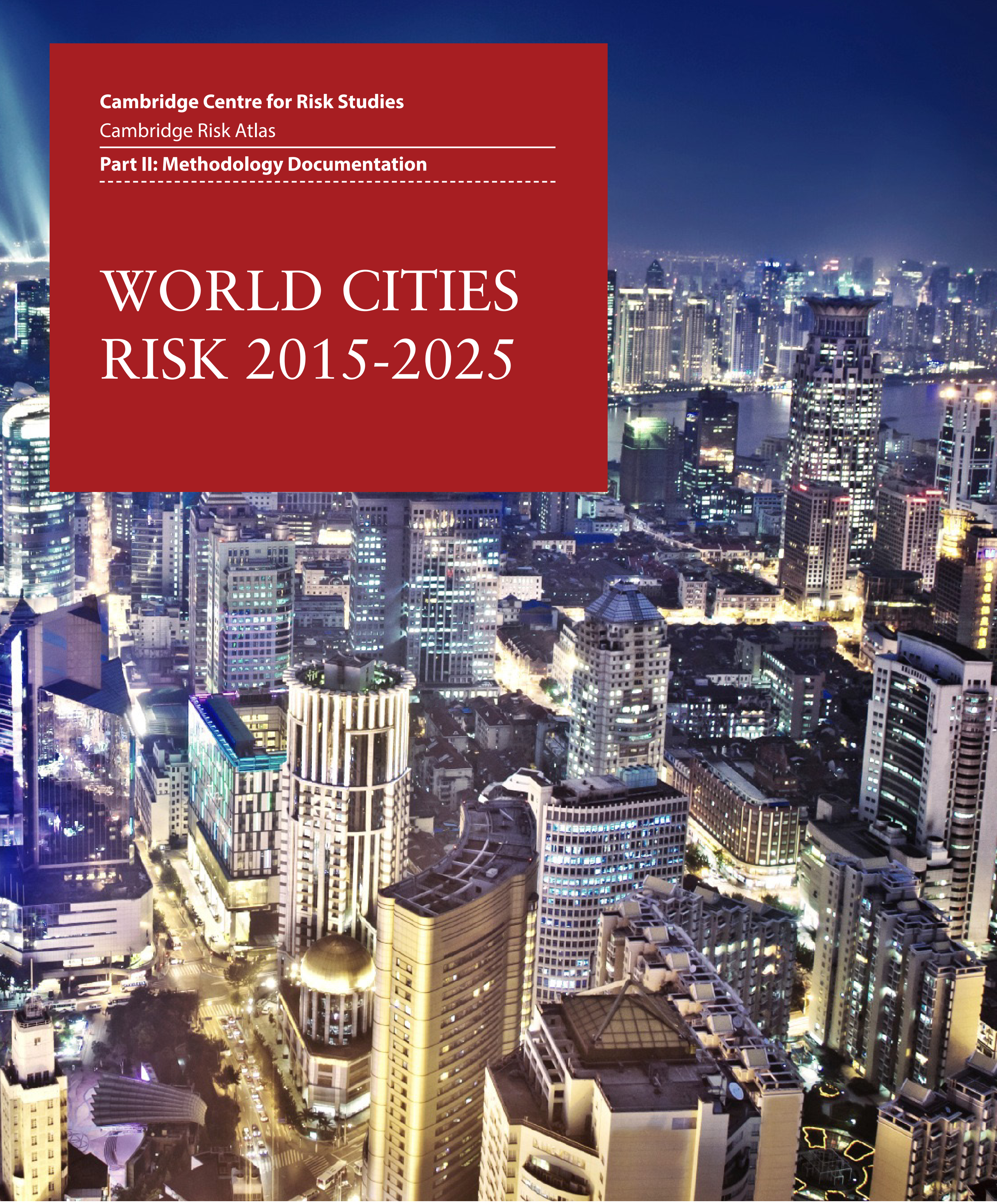

Cambridge Centre for Risk Studies

Cambridge Risk Atlas

Part II: Methodology Documentation

WORLD CITIES RISK 2015-2025

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Risk Studies

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Part II: Methodology Documentation

World Cities Risk 2015-2025

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World City Risk 2015

Part II: Methodology Documentation

1 Cities at Risk

At its heart, the city is an engine of wealth creation.

The first successful settlements to achieve the status of 'city' were those which sat at a crossroads of commercial exchange and transportation. The metropolises of antiquity were hubs of intercultural trade situated on economically vital bodies of water which, in a pre-industrial age, provided access and agricultural support for as greater numbers flocked towards stable urban centres. The rise of such densely populated, multicultural communities produced new and expanding social and cross-cultural networks, stimulating technological innovation in all sectors of the agrarian economy. Unchecked expansion and advancement were unsustainable, however. Reliance on traversable terrain and available natural resources meant that, for much of human history, cities were limited in their maximum size and capacity for wealth.

This pattern changed drastically with the technological advancements of the 18th century. Improvements in medicine and farming methods in Europe broke all limitations on socioeconomic growth. Populations doubled in the space of half a century and a sustainable labour class appeared. A new breed of city arrived with the Industrial Revolution, one that was a centre of productivity rather than a centre for trade. In the long global transition from an agrarian economy, new and wealthy cities grew up out of poor farming and fishing villages. These cities prospered, and continue to prosper, from the rise of particular industries - cotton, steam, steel, automation, aviation, plastics, etc. The newest crop of world metropolises featured in the 300 has appeared out of the emerging economies.

The same methodology of success links all 300 cities on our list. Damascus, arguably the 'oldest' of the selection, floundered as a minor desert outpost from 6000BCE until the domestication of the camel some four millennia later linked it to the economic highway of the Silk Road. The 'youngest', Saitama, now Japan's ninth largest city, was established in 2001 when three neighbouring towns announced plans to amalgamate in order to stimulate business interest and enhance the region's profile, thereby fostering local fiscal growth in a period of national decline. In each case, city dominance is established on and sustained by the availability of its markets and its capacity for wealth creation. Today's global cities 'design, make and sell everything,' from goods and services, to image and lifestyle.[1]

With increasing globalisation, the growth of the world city seems largely unhindered. Wealth creation worldwide is currently going through an unprecedented phase of concentration. The London economic region, for example, has increased its share of UK output from 15% in 1960s to 45% today. Major cities now emerging as international hubs of global wealth creation are sucking commercial activity from smaller cities and towns. To combat the imbalance, countries such as Saudi Arabia and Egypt are investing billions in the building of new cities to ease the growth of mega-centres like Riyadh and Cairo.

Those factors which contribute to a city's dominance and wealth also pose a great danger to its continued success. With a higher urban density comes the risk of disease, dissent and degradation. With increased globalisation and technological advancement comes the threat of war, cyber sabotage, terrorism and environmental catastrophe. In the last 30 years alone, the frequency of natural disaster events worldwide has quadrupled. Reported economic losses have increased by a factor of 2,000 to 3,000; insurance losses, by a factor of 1,000.[2] The uptake in the global cost of such disasters far exceeds the rate of economic growth in developing countries for the same period, as a city's resilience to such threats lies in the strength and diversity of its economy.[3] With the urban population of the developing world expected to grow by 2 billion by 2050, the growing trend in the frequency of catastrophes poses a severe threat to the financial stability and success of these emerging markets.[4]

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[1] 'Lump together and like it', *The Economist*, Nov. 6, 2008

[2] T. Anderson, 'Globalisation and Natural Disasters: An Integrative Risk Management Perspective', in *Building Safer Cities: the future of disaster risk*, (Washington, 2003) 58

[3] C. Benson and E. Clay, 'Disasters, Vulnerability and the Global Economy', in *Building Safer Cities*, 8

[4] 'How to feed the world in 2050,' Food and Agriculture Organisation of the United Nations, Conference report; (Rome, 2009) 2

Shanghai, China

2 Selecting the 300 cities

We selected the world's leading 300 cities for this analysis. This number provides a tractable quantity of locations for a study and also captures a representative range of economically important urban areas worldwide. The selection is necessarily arbitrary and almost certainly omits some cities which arguably ought to belong on a list of the "world's top". The selection, however, blends strong economies with geographical coverage so that emerging regions, like Africa and Eastern Europe, are adequately represented. It was important to ensure a global spread of economic capitals in order to make meaningful conclusions about geographical patterns of risk.

The Centre for Risk Studies maintains a database of over 5,000 cities in the world. The 300 cities were selected from that database. All cities with a population of more than 3 million were automatically included in our selection.

The inclusion of the most economically important cities was ensured by including the largest cities of the 50 largest national economies of the world, judged by GDP output in 2012. Generally the number of cities selected for each country was proportional to their economic power - the strongest economies are represented by a greater number of cities.

The number of cities selected also depended on both the urban characteristics and the population grade of each country. These features were used to select the top rank of significant cities in each region.

The top 25 cities were selected for the United States, the world's largest economy. The top 32 cities were selected for China, which is both the world's second largest economy and a country with a vast number of densely populated financial centres to represent it. The next tier of economic states – the next 17 largest economies – all had between 5 and 12 of their largest cities selected.

Major nations that are not strong economic powers were also represented by a selection of major cities in each region of the world, mainly the capital cities of major nations. The list of 300 includes half of all of the capital cities in the world.

The selection of 300 cities is the 'A list' of the world's important cities. Collectively, this list of cities generates around half of the world's GDP today. The current trend in concentrated wealth creation in cities and the growth rate of those on the list suggests that this same collection of 300 cities will be responsible for two-thirds of the world's GDP in 2025.

Projecting GDP to 2025

According to McKinsey, 80% of global productivity occurs in cities (Dobbs et al., 2011). Cities are therefore the economic engines of growth for the majority of the world's countries. Economic output measured as the total annual sum of final demand varies significantly between cities, both across the world and within a single country itself.

City level economic output is increasing due to: increased productivity linked to the diffusion and development of new technologies; enhanced division of labour; higher education and competencies of the work force; improved organisational methods; improvements to physical infrastructure; strong public institutions and rule of law; and, capital accumulation through investment. Most cities also benefit from an expanding workforce as the process of urbanization drives people from rural environments into major cities seeking an improved standard of living.

In order to model the economic impacts of various disasters on the 300 selected cities, it is necessary to have robust estimates of future GDP for each individual city. The process for modeling city level GDP is described by the following equation:

$$CityGDP_t = CityPop_t \left[\frac{CityGDP_{t-1}}{CityPop_{t-1}} + \frac{CityGDP_{t-1}}{CityPop_{t-1}} \cdot \frac{d}{dt} \left(\frac{CountryGDP}{CountryPop} \right) \right]$$

$CityGDP_t$ is the expected GDP output in year, t; $CityPop_t$ is the expected population of the city in year, t; the derivative $\frac{d}{dt}\left(\frac{CountryGDP}{CountryPop}\right)$ is the growth in GDP per capita for the country in which the city belongs. The growth in country level GDP per capita was taken as the average growth over the last ten years.

The advantage of using growth in GDP per capita compared to using simply growth in GDP is that it allows for the changing demographics of cities. The equation stipulates that GDP per capita for this period is equal to GDP per capita in the previous period plus any change in the relative level of expected GDP per capita for the country. Determining city GDP therefore simply requires multiplication by the expected City Population in period t.

Thus if the population of a city grows fast due to urbanization then the GDP of that city will also be expected grow both from increasing GDP per capita because of increased productivity and an expanding workforce.

On the other hand, if a city's population is shrinking, or growth is slow, then the GDP estimates as described above would reflect this.

Several sources of data are required to make this estimation:

1. City GDP in the base year (2012);
2. City population estimates for each year from 2012 to 2025;
3. Country level GDP estimates;
4. Country level population estimates.

Country level data for GDP and population estimates is available with a high degree of accuracy. Country level data was taken from the World Bank data repository (The World Bank, 2014). Population estimates at the city level were taken from the 2010 UN Habitat report on the State of the World's Cities.

Obtaining good estimates of base year city level GDP estimates was challenging, however, as GDP at the individual city level is not typically evaluated by government agencies or other reporting bodies. Productivity estimates like GDP are usually reserved for calculating output at the level of a country or region. In spite of this there have been several reports in recent years which have attempted to place estimates on city level GDP but available reputable data on cities is scarce. In order of importance, the following resources were used to build a database on city GDP:

- OECD;
- Country (own estimates);
- Brookings Institute;
- McKinsey (Urban World: Mapping the Economic Power of Cities - (Dobbs et al., 2011));
- PWC (Cities of Opportunity - (Cizmar et al., 2014));
- Other online resources.

Two hundred of the 300 hundred cities were matched from one of these four sources. Many cities had overlapping data across all four databases, thus priority was given to the city level GDP estimates in the order given above. For the remaining 100 cities, extensive internet searches were completed to find any historical information or analysis that had been done to estimate individual GDP. As a last resort country level GDP/capita estimates were used to estimate each city's GDP. Error checking and validation was completed by comparing GDP/capita estimates across cities and comparing with them with country level GDP/capita estimates. The ratio of city GDP/capita and country GDP/Capita was used to check for anomalies and identify those cities with extremely low or extremely high ratios.

Economic Mix (Percentage composition)	Example cities	Economic Vulnerability to Services	Economic Vulnerability to Capital
Service-dominated; Service-oriented (>67% service)	Paris, London, New York, Tokyo, Singapore, Taipei	Very high	Moderate
Service with industry; Service-industrial (>50% service and >33% ind)	Istanbul, Zagreb, Delhi, Buenos Aires, Manila, Seoul,	High	High
Service with industrial-agricultural mix; Industry with service (Service 30-50%; industry 15-30%)	Kathmandu, Beijing, Shanghai, Jakarta	Moderate	Moderate
Industrial-oriented (>50% ind)	Doha, Brazzaville, Jeddah, Dubai	Low	High
Agricultural with industrial-service mix (>30% agric)	Lagos, Phnom Penh, Yangon, Kabul	Very low	Low

Table 1: Cities categorization by economic mix

Cities with either very low ratios or very high ratios were sanity checked against the city and corroborated with other published material. City to country GDP/capita ratios ranged from under 1.0 to 14. The final output from this modeling procedure is a database of estimates for GDP, population and GDP/Capita for each of the 300 cities for each year from 2012 to 2025.

Categorization of cities by economic mix

Cities can be categorised by their economic mix, that is, the composition of GDP from different sectors of the economy such as services, industrial or agricultural sectors.

As shown above in Table 1, the final list of 300 cities is categorised according to their economic mix. Each city is differentiated by the percentage composition coming from each of the major economic sectors. Example cities are provided, alongside each classification with the respective economic vulnerability classifications to services or capital.

Dependency on tourism

Importance and volatility of tourism in the economies of cities

Tourism is defined as the activity of people travelling for leisure, business or other purposes where one or more nights are spent outside their usual environment for not more than one consecutive year (WTO 1995).[1] While tourism is usually associated with trans-national travel, it may also refer to travelling within the same country.

[1] World Tourism Organisation, 'Collection of Tourism Expenditure Statistics', No. 2, 1995 http://pub.unwto.org/WebRoot/Store/Shops/Infoshop/Products/1034/1034-1.pdf

Tourism can be domestic or international and is a major source of income for many countries; it expands the economic base, creates new job opportunities and also helps diversify the economy by bringing new services to the existing economic mix.[2] As a result, the tourism industry can have a significant impact on the economies of both the source and host countries and, in some economies, tourism is a major financial sector, providing a significant share of overall GDP.

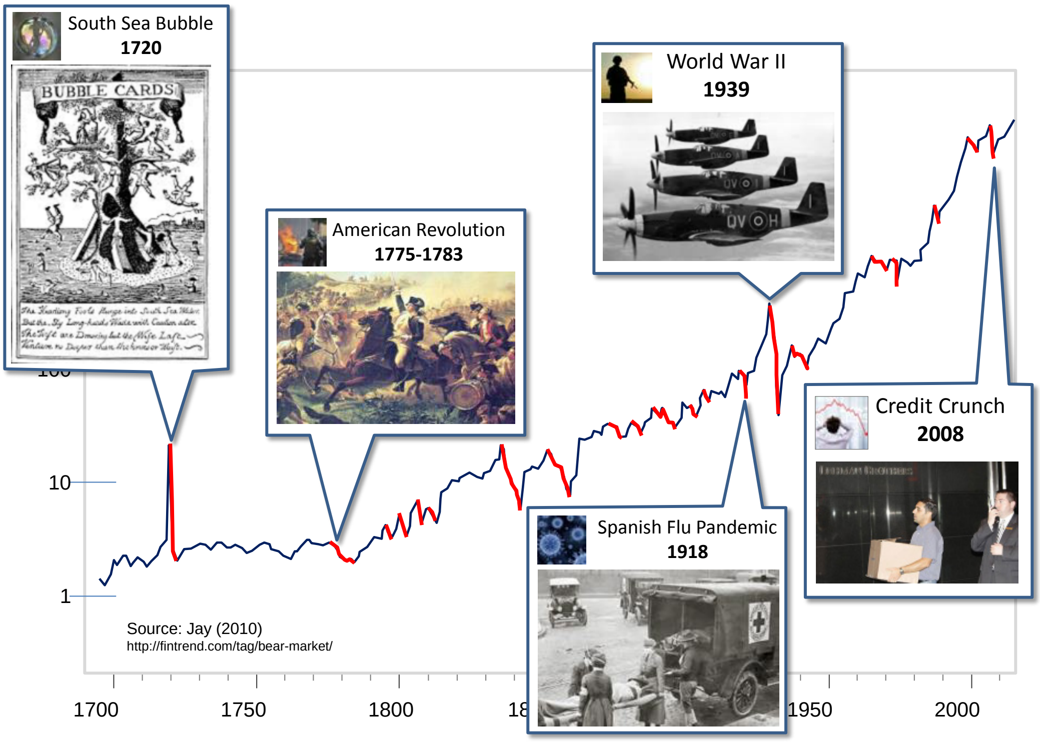
Despite its vital importance to many countries and cities, the tourism industry is highly sensitive and volatile to demand-side impacts. Global tourism has suffered greatly from the effects of recessions and other disasters (e.g. the global recession between 2008 and 2009, the outbreak of the H1N1 influenza virus in 2009). The tourist industry's rate recovery from these particular disasters has been slow and it has taken two years for growth rates to return those before the decline.[3]

Categorising countries and cities on economic dependence based on tourism

Countries and their cities can be categorised by their economic dependency on tourism. However, a city's dependency on tourism is defined differently from that of a country, giving rise to separate means of categorization. The tourist economies of countries are commonly ranked according to the absolute numbers of visitors and the total amount of revenue earned through those visitors, a method of measurement

[2] Tourism Resources, 'Is Tourism an Economic Activity to Pursue?' http://www.communitydevelopment.uiuc.edu/tourism/n_resources.html

[3] World Tourism Organisation, 'World Tourism Barometer', Vol. 11, (January 2013) 3 http://dtxtq4w60xqpw.cloudfront.net/sites/all/files/pdf/unwto_barom13_01_jan_excerpt_0.pdf



which typically ranks the largest economies in the most popular countries first (e.g. United States, China, France, United Kingdom, Germany, etc.)[4]

However, to better assess the importance and volatility of tourism in the national economies, countries can also be categorised according the percentage of the respective GDP accrued through tourism and tourist revenue. Subscribing to this method of classification, it is emerging markets and newly industrialised countries that rank highest, and are identified as having a large proportion of their GDP coming from tourism (e.g. Croatia, Lebanon, Jordan, Cambodia, Thailand, etc.)

The rocky road to growth

Economists like to project smooth growth curves, but it is unrealistic to suppose such a simple, straightforward pattern of development on something as variable as a city. The 300 cities of the list have not had a smooth path to the world's A list.

In the past 50 years alone, they have:

- Lost more than a million of their citizens to earthquakes;
- Seen a third or more of their economic capital wiped out by stock market crashes, five times on average;
- Coped with the financial crisis caused by individual governments defaulting on sovereign debts on more than 50 separate occasions;
- Been involved in more than 50 wars;
- Seen political instability manifest in separatist movements and the social unrest of their citizens, which has escalated into civil war in a dozen circumstances;
- Suffered thousands of terrorist attacks, including 1000 car bombs in city centres;
- Experienced technology failures, including thousands of cyber attacks, which have degraded the IT productivity tools that underpin their steady economic growth;
- Combated the outbreak of a new disease types and epidemics five times.

Additionally:

- Half of them have suffered a serious flood event;
- A quarter of them have been flooded more than five times.
- 32 have experienced a volcanic eruption within 100km of the city;
- More than a dozen have been bombed to ruins.

[4] Y. Hendrick-Wong and D. Choog, *Mastercard Global Destination Cities Index*, 2Q, 2013: http://insights.mastercard.com/wp-content/uploads/2013/05/Mastercard_GDCI_Final_V4.pdf

3 Threat list

	Definition of Threat	Precedents
Natural Catastrophe & Climate		
Earthquake	Seismic fault rupture causes high levels of damage to infrastructure of a major populated area	Tohoku, Japan 2011; Kobe, Japan 1995; Northridge, California 1994; Great Kanto earthquake, Japan 1923; San Francisco 1906
Volcanic eruption	Ash, pyroclastic hot gasses, lava, and lahar-triggered mudflows cause localized destruction and regional disruption	Ash eruption of Eyjafjallajökull, Iceland 2010; Pinatubo eruption, Philippines 1990
Windstorm	Tropical windstorm of hurricane/typhoon/ cyclone wind system makes landfall onto a major populated area; or Temperate windstorm of European-type windstorm system, large scale, fast-moving, gale force wind speeds	Hurricane Katrina, US 2005; Hurricane Andrew, US 1992; Typhoon Mireille, Japan 1991; European Windstorm Lothar 1999;
Flooding	Coastal Flood from sea surge caused by low pressure weather systems, exceptional tides and extreme winds; or River Flood from high rainfall/sudden water release across one or more river systems	East Coast UK 1953; Queensland Australia 2011
Tsunami	Coastal impact of a tidal wave, caused by offshore earthquake, marine landslide, or meteorite in the sea	Tohoku Tsunami 2011; Boxing Day Tsunami 2004
Drought	Extended period of below-average precipitation, leading to shortage of water for human consumption and agriculture	Horn of Africa 2011; Texas, US 2011; Australia 1994; Europe 1976; Sahel, Africa 1960s-; China 1941; US 'Dust Bowl' 1931-38
Freeze event	Extended period of below-average temperatures	UK 2010; Moscow; Russia 2010; North American Ice Ice Storm 1998; Idaho Ice Storm 1961
Heatwave	Extended period of above-average temperatures: The definition recommended by the World Meteorological Organization is when the daily maximum temperature of more than five consecutive days exceeds the average maximum temperature by 5 °C	US 2011; Russia 2010; France 2003; Chicago 1995; US 1980
Financial, Trade & Business		
Market Crash and Banking Crisis	Extreme correlated mass movement of share prices, possibly driven by information or perception about economic fundamentals	Sub-Prime Property bubble 2008; 'dot-com' bubble 1999; Black Monday Stock Market crash 1987; Wall Street Crash 1929
Sovereign Default	Debt default; currency devaluation; government failure and/or change	Greek sovereign debt crisis 2010-; Argentina crisis 1999-2002; Russian crisis and LTCM 1998; Black Wednesday (UK withdrawal from ERM) 1992; Repudiation of Confederate debt (post US civil war) 1864
Commodity Price Shock (Oil)	Hike in commodity prices	Oil Crisis 1973; Global Oil Price Hike 2008

Political, Crime & Security		
Interstate Conflict	The engagement of two or more nations in military conflict, using conventional weapons to target military infrastructure and invade/defend sovereignty	Gulf War II Iraq 2003; Gulf War Kuwait & Iraq 1990-91; Falklands War 1982; World War II 1939-45
Political Instability (Social Unrest and Separatism)	Internal conflict within a country, including wars of succession and coups d'etat	Libya civil war 2011 (coup 1969); Darfur, Sudan 2009; Rwanda 1990-93; Bosnia 1992-95; Russian coup 1993; American Civil War 1861-65
Terrorism	Politically-motivated single or coordinated attack(s) to inflict societal and/or economic fear and disruption	London July bombings 2005; US September 11 attacks by Al Qaeda 2001; Tokyo Subway Sarin gas attack by Aum Shinrikyo 1995; Mumbai shooting massacre 2008; Beirut US barracks bombing 1983
Technology and Space		
Infrastructure Failure - Power Grid	Blackouts in the electricity supply network and other systems failures due to accidents and technical breakdowns	Great New York Blackout of 2003; Enron California brown-outs 2000
Cyber Catastrophe and Technology Failure	Computer networks, communications and information technology systems destabilized by computer virus, hacking, denial of service attacks or other cyber-security issues	Unlimited Operation' $45m cash stolen in 12 hours 2012-2013; 'Comment Crew' / 'APT1' espionage attacks 2006-2013; 'Stuxnet' attack on Iran Natanz nuclear facility 2010;
Space Weather	Solar flare activity that can impact satellites, communication technology, power distribution systems and other infrastructure	Carrington Event geomagnetic storm of 1859
Nuclear Power Plant Accident	Major core meltdown of a nuclear power station, causing radioactive fallout over a large area of population and economic and agricultural productivity	Fukushima Daiichi, Japan 2011; Chernobyl 1986; Three Mile Island 1979; Windscale, UK 1957
Health & Environmental		
Human Pandemics	Influenza pandemics, emerging infectious diseases and re-emergent disease epidemics that cause death and illness in human populations	2009 Swine Flu Pandemic; SARS 2002; HIV/AIDS 1982-; Influenza Pandemic 1918
Plant epidemic (crop failure)	Diseases in plants that impact food production in many agricultural areas or cause destruction of the ecological environment.	Sudden death syndrome (SDS) in soybeans US Corn Belt 2010; Dutch Elm Disease, Europe 1967; Wheat Stem Rust Outbreak, US 1962; Wheat Stem Rust Outbreak, West Africa 1999

Table 2: Threat list and definitions.

4 Threat assessment

The Lloyds World City Risk Project uses several datasets in order to provide hazard, vulnerability and exposure data for input to the GDP @Risk model. There are five stages in the data compilation process:

1. Data collection - Internet searches to find available data for various hazards which was then downloaded.
2. Formatting - Data re-formatted to be compatible with ArcGIS and PostGIS.
3. Mapping - Data mapped/projected in ArcGIS.
4. Spatial analysis - Spatial analysis and zonal statistics used on previous city and country data to assign values to nodes from raster files and polygons for countries.
5. Final spreadsheets - Results from spatial analysis and other data combined into separate spreadsheets for cities and countries.

Table 3, below, summarises these data sources, all of which are freely available with global coverage.

The table is subdivided into threat maps with the data sources used in each threat map listed alongside.

Each data source is also given a rating from 1 to 3 which indicates the varying levels of quality of the data: 1 is the highest quality and indicates data from peer reviewed sources or scientific studies; 2 is medium quality and indicates data sourced from other named sources; 3 is lower quality data and is digitalised images from business reports, slides, or data from unidentified sources.

Threat map	Dataset	Source	Data Quality Code	Brief Description	Units	Coverage
 Earthquakes	Ss and S1	World Wide Seismic Design Tool & US Seismic Design Maps (USGS)	1	The "SS" and "S1" columns provide the spectral acceleration values experienced by a structure with a period of 0.2s and 1.0s	g	Lloyds Cities
	Significant Earthquakes Database	National Geophysical Data Center (National Oceanic and Atmospheric Administration)	1	Nodes/locations of previous significant earthquakes. Can be filtered to show earthquakes of particular types	n/a	Global
	Physical exposure to earthquakes of MMI categories higher than 9 1973-2007	Earthquake Frequency Metadata, Global Risk Data Platform (UNEP/ DEWA/GRID-Europe)	2	Number of inhabitants exposed to earthquakes	expected average annual population (2010 as the year of reference) exposed inhabitants	Global
	Economical exposure to earthquakes of MMI categories higher than 9 1973-2007	Earthquake Frequency Metadata, Global Risk Data Platform (UNEP/ DEWA/GRID-Europe)	2	Economical exposition to earthquakes	expected average annual GDP (2010 as the year of reference) exposed in (US $, year 2000 equivalent)	Global

 Earthquakes	Seismic hazard map: Peak ground acceleration (PGA): 250, 475, 1000, 1500, 2500 year return periods	Earthquake Frequency Metadata, Global Risk Data Platform	1	Peak ground acceleration for, 250, 475, 1000, 1500, 2000 year return periods.	Units = cm/s2	Global
Other	Plate Tectonics	Institute for Geophysics, Plate Tectonic Reconstruction project	1	Ridge, strike slip and trench boundaries	n/a	Global
 Volcanoes	VEI	Volcano Global Risk Identification & Analysis Project (BGS)	1	Previous Eruptions by VEI	The VEI is a simple 0-to-8 index of increasing explosivity, with each successive integer representing about an order of magnitude increase.	Global
	Volcanoes of the world	Smithsonian Institution Global Volcanism Program	1	Holocene volcanoes of the world	n/a	Global
	Global Volcano Density	Pacific Disaster Center geodata	2	Density of volcanic eruptions based on volcanic explosivity index	The VEI is a simple 0-to-8 index of increasing explosivity, with each successive integer representing about an order of magnitude increase.	Global
 Windstorm	Tropical cyclone frequency of Saffir-Simpson category 5 1970-2009	Cyclone surge events Metadata, Global Risk Data Platform (UNEP/DEWA/GRID-Europe)	2	Tropical Cyclone Frequency.	Unit is expected average number of event per 100 years multiplied by 100	Global
	Tropical cyclones windspeed buffers footprint 1970-2009	Cyclone surge events Metadata, Global Risk Data Platform (UNEP/DEWA/GRID-Europe)	2	Estimate of tropical cyclones windspeed buffers footprint.	Unit is estimated maximum Saffir-Simpson categories over the period 1970-2009	Global
	Tropical cyclones average sum of windspeed 1970-2009	Cyclone surge events Metadata, Global Risk Data Platform (UNEP/DEWA/GRID-Europe)	2	The estimated annual wind speed of cyclones between 1970-2009		Global
	Cyclones Winds - Hazard, Wind Speed 50RP	Cyclone surge events Metadata, Global Risk Data Platform (UNEP/DEWA/GRID-Europe)	2	Peak velocity gusts for 50RP	Units = km/hr	Global

	Saffir-Simpson Scale - for peak velocity gusts 50rp	n/a	n/a	n/a	n/a	n/a
	Cyclones Winds - Hazard, Wind Speed 100RP	Cyclone surge events Metadata, Global Risk Data Platform (UNEP/DEWA/GRID-Europe)	2	Peak velocity gusts for 100RP	Units = km/hr	Global
	Saffir-Simpson Scale - for peak velocity gusts 100rp	n/a	n/a	n/a	n/a	n/a
	Cyclones Winds - Hazard, Wind Speed 250RP	Cyclone surge events Metadata, Global Risk Data Platform (UNEP/DEWA/GRID-Europe)	2	Peak velocity gusts for 250RP	Units = km/hr	Global
	Saffir-Simpson Scale - for peak velocity gusts 250rp	n/a	n/a	n/a	n/a	n/a
	Cyclones Winds - Hazard, Wind Speed 500RP	Cyclone surge events Metadata, Global Risk Data Platform (UNEP/DEWA/GRID-Europe)	2	Peak velocity gusts for 500RP	Units = km/hr	Global
	Saffir-Simpson Scale - for peak velocity gusts 500rp	n/a	n/a	n/a	n/a	n/a
Windstorm	Cyclones Winds - Hazard, Wind Speed 1000RP	Cyclone surge events Metadata, Global Risk Data Platform (UNEP/DEWA/GRID-Europe)	2	Peak velocity gusts for 1000RP	Units = km/hr	Global
	Saffir-Simpson Scale - for peak velocity gusts 1000rp	n/a	n/a	n/a	n/a	n/a
	Global estimated risk index for tropical cyclone hazard	Cyclone surge events Metadata, Global Risk Data Platform (UNEP/DEWA/GRID-Europe)	2	Global risk induced by tropical cyclones.	Unit = estimated risk index (1 = low, 5 = extreme)	Global
	Economical exposition to tropical cyclone of Saffir-Simpson category 5 1970-2009	Cyclone surge events Metadata, Global Risk Data Platform (UNEP/DEWA/GRID-Europe)	2	Economical exposition to tropical cyclones of Saffir-Simpson category 5	Unit is expected average annual GDP (2010 as the year of reference) exposed in (US $, year 2000 equivalent)	Global
	Physical exposition to tropical cyclone of Saffir-Simpson category 5 1970-2009	Cyclone surge events Metadata, Global Risk Data Platform (UNEP/DEWA/GRID-Europe)	2	Number of inhabitants exposed to tropical cyclones of Saffir-Simpson category 5.	Unit is expected average annual population (2010 as the year of reference)	Global

 Windstorm	Previous Storm Events: Country Level. Includes, occurrence since 1900, deaths, affected, amount injured, amount homeless and total damage ('000$)	EM-DAT Database, disaster list	1	Previous Storm Events: Country Level. Includes, occurrence since 1900, deaths, affected, amount injured, amount homeless and total damage ('000$)	n/a	Global
	Manually Assigned Coastal Town	n/a - manually identified through looking at map	3	n/a		Global
	World's Major Rivers (Calculated Distance to)	ESRI	3	World's major rivers	n/a	Global
	World linear water (Calculated distance to)	ESRI	3	World's non-major rivers	n/a	Global
	Flood events and type (1985 - 2008)	Dartmouth Flood Observatory	1	Global Archive Map of Extreme Flood Events since 1985 - Spatial query undertaken o identify number of flood events affecting each city	n/a	Global
 Flood	Flood Frequency	Flood frequency metadata, Global Risk Data Platform (UNEP/ DEWA/GRID-Europe)	2	Predicted frequency of flood events	Unit is expected average number of event per 100 years	Global
	Global estimated risk index for flood hazard	Flood risk metadata, Global Risk Data Platform (UNEP/DEWA/ GRID-Europe)	2	Estimate of risk to flooding	Unit is estimated risk index from 1 (low) to 5 (extreme).	Global
	Previous Flood Events: Country Level. Includes, occurrence since 1900, deaths, affected, amount injured, amount homeless and total damage ('000$)	EM-DAT Database, disaster list	1	Previous Flood Events: Country Level. Includes, occurrence since 1900, deaths, affected, amount injured, amount homeless and total damage ('000$)	n/a	Global
Tsunami	Tsunami Frequency (500 year run up)	Tsunami frequency metadata, Global Risk Data Platform (International Centre for Geohazards/NGI)	2	Frequency of Tsunamis over a 500 year return period	Unit is expected affected percentage of each pixel over a minimum return period of 500 years	Global

	Max Flooded Area	Hazard, Max area flooded, Global Risk Data Platform (NGI)				
	Tsunami Run-up	Global Historical Tsunami Database (NOAA/WDS)	1	Nodes identifying tsunami effects e.g. number of deaths and damage.		Global
 Tsunami	Physical exposition to tsunamis	Tsunami frequency, Global Risk Data Platform (International Centre for Geohazards/ NGI)	2	Number of inhabitants exposed to tsunamis	Unit is expected average annual population (2010 as the year of reference) exposed inhabitants	Global
	Economical exposition to tsunamis	Global Risk Data Platform (International Centre for Geohazards/ NGI)	2	Economical exposition to tsunamis	Unit is expected average annual GDP (2010 as the year of reference) exposed in (US $, year 2000 equivalent)	Global
	Droughts events 1980-2001	Event metadata, Global Risk Data Platform (UNEP/DEWA/GRID-Europe)	2	Areas affected by drought and year of occurrence	n/a	Global
 Drought	Country Level Drought Events	EM-DAT database, disaster list	1	1900 - 2014 drought events: Occurrence, deaths, injured, affected, homeless, total affected, total damage	n/a	Global
	Average number of people affected by droughts, floods and extreme temperatures	The World Bank, Climate Change Knowledge Portal	1	Average number of people/population within a country affected by natural disasters (droughts, floods or extreme temperature events)	n/a	Global
	Historic rates of human casualty in extreme temperature events	V. Lee, 'Historical global analysis of occurrences and human casualty of extreme temperature events', Natural Hazards, Vol 2.2, pp.1453-1505	1	Historic rates of human casualty in extreme temperature events	n/a	Global
 Freeze & Heatwave	Event frequency	EM-DAT database, disaster list	1	Frequency of ETEs based on historic data	n/a	Global
	Expected ETE predictions	IPCC, 2012	2	IPCC predicts an increase in the number of both hot/cold ETEs in both directions in the 21st century	%	Global
	Heatwave events	'Marble Bar' heatwave, Australian Bureau of Meteorology	1	Informed creation of characteristic scenarios and variables	n/a	n/a
	Previous events: human casualties, numbers affected	EM-DAT database, disaster list , WHO, CDC	1	Human damage of previous ETE events	n/a	Global

 Sovereign Default	Historical defaults	'List of sovereign defaults', Wikipedia	2	List of sovereign defaults'	n/a	Global
	Cumulative corporate default ratings	Standard & Poor's Global Fixed Income Research and CreditPro©	1	Average cumulative default rations 1981-2011		
	Country credit ratings	'2011 Annual U.S. Corporate Default Study And Rating Transitions' (Standard & Poor)	1	S&P Credit Ratings applied to countries	Credit rating	n/a
 Oil Shock	Energy Consumption per capita	The World Bank, World Development Indicators	3	List of countries by total energy consumption per capita	The data is given in kilogrammes of oil equivalent per year, and gigajoules per year, and in watts, as average equivalent power.	Global
	GDP per unit of energy use (constant 2011 PPP $ per kg of oil equivalent)	The World Bank, PPP data and OECD/IEA statistics	1	GDP per unit of energy use is the PPP GDP per kilogram of oil equivalent of energy use. PPP GDP is gross domestic product converted to 2011 constant international dollars using purchasing power parity rates. An international dollar has the same purchasing power over GDP as a U.S. dollar has in the United States. International Energy Agency (IEA Statistics © OECD/IEA, http://www.iea.org/stats/index.asp), and World Bank PPP data.	GDP/unit	Global
	Alternative and nuclear energy (% of total energy use)	The World Bank, OECD/IEA statistics	1	Alternative and nuclear energy (% of total energy use)	%	Global
	Energy imports, net (% of energy use)	The World Bank, World Development Indicators, OECD/IEA statistics and UN Energy Statistics Yearbook	1	Net energy imports are estimated as energy use less production, both measured in oil equivalents.	%	Global
	Energy production (kt of oil equivalent)	The World Bank, World Development Indicators, OECD/IEA statistics	1	Energy production (kt of oil equivalent)	kt of oil equivalent	Global
	Fossil fuel energy consumption (% of total)	The World Bank, World Development Indicators, OECD/IEA statistics	1	Fossil fuel energy consumption (% of total)	%	Global

 Oil Shock	Energy use (kg of oil equivalent per capita)	The World Bank, World Development Indicators, OECD/IEA statistics	1	Energy use (kg of oil equivalent per capita)	kg of oil equivalent per capita	Global
	Energy use (kt of oil equivalent)	The World Bank, World Development Indicators, OECD/IEA statistics	1	Energy use (kt of oil equivalent)	kt of oil equivalent	Global
	Oil refineries	World Oil Refineries List, ENI S.p.A	3	List of oil refineries, country, state and capacity (bdp crude)	bdp crude	Global
	Oil pipelines	Theodora.com	3	Shapefile created by drawing over raster file (geoprocessed) in ArcGIS	n/a	Global
 Interstate Conflict	Geographical distance between countries	Cytora python script development	1	Relative and absolute distance between states	Km	Global
	Contiguity	COW Direct Contiguity, 1816-2000 (v.3.1)	1	Relationships categorised by mode of separation between states	1 – 5 scale	Global
	Power Symmetry and Status	COW National Material Capabilities Dataset (v.3.02)	1	Measure in difference of power between country pairs; accounted for the fact that nations with similar power balances are likely to engage in war	n/a	Global
	State alliances	Cytora compiled dataset	1	Members of NATO identified	n/a	Global
	State Fragility Index	Polity IV State Fragility Index and Matrix 2013	1	Country pairs with a higher relative ranking would be expected to experience a higher likelihood of experiencing social unrest.	SFI score (0 - 50)	Global
	Regime Type	Polity IV: Regime Authority Characteristics & Transitions	1	Regime type and level of democracy for each country in dataset	Polity2 score (-10 – 10)	Global
	GDP Difference	IMF's World Economic Outlook Database, April 2014	1	Difference in size of GDP between state pairs; absolute value of State A subtracted from State B to create degree of difference	Absolute scale of difference	Global
	State economy and trade	COW International Trade, 1870-2009 (v3.0)	1	Sum of trade flows between countries, assuming high levels of trade act as an effective deterrent against conflict	Absolute scale	Global

 Interstate Conflict	State militarization	Global Firepower Index 2014	1	Measures of dyad state militarization added to create relative value for each country pair; higher militarization scores account for higher chance of conflict between states	PowerIndex	Global
	History of Conflict	COW Interstate Disputes (v4.01), New COW War Data, 1816 - 2007 (v4.0)	1	Number of wars and number of interventions both calculated; wars weighted with twice significance of interventions	n/a	Global
 Social Unrest	Political stability	World Governance Indicator of 'Political Stability' created by the World Bank, 'Polity 4' index (Centre for International Peace)	1, 2	Political health and government accountability	Polity 4 scale (CIP)	Global
	Democratic accountability	World Governance Indicator of 'Voice and Accountability (The World Bank)	1	Democratic accountability	Voice and Accountability score (WGI)	Global
	Bureaucratic quality	World Governance Indicator of 'Government Effectiveness' (The World Bank)	1	Bureaucratic quality	Government Effectiveness score (WGI)	Global
	Democratic rating	Polity IV: Regime Authority Characteristics & Transitions	1	Dataset scores countries on their democratic rating on a scale of -10 to 10, however, since the relationship between democratic rating and chances of instability was not linear (i.e. the more democratic a country, the lower chance of instability the dataset was reformatted on a new scale	Polity2 score	Global
	State corruption	Transparency International global corruption index	1	Level of political and public corruption		Global
	Socio-economic conditions	World Bank unemployment database, GINI Coefficient and inflation index	1	Levels of unemployment, inequality and inflation over the last four years per state	World Bank indices	Global
	Demographic pressures	WUP2014-F02-Proportion Urban dataset and "WPP2012_DB02_Stock_Indicators" (United Nations Populations Department Statistics), 'State of the World's Children 2011' dataset (Unicef)	1	Factoring in measures of urban migration and mortality	% of population/ bracket	Global

Social Unrest	Law and order	Minorities at Risk dataset (Cytora), United Nations Office on Drugs and Crime global homicide dataset	1, 2	Composite index based on state capacity and propensity for conflict, combining ‘ intercommunal’ and ‘protest’ scores per group	1 – 5 scale	Global
 Power Grid Collapse	Electrical Outages	NationMaster	2	Electrical outages are the average number of days per year that establishments experience power outages or surges from the public grid.	Days	Global
	Value lost due to electrical outages	The World Bank, World Development Indicators, World Bank Enterprise surveys	1	Value lost due to electrical outages is the percentage of sales lost due to power outages.	%	Global
 Cyber Threat	Cyber threat index	GEM Socio-economic vulnerability score	2-3	Based on country wide GDP 2011, cities with high GDP given a high threat of attack score and cities with low GDP given a low score; remaining cities given B grade	A – C	Global
	City industry sector	GEM Socio-economic vulnerability	2-3	Cities classed by percentage of economy dominated by service, agriculture or industry	A - H	Global
	Cyber vulnerability	n/a - mapping	1	Vulnerability score derived from sector classification code by mapping	1 – 5 scale, % of city at risk	Global
	Validation	Host Exploit Index (Global Security Map)	1	n/a	HE Index	Global
 Space Weather	Geomagnetic latitude/ longitude coordinates	Virtual Ionosphere, Thermosphere, Mesosphere Observatory	1	System based on magnetic poles	Lat/Long	Global
	Solar storm risk	AER, Lloyd’s ‘Solar Storm Risk to the North American Electrical Grid’	1	Map displaying bands of magnetic latitude most at risk	n/a	Global
	History of solar storms	Wikipedia, ‘Carrington Event’	2	Previous solar storm events	n/a	Global
 Nuclear Power Plant Accident	Nuclear Power Plants	Wikipedia	2	Nuclear Power Plants and Capacity	Capacity = Mwe	Global
	Country table and nuclear power plants	World Nuclear Association Information Library	1	Future reactors envisaged in specific plans and proposals and expected to be operating by 2030.	Billion kWh; % e; MWe net; MWe gross; tonnes U	Global

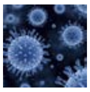
 Nuclear Power Plant Accident	Nuclear Reactors	World Nuclear Association Information Library, Nuclear Database	1	The WNA Reactor Database contains information on past, present and future nuclear reactors globally.	n/a	Global
	Life span of reactors	P. Behr, Climatewire, ‘How long can nuclear reactors last?’, Scientific American, Sep 20, 2010	3	Life span of reactors is planned to be 40 years	n/a	n/a
 Human Pandemic	Risk of outbreak	Global distribution of the relative risk of an EID event, from ‘Global trends in emerging infectious diseases’, Jones et al., (2007); Study by Institute of Zoology, UK, Consortium for Conservation Medicine, New York.	2	Maps derived from past EID events separated by carrier	Mapped images	Global
	National health systems	World Health Report 2011 (WHO)	1	National health systems ranked based on health distribution, responsiveness and financial contribution	WHO index	Global
 Plant Epidemic	Spread of plant disease	2003 Distribution Maps of Plant Diseases,(CAB International)	1	Mapping spread of plant diseases	n/a	Global
	Disease per country	Plantwise species selector	1	Instances of plant disease per country and present status	n/a	Global
	Multiple plant diseases	Plantwise species selector	1	Instances of disease effecting >1 plant species per country and present status	n/a	Global

Table 3: Data sources used in the World City Risk Project

5 Catastronomics

Catastronomics is a field of economics that describes the economics of catastrophes.

There are several important aspects of catastronomic analysis that make it unique among other forms of economic impact study. These aspects involve the definition of a catastrophe and its relationship to economic growth.

Firstly, catastrophes are defined by their significant destruction of capital, physical infrastructure and inventories.

Secondly, they cause serious social disorder disrupting the workforce and the supply of labour in the economy for long periods of time.

Thirdly, they disrupt supply chains, may have long-term impacts on foreign direct investment and can precipitate disinvestment and capital flight from a region.

Fourthly, catastrophes have devastating impacts on the environment causing damage to ecosystems, agricultural output and water resources. Catastrophes therefore have significant potential to cause large macroeconomic shocks that may cascade through sectors of the economy destroying businesses, livelihoods and means of production.

Catastronomics is related to, but distinct from, other fields of economic analysis because of the significant and occasionally irreversible consequences resulting from a catastrophic event. The economic impacts of catastrophes are so large that they often flow through regional and global economic networks, disrupting supply chains and limiting output. The severity of the catastrophe may even lead to the collapse of some industries and the complete unbundling and restructuring of a country's economic activity, shifting supply and demand characteristics, affecting prices and changing the comparative advantage of various sectors within the economy.

The extent of economic disruption

Catastronomics aims to understand the economic processes and activities prior to, during and after a catastrophic event.

It is first necessary to understand the nature of an economy before a disaster, as it provides a point of comparison, helps formulate an understanding of the potential impacts of a disaster and, therefore, how an economy can be made more resilient.

Each city's economy is unique, and so specific information on the economic activity within each city is needed in order to understand the extent of disruption caused by a catastrophe. Other economic data important to understanding the impacts of catatrophes includes:

- the value of exposed capital within the city;
- the relationship between labour and capital to economic output and growth;
- the economic structure of trade between different economic sectors within the city;
- the relative importance of imports and exports within the economy;
- the relative importance of services, industrial and agricultural activity for each city;
- the importance of consumption activity and the components of final demand.

Mitigating economic impact during the catastrophe

Assessing the economy's ability and capacity to respond at the point of a catastrophic event is similarly crucial to understanding a disaster's full impact on that economy. Some economies are better prepared than others, particularly those which: regularly experience hazards of a particular type; have prepared disaster strategies and contingency plans that are deployed before a disaster (e.g. early warning systems); have good capital infrastructure systems which help to defend the city in an efficient and timely manner; and that have trained emergency services personnel who can be quickly deployed in order to stem disaster damage and mitigate potential impacts and losses.

Those cities with back-up systems (e.g. diesel generators) or stockpiled supplies that may be used while primary systems are repaired are those best able to defend themselves against further economic losses.

Recovering from the catastrophe

The speed at which an economy is able to recover in the days, weeks and months following a catastrophe is similarly crucial in assessing overall economic losses. As previously stated, robust and functioning infrastructure systems play an important role in restoring the economy to a pre-disaster condition. Possessing a strong system of infrastructure means cities are able to deliver raw materials to reparation zones and ensure the efficient transport of labour throughout the city.

Tipping points and other non-linearities also matter. When infrastructure systems are destroyed in a disaster, it will place serious limitations on the city's ability to restore its economy in the wake of the event. In order for the city to recover, its infrastructure systems must first be mended.

During the recovery process and because of an increase in the output gap between actual and potential economic output, the Keynesian multiplier effect will increase economic output and encourage economic growth. The rate of growth after a disaster and during the recovery period is therefore typically much higher than the rate of growth prior to the disaster. The full impact of the Keynesian multiplier depends on the structure of the economy and how much potential output has been affected by the disaster.

GDP@Risk

The Centre for Risk Studies has developed a bespoke metric called GDP@Risk for comparing the economic impact of different threats to cities. It is calculated as the product of threat likelihood and the potential severity of economic loss. We define GDP@Risk as the economic loss experienced by an economy over a five-year period compared to the baseline economic trajectory (or "counterfactual"). It can be described mathematically as the sum of GDP over five years in the baseline trajectory, minus the sum of GDP over five years in the scenario where a catastrophe occurs. This is shown by the equation below where Y_B represents the baseline trajectory of economic output and Y_C represents economic output in the catastrophe scenario. These equations are represented by the two trajectories in Figure 1 where the shaded area represents the GDP@Risk.

$$GDP@Risk = \int_{t_0}^{t_5} Y_B - Y_C \, dt$$

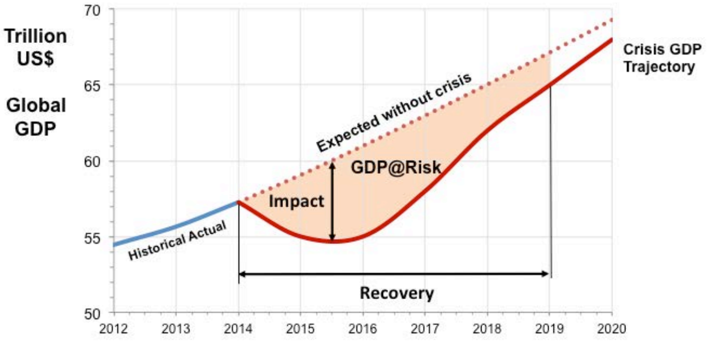


Figure 1: GDP@Risk, Cumulative first five year loss of global GDP, relative to expected, resulting from a catastrophe or crisis

The economic trajectory after a disaster has occurred is modelled using a number of key parameters. Two key parameters are the *economic impact* and the *economic recovery*.

The *economic impact* is an estimate of how much economic output decreases from the baseline trajectory before economic recovery begins. *Economic recovery* refers to the rate at which the economy recovers over time. Taken together, the economic impact and the economic recovery are used to estimate *total economic loss* or the expected loss in GDP for the given scenario.

The overall economic impact experienced by a disaster is proportional to the *vulnerability* of the economy to a particular disaster the size of the disaster and the exposure of the city. Economic recovery is proportional to the *resilience* of the economy and captures how well the economy is expected to recover from the disaster after it has occurred. Using this method it is possible to have a city that is vulnerable to a particular disaster with a corresponding large initial economic impact but with strong economic resilience, and which is therefore able to recover from a large economic impact relatively quickly. The opposite is also true: it is possible to have a city that is not vulnerable to a particular disaster but has low economic resilience so its economy will have a longer recovery period.

The final estimate of the expected GDP loss for each particular event, therefore, is a combination of assessed threat type, vulnerability and resilience. For computational reasons, the 300 cities were categorised separately based on their underlying characteristics. Each city was graded on a scale from 1 to 5, representing that city's vulnerability to a particular disaster (e.g. 1. Very Strong, 2. Strong, 3. Moderate, 4. Weak, 5. Very Weak). This same process was also done for resilience assessment.

Each city was also given a Threat Assessment Grade (TAG) based on its level of exposure to each particular threat type. Again, for computational reasons, the cities were categorised based on their level of exposure.

For each threat type we consider three "characteristic scenarios" (Small, Medium and Large) categorised by the probability and severity of each catastrophe event. A small event has relatively high probability with corresponding low severity while a large event has low probability with corresponding high severity. Economic losses are truncated at 5 years but taken as a proportion of the total GDP loss over a 10-year horizon. Figure 2 exhibits the various components used in performing the GDP@Risk calculations.

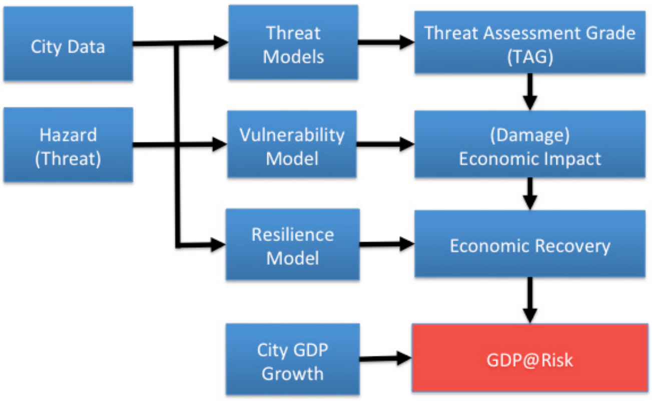


Figure 2: GDP@Risk process of estimation

There are many additional factors that may contribute to a reduction in GDP following a disaster event. These can be broken down into the following categories:

- Supply Shock
  - Destruction of physical infrastructure;
  - Disruption to work activity and employment ;
  - Increasing costs of production;
  - Reduction in productivity levels.
- Demand Shock
  - Lower incomes and reduced household consumption;
  - Changes in the availability of credit;
  - Loss of public morale and confidence;
  - Import restrictions limiting input factors of production;
  - Loss of ability to supply export markets.

Other factors include:

- Government emergency response stimuli;
- Inflation and increased cost of inputs;
- Exchange rate fluctuations;
- Share price shock;
- Oil price shock.

This analysis assumes that an event could occur at any time between 2015 and 2025 (10 year period). It also assumes that there is an equal probability of an event occurring in any year over this period and that each event is independent. The binomial distribution was used to estimate the statistical likelihood of each threat occurring in each of the small, medium and large scenarios.

The probability that an event will occur at any time in the ten-year period was estimated using the following formula:

$$P_{10} = 1 - (1 - P_1)^{10}$$

where P_{10} is the probability that at least one event of this type occurs over the 10 year period and P_1 is the probability of occurrence in any given year. To simplify the analysis of estimating GDP@Risk we assume economic loss occurs over the period 2018-2023. GDP@Risk is calculated by multiplying the probability that a particular catastrophe, *c*, will occur at any time over the 10 year period by the severity of that particular shock, measured as a loss to GDP_C, where GDP_C represents the GDP loss for each catastrophe scenario, *C*.

$$GDP@Risk = GDP_c \times P_{10}$$

Return to steady state growth

This analysis assumes that a city's economy will eventually return to its pre-disaster growth-rate. GDP@Risk is defined as the economic loss compared to its baseline growth over a five-year period. For many of the catastrophes analysed – particularly the secondary threat types – the economy returns to pre-disaster growth within the five year period.

For some of the larger catastrophes, however, economic output does not return to pre-disaster levels within this five year window. In these scenarios, economic output may ultimately remain perpetually below baseline output levels, albeit at the same rate of growth as the pre-disaster economy. As GDP@Risk is defined as the loss in economic output over a five year period losses beyond the five years are ignored for the purposes of this analysis.

As already discussed, an economy that is operating below its potential economic output will grow faster as it catches up to its full economic potential. This is because of an oversupply of spare capital and labour driving down prices encouraging investment. When additional investment is combined with the Keynesian multiplier effect output in the economy it will accelerate and "catch up" to its potential output. Some analysts argue that investment and inertia may increase economic output beyond the base-line trajectory in the counterfactual scenario.

Evidence for this theory is weak, however, and so a conservative assumption has been made to limit economic output to remain below the base-line trajectory.

6 Cambridge Risk Atlas database

The data gathered during this project will be uploaded in a structured manner to the Cambridge Risk Framework database. Country data is keyed by 3 letter ISO code, cities by the unique CRS identifier. Once in the Cambridge Risk Framework, the data can potentially be viewed online, in maps, network diagrams and charts.

The models developed by the project will be programmed into the Cambridge Risk Framework modelling engine. Both data and models will be made Open Source, available to the Centre's research partners and stakeholders, and a public audience.

Part of this material is now available on the Cambridge Risk Framework site:

http://cambridgeriskframework.com/wcr

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