td>NP Nuclear Meltdown</td>
<td>2</td>
<td>World Nuclear Association Information Library</td>
<td>Intl Nuclear Events Scale (INES)</td>
<td>Man-Made</td>
<td>Constant</td>
<td>Low</td>
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<tr>
<td><strong>Health &amp; Environmental</strong></td>
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<tr>
<td>5.1</td>
<td>HE Human Epidemic</td>
<td>1</td>
<td>Emerging Infectious Diseases, Institute of Zoology</td>
<td>US CDC Pandemic Severity Index</td>
<td>Natural</td>
<td>Dynamic</td>
<td>Medium</td>
</tr>
<tr>
<td>5.2</td>
<td>PE Plant Epidemic</td>
<td>2</td>
<td>Wallingford Distribution Maps of Plant Diseases</td>
<td>Staple Crop (Wheat) Price Index</td>
<td>Natural</td>
<td>Dynamic</td>
<td>Medium</td>
</tr>
</tbody>
</table>
## Mapping Threat Models to Cities

<table>
<thead>
<tr>
<th>City Name</th>
<th>Delhi</th>
<th>Istanbul</th>
<th>Los Angeles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country</td>
<td>India</td>
<td>Turkey</td>
<td>United States</td>
</tr>
<tr>
<td>CRS Index</td>
<td>IND_DEL</td>
<td>TUR_IST</td>
<td>USA_CAL</td>
</tr>
</tbody>
</table>

| GDP 2014 | 246.6 | 343.6 | 774.8 |
| GDP 2025 | 578.0 | 679.4 | 880.7 |

| Economic Resilience | 5 Very Weak | 3 Moderate | 1 Very Strong |
| Economic Sectoral Type | C Service with Industry | C Service with Industry | A Service-Dominated Economy |

| Physical Vulnerability | 4 Weak | 3 Moderate | 1 Very Strong |
| Flood Vulnerability    | 4 Economy Highly Vulnerable to Flood Disruption | 4 Economy Highly Vulnerable to Flood Disruption | 5 Economy Very Highly Vulnerable to Flood Disruption |
| Financial Vulnerability | 3 Moderate Reliance on Private Capital | 2 Low Reliance on Private Capital | 5 High Reliance on Private Capital |
| Cyber Vulnerability    | 4 High Vulnerability to Cyber Attack | 4 High Vulnerability to Cyber Attack | 5 Very High Vulnerability to Cyber Attack |
| Pandemic Vulnerability  | 3 Moderate Healthcare System | 3 Moderate Healthcare System | 1 Very Strong Healthcare System |

| Earthquake Threat      | D Some Hazard | B High Hazard | A Very High Hazard |
| Volcano Threat         | F No recent volcanic activity in region | F No recent volcanic activity in region | F No recent volcanic activity in region |
| Flood Threat           | A High Threat from Flood | F No Information on Flood | B Moderately High Threat of Flood |
| Market Crash Threat    | C Integral part of International Financial System | B Local Markets Volatile | C Integral part of International Financial System |
| Sovereign Default Threat | C Moderate Chance of Sovereign Default | B Significant Chance of Sovereign Default | D Low Chance of Sovereign Default |
| Cyber Threat           | A High Cyber Threat | B Moderate Cyber Threat | A High Cyber Threat |
| Pandemic Threat        | A High Threat of Emerging Infectious Diseases | B Moderately High Threat of Emerging Infectious Diseases | C Possible Threat of Emerging Infectious Diseases |

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*Note: The table above provides a mapping of threat models to cities, including data on economic resilience, economic sectoral type, physical vulnerability, flood vulnerability, financial vulnerability, cyber vulnerability, pandemic vulnerability, earthquake threat, volcano threat, flood threat, market crash threat, sovereign default threat, and cyber threat.*
Geographical Mapping the Threats

- Earthquake
- Volcano
- Windstorm
- Flood
- Tsunami
- Drought
- Freeze
- Heatwave
- Market Crash
- Sovereign Default
- Oil Price Shock
- Interstate War
- Separatism
- Terrorism
- Social Unrest
- Power Outage
- Cyber Attack
- Solar Storm
- Nuclear Meltdown
- Human Epidemic
- Plant Epidemic
Cambridge World City Risk Atlas

http://wcr.cambridgeriskframework.com
World City Risk: Interactive Maps - Windstorms

Tropical Windstorms
Hurricanes, typhoons, and cyclones

*NatCat*

Windstorm threats consist of tropical storms and temperate windstorms. By far the most destructive storms are tropical storms, also commonly known as hurricanes, cyclones, and typhoons in different parts of the world. The mapping here shows the Pacific Research Centre zoning for the likelihood of hurricane force wind speeds from tropical storms.

Wind speed assessments for tropical wind storms are derived from the United Nations Environmental Programme and the Emergency Events Database (EM-DAT) International Disaster Database of the Centre for Research on the Epidemiology of Disasters.

Each city is analyzed for the GDP impact and likelihood of experiencing characteristic windstorm scenarios:

- **HU1. Category 1 Hurricane:** Windspeed 118 - 153km/hr
- **HU2. Category 3 Hurricane:** Windspeed 175 - 200km/hr
- **HU3. Category 5 Hurricane:** Windspeed >250km/hr

*Windstorm Threat Zones*  
Wind speed with 10% probability of exceedance in 10 years:

- 1: 118 - 153 km/hr  
- 2: 154 - 177 km/hr  
- 3: 178 - 209 km/hr  
- 4: 210 - 249 km/hr  
- 5: 250+ km/hr
Tropical Windstorm
World City Risk:
Interactive Maps - Windstorms

Tropical Windstorms
Hurricanes, typhoons, and cyclones

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**Windstorm Threat Zones**
Wind speeds with 10% probability of exceedance in 10 years

- 1. 118-153 km/hr
- 2. 164-177 km/hr
- 3. 178-209 km/hr
- 4. 210-249 km/hr
- 5. 250+ km/hr
# 5 NATURAL CATASTROPHE
Naturally occurring phenomena causing widespread disruption

<table>
<thead>
<tr>
<th>Threat Class</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>5.1 Earthquake</td>
<td>Seismic fault rupture causes high levels of damage to infrastructure of a major populated area</td>
</tr>
<tr>
<td>5.2 Windstorm</td>
<td>Hurricane/tropical cyclone wind system makes landfall onto a major populated area; European-type windstorm system, large scale, fast-moving, gale force wind speeds</td>
</tr>
<tr>
<td>5.3 Tsunami</td>
<td>Coastal impact of a tidal wave, caused by offshore earthquake, marine landslide, or meteorite in the sea</td>
</tr>
<tr>
<td>5.4 Flood</td>
<td>River flood from high rainfall/sudden water release across one or more river systems; Coastal flood from sea surge caused by low pressure weather systems, exceptional tides and extreme winds</td>
</tr>
<tr>
<td>5.5 Volcanic Eruption</td>
<td>Ash, pyroclastic hot gases, lava, and lahar-triggered mudflows cause localized destruction and regional disruption</td>
</tr>
</tbody>
</table>
Risk Briefing – Lloyd’s City Risk Index 2015-2025
6 October 2015

Catastronomics and World City Risk

Dr Scott Kelly
Cambridge Centre for Risk Studies
Catastronomics

Risk

Hazard
[Probability and Magnitude]

Catastrophe

Resilience
[Adaptive Capacity and Response]

Vulnerability
[Exposure and Fragility]

Unknown Risk
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
GDP@Risk Estimation Process

Hazard Data

City Data

Hazard Analysis

Threat Assessment Grade (TAG)

Vulnerability Analysis

(Damage) Economic Impact

Resilience Analysis

Economic Recovery

City GDP Growth

GDP@Risk
Hazard Analysis - TAGs

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

<table>
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<tr>
<th>Quake Map Banding of City</th>
<th>PGA 2500</th>
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<tr>
<td></td>
<td>250-400</td>
</tr>
<tr>
<td></td>
<td>400-600</td>
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<tr>
<td></td>
<td>600-1000</td>
</tr>
<tr>
<td>PGA 250</td>
<td>VII</td>
</tr>
<tr>
<td></td>
<td>VIII</td>
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<td>XI</td>
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<td>MidRange MMI equiv Annual Frequency</td>
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<th>100-250</th>
<th>175 VI</th>
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<td>325 VII</td>
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<td>400-600</td>
<td>500 VIII</td>
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<td>B</td>
<td>D</td>
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<tr>
<td>600-1000</td>
<td>800 XI</td>
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<th>PGA</th>
<th>A</th>
<th>B</th>
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<td>0.000275</td>
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Annual Prob

PGA

A
B
C
D
E
F
G

Data and Science
Geographical Mapping
Frequency Severity
Define Three Scenarios
TAG Cities
### City Vulnerability Analysis

<table>
<thead>
<tr>
<th></th>
<th>Small</th>
<th>Medium</th>
<th>Large</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1 Very Strong</strong></td>
<td>97.0%</td>
<td>95.0%</td>
<td>80.0%</td>
</tr>
<tr>
<td><strong>2 Strong</strong></td>
<td>95.0%</td>
<td>85.0%</td>
<td>70.0%</td>
</tr>
<tr>
<td><strong>3 Moderate</strong></td>
<td>90.0%</td>
<td>75.0%</td>
<td>60.0%</td>
</tr>
<tr>
<td><strong>4 Weak</strong></td>
<td>80.0%</td>
<td>68.0%</td>
<td>50.0%</td>
</tr>
<tr>
<td><strong>5 Very Weak</strong></td>
<td>75.0%</td>
<td>50.0%</td>
<td>40.0%</td>
</tr>
</tbody>
</table>

- **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

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 in a Catastrophe

Supply Shock
- Destruction of Physical Assets
- Disruption of Labour Availability
- Flight of Capital
- Inability to Export
- Government Recovery Stimulus

Demand Shock
- Consumer Confidence
- Shortage of Private Capital
- Share Price Reduction
- Inability to Import
- Inflation: increased cost of inputs

Catastronomics Model
What if a severe earthquake hits Taipei in 2018?

- Taipei has a Threat Assessment Grading for earthquake of ‘Very high threat’ based on United States Geological Survey earthquake design code assessment of Taipei
- An earthquake that would affect the city centre with shaking of PGA 400-600 cm/s² (MMI VIII) could be expected approximately once every 133 years (annual probability of 0.0075)

Taipei’s total lost GDP = $194 Bn
GDP projections for each year to 2025 have been derived for each of the 300 cities.

These draw on studies from McKinsey, Brookings Institute, and macroeconomic projections by country from Oxford Economics.

Projections take account of trends in GDP per capita, future demographic change, capital investment, and sectoral economic outputs.
Economy Mix: Classification of Cities

A: Service-Dominated Economy
- Agriculture: 1%
- Industrial: 22%
- Service: 77%

B: Service-Oriented Economy
- Agriculture: 3%
- Industrial: 26%
- Service: 71%

C: Service with Industrial
- Agriculture: 10%
- Industrial: 29%
- Service: 61%

D: Service-Industrial
- Agriculture: 5%
- Industrial: 36%
- Service: 59%

Average mix within cities classified in that category

E: Industrial-Oriented Economy
- Agriculture: 4%
- Industrial: 63%
- Service: 33%

F: Industrial with Service
- Agriculture: 11%
- Industrial: 46%
- Service: 43%

G: Agriculture with Ind & Service
- Agriculture: 39%
- Industrial: 37%
- Service: 24%

H: Service with Industria/Ag Mix
- Agriculture: 21%
- Industrial: 57%
- Service: 22%
## Vulnerability (Physical Destruction Threats)

<table>
<thead>
<tr>
<th>Resilience</th>
<th>Example cities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – Very Strong</td>
<td>San Diego, Tokyo, Wellington, Helsinki, Singapore, Santiago</td>
</tr>
<tr>
<td>3 – Moderate</td>
<td>Beijing, Sao Paulo, Seol, Ankara, Izmir, Warsaw, Buenos Aires</td>
</tr>
<tr>
<td>4 – Weak</td>
<td>Moscow, Delhi, Cape Town, Durban, Bangkok, Lahore, Ho Chi Minh</td>
</tr>
<tr>
<td>5 – Very weak</td>
<td>Douala, Abidjan, Accra, Pyongyang, Dakar, Lusaka, Harare</td>
</tr>
</tbody>
</table>

## Resilience (All Threats)

<table>
<thead>
<tr>
<th>Resilience</th>
<th>Example countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – Very Strong</td>
<td>New Zealand, Singapore, Japan, Germany, United Kingdom</td>
</tr>
<tr>
<td>2 – Strong</td>
<td>Chile, Kuwait, Israel, United Arab Emirates, Taiwan</td>
</tr>
<tr>
<td>3 – Moderate</td>
<td>Greece, Hungary, Czech Republic, Georgia, Brazil</td>
</tr>
<tr>
<td>4 – Weak</td>
<td>Armenia, Morocco, Philippines, Argentina, Guatemala</td>
</tr>
<tr>
<td>5 – Very weak</td>
<td>Kenya, Tanzania, Ethiopia, Cote d'Ivoire, Myanmar</td>
</tr>
</tbody>
</table>
World Cities at Risk essentially adds up impacts across 20-some threat types and 300 cities
- Events and cities are treated as independent
  ⇒ **Introduce interdependence**

**What is the arithmetic of catastrophe?**
- Does a combined 1-in-50 year Hurricane and 1-in-50 year Sovereign Default cause more havoc than a 1-in-100 year event?
  ⇒ **Nonlinearity of combined effects**

- Can a War cause a Pandemic resulting in far greater mortality than either event on their own?
  ⇒ **Cascading risks**
Model Results and Next Steps

Louise Pryor
Cambridge Centre for Risk Studies
Agenda

- Model results
- They are reasonable
- … but more could be done
GDP@Risk metrics for a city – a risk profile

**Seoul**

GDP@Risk: All threats

$103.50bn

<table>
<thead>
<tr>
<th>Rank</th>
<th>Event Description</th>
<th>Value (bn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Wind storm</td>
<td>$44.68bn</td>
</tr>
<tr>
<td>2</td>
<td>Oil price shock</td>
<td>$12.72bn</td>
</tr>
<tr>
<td>3</td>
<td>Market crash</td>
<td>$12.63bn</td>
</tr>
<tr>
<td>4</td>
<td>Flood</td>
<td>$9.83bn</td>
</tr>
<tr>
<td>5</td>
<td>Human pandemic</td>
<td>$7.61bn</td>
</tr>
<tr>
<td>6</td>
<td>Drought</td>
<td>$6.08bn</td>
</tr>
<tr>
<td>7</td>
<td>Cyber attack</td>
<td>$2.71bn</td>
</tr>
<tr>
<td>8</td>
<td>Sovereign default</td>
<td>$2.02bn</td>
</tr>
<tr>
<td>9</td>
<td>Freeze</td>
<td>$1.42bn</td>
</tr>
<tr>
<td>10</td>
<td>Solar storm</td>
<td>$1.08bn</td>
</tr>
<tr>
<td>11</td>
<td>Power outage</td>
<td>$1.01bn</td>
</tr>
<tr>
<td>12</td>
<td>Volcano</td>
<td>$0.85bn</td>
</tr>
<tr>
<td>13</td>
<td>Plant epidemic</td>
<td>$0.66bn</td>
</tr>
<tr>
<td>14</td>
<td>Terrorism</td>
<td>$0.19bn</td>
</tr>
<tr>
<td>15</td>
<td>Earthquake</td>
<td>$0.00bn</td>
</tr>
<tr>
<td></td>
<td>- Heatwave</td>
<td>$0.00bn</td>
</tr>
<tr>
<td></td>
<td>- Nuclear accident</td>
<td>$0.00bn</td>
</tr>
<tr>
<td></td>
<td>- Tsunami</td>
<td>$0.00bn</td>
</tr>
</tbody>
</table>

[$11.50bn] [$23.00bn] [$34.50bn] [$46.00bn]
City totals

### GDP@Risk: Top 20 cities - All threats

<table>
<thead>
<tr>
<th>Rank</th>
<th>City</th>
<th>GDP (bn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Taipei</td>
<td>$181.20bn</td>
</tr>
<tr>
<td>2</td>
<td>Tokyo</td>
<td>$153.28bn</td>
</tr>
<tr>
<td>3</td>
<td>Seoul</td>
<td>$103.50bn</td>
</tr>
<tr>
<td>4</td>
<td>Manila</td>
<td>$101.09bn</td>
</tr>
<tr>
<td>5</td>
<td>New York</td>
<td>$90.36bn</td>
</tr>
<tr>
<td>6</td>
<td>Los Angeles</td>
<td>$90.32bn</td>
</tr>
<tr>
<td>7</td>
<td>Istanbul</td>
<td>$82.50bn</td>
</tr>
<tr>
<td>8</td>
<td>Osaka</td>
<td>$79.32bn</td>
</tr>
<tr>
<td>9</td>
<td>Shanghai</td>
<td>$78.21bn</td>
</tr>
<tr>
<td>10</td>
<td>Hong Kong</td>
<td>$74.51bn</td>
</tr>
<tr>
<td>11</td>
<td>Lima</td>
<td>$69.36bn</td>
</tr>
<tr>
<td>12</td>
<td>Tehran</td>
<td>$64.14bn</td>
</tr>
<tr>
<td>13</td>
<td>Sao Paulo</td>
<td>$62.95bn</td>
</tr>
<tr>
<td>14</td>
<td>Mexico City</td>
<td>$60.74bn</td>
</tr>
<tr>
<td>15</td>
<td>Moscow</td>
<td>$55.77bn</td>
</tr>
<tr>
<td>16</td>
<td>Paris</td>
<td>$54.94bn</td>
</tr>
<tr>
<td>17</td>
<td>London</td>
<td>$53.43bn</td>
</tr>
<tr>
<td>18</td>
<td>Singapore</td>
<td>$51.11bn</td>
</tr>
<tr>
<td>19</td>
<td>Buenos Aires</td>
<td>$50.31bn</td>
</tr>
<tr>
<td>20</td>
<td>Jakarta</td>
<td>$48.23bn</td>
</tr>
</tbody>
</table>

### GDP@Risk: Top 20 cities - Natural threats

<table>
<thead>
<tr>
<th>Rank</th>
<th>City</th>
<th>GDP (bn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Taipei</td>
<td>$137.69bn</td>
</tr>
<tr>
<td>2</td>
<td>Tokyo</td>
<td>$99.38bn</td>
</tr>
<tr>
<td>3</td>
<td>Manila</td>
<td>$91.68bn</td>
</tr>
<tr>
<td>4</td>
<td>Seoul</td>
<td>$72.22bn</td>
</tr>
<tr>
<td>5</td>
<td>Shanghai</td>
<td>$58.06bn</td>
</tr>
<tr>
<td>6</td>
<td>Osaka</td>
<td>$52.72bn</td>
</tr>
<tr>
<td>7</td>
<td>Hong Kong</td>
<td>$48.39bn</td>
</tr>
<tr>
<td>8</td>
<td>Istanbul</td>
<td>$48.13bn</td>
</tr>
<tr>
<td>9</td>
<td>Mexico City</td>
<td>$47.94bn</td>
</tr>
<tr>
<td>10</td>
<td>Lima</td>
<td>$46.73bn</td>
</tr>
<tr>
<td>11</td>
<td>Los Angeles</td>
<td>$46.45bn</td>
</tr>
<tr>
<td>12</td>
<td>Tehran</td>
<td>$44.73bn</td>
</tr>
<tr>
<td>13</td>
<td>Hangzhou</td>
<td>$37.63bn</td>
</tr>
<tr>
<td>14</td>
<td>Tianjin</td>
<td>$34.70bn</td>
</tr>
<tr>
<td>15</td>
<td>Dongguan</td>
<td>$33.59bn</td>
</tr>
<tr>
<td>16</td>
<td>Guangzhou</td>
<td>$31.86bn</td>
</tr>
<tr>
<td>17</td>
<td>New York</td>
<td>$31.19bn</td>
</tr>
<tr>
<td>18</td>
<td>Shenzhen</td>
<td>$30.36bn</td>
</tr>
<tr>
<td>19</td>
<td>Beijing</td>
<td>$29.87bn</td>
</tr>
<tr>
<td>20</td>
<td>Jakarta</td>
<td>$27.58bn</td>
</tr>
</tbody>
</table>
Risk as a % of GDP

% GDP@Risk

0% 1% 2% 3% 4% 5% 6%

Manila
Rosario
Taipei
Xiamen
Kabul
Port au Prince
Kathmandu
Santo Domingo
Ningbo
Hangzhou
Guangdong
Quito
Tehran
Managua
Guatemala City
Calcutta
Damascus
Hanoi
Sana'a
Beirut
If Manila improved its ‘resilience’ and ‘economic vulnerability’

<table>
<thead>
<tr>
<th>Resilience Category</th>
<th>Total $GDP@Risk (Bn)</th>
<th>World Ranking by $GDP@Risk</th>
<th>as % of total GDP 2015-2025</th>
<th>World Ranking by % of GDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resilience 'Weak'</td>
<td>$101</td>
<td>4</td>
<td>5.0%</td>
<td>1</td>
</tr>
<tr>
<td>Resilience 'Moderate'</td>
<td>$89</td>
<td>6</td>
<td>4.4%</td>
<td>2</td>
</tr>
<tr>
<td>Resilience 'Very Strong'</td>
<td>$70</td>
<td>10</td>
<td>3.5%</td>
<td>5</td>
</tr>
<tr>
<td>Resilience and economic vulnerability up one grade</td>
<td>$58</td>
<td>13</td>
<td>2.9%</td>
<td>13</td>
</tr>
<tr>
<td>Same level as Los Angeles</td>
<td>$27</td>
<td>42</td>
<td>1.3%</td>
<td>101</td>
</tr>
</tbody>
</table>
Comparison with History

**Expected Loss of Economic Output**
- Modelled over next 10 years
- 300 cities
- Economic output

**Historical Data Direct Costs of Natural Catastrophe**
- Observed Past 100 years
- Worldwide
- Repair costs to physical infrastructure

EM-DAT Database of CRED
3,806 events since 1900

**US$ Billions**

- Earthquake
- Volcano
- Wind Storm
- Flood
- Drought
- Extreme temperature

**Expected Loss of Economic Output**

- Tropical Windstorms
- Temperate Windstorms

<table>
<thead>
<tr>
<th>Event</th>
<th>US$ Billions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Earthquake</td>
<td>400</td>
</tr>
<tr>
<td>1.2 Volcano</td>
<td>100</td>
</tr>
<tr>
<td>1.3 Wind Storm</td>
<td>400</td>
</tr>
<tr>
<td>1.5 Flood</td>
<td>400</td>
</tr>
<tr>
<td>1.8 Drought</td>
<td>100</td>
</tr>
<tr>
<td>1.10 Freeze + Heatwave</td>
<td>50</td>
</tr>
</tbody>
</table>
Comparisons with other models

- US National Bureau of Economic Research compared GDP erosion from cyclones with estimates of other threats

<table>
<thead>
<tr>
<th>US NBER</th>
<th>National GDP Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyclone</td>
<td>1.00</td>
</tr>
<tr>
<td>Civil War</td>
<td>0.86</td>
</tr>
<tr>
<td>Currency Crisis</td>
<td>1.11</td>
</tr>
<tr>
<td>Banking Crisis</td>
<td>2.08</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cambridge Model</th>
<th>Global GDP Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropical Windstorm</td>
<td>1.00</td>
</tr>
<tr>
<td>Separatism</td>
<td>0.45</td>
</tr>
<tr>
<td>Sovereign Default</td>
<td>0.32</td>
</tr>
<tr>
<td>Market Crash</td>
<td>1.88</td>
</tr>
</tbody>
</table>

- Swiss Re’s CatNet – data on natural hazards and cities
Doing more and better

- More cities, more threats
- More detail
- Interactions and connections
- More use cases
- Better metrics