The Normalisation of socio-economic losses from historic worldwide earthquakes from 1900 to 2012

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SUMMARY:

The normalisation of historic earthquake economic losses in the CATDAT Damaging Earthquakes Database is discussed using the most in-depth worldwide earthquake loss database (7103 damaging earthquakes from 20000+ sources from 1900-2012). The great worldwide detail of the CATDAT socio-economic index datasets allows for better normalisation of losses than ever before.
A hybrid index (HNDECI) is shown to better account for the historical cost of earthquakes in today's terms, using a spatio-temporal combination of HDI, country-specific wages, capital stock, construction costs, workers' production, GDP, CPI and other tools. To analyse vulnerability changes, a country-by-country global building inventory and vulnerability index has been produced for 245 nations, using individual country studies, a seismic code index and a building practice factor over the last 113 years.
In addition, global population and other socio-economic indicator modelling is used to normalise earthquake losses to current worldwide conditions in order to quantify better the potential recurrence risk of earthquakes.

Keywords: CATDAT, Socio-economic losses, earthquake risk, economics, building inventories

1. INTRODUCTION

In this study, the normalisation of historic earthquake economic losses in the CATDAT Damaging Earthquakes Database to present day conditions is presented from 7103 damaging earthquakes from 1st January 1900 to 17th April 2012 – the largest worldwide damaging earthquake loss database. (Daniell, 2003-2012, Daniell et al., 2011b). For earthquake loss estimation analysis, it is important to know the historical socio-economic effects of earthquakes. Normalisation studies look at the historical event losses and attempt to bring them via multiplication factors and trend analysis to the present day population and economic output, giving a potential reoccurrence cost of events for today's exposure.

Existing normalisation strategies have been undertaken for other natural disasters by multiplying historical losses by an economic conversion index to bring it to today's costs. The difference in current population versus historical population in the area is then multiplied to create normalised losses. Bouwer et al. reviewed 22 papers looking at the methodologies used for trending natural disaster losses. The only existing earthquake-only normalisation study is from Vranes et al. (2009) for US earthquakes from 1900 to 2005, using wealth (GDP), inflation, mitigation and population. For a worldwide analysis of storms from 1950 to 2005, only GDP per capita and population have been used by Miller et al. (2008), due to a lack of socio-economic data.

Neumayer and Barthel (2011) provide a very in-depth study, using the MunichRe NatCat database from 1980 to 2009 with a similar methodology of normalising the GDP deflator, a wealth factor and population. An alternative method is also proposed using only the wealth per capita difference. They propose a worldwide methodology based on capital stock, but are unable to undertake this due to a lack of data. Instead they use the G-ECON dataset, which takes a geocell product of PPP-adjusted GDP mostly based on 1995 GDP data, from 180 nations. A large disadvantage of this work, apart from the quality of the spatial economic dataset utilised, is that only 29 years of data were used, due to the short nature of the NatCat database; thus, the shorter the time series of annual loss data, the greater the standard error of the estimate (statistical significance).

A similar approach to that of Crompton and McAveney (2008) for meteorological hazards has been utilised to normalise historic Australian earthquakes but uses the value of dwellings. The appropriate documentation for indexing the Insurance Council of Australia database of Crompton et al. (2005) has not been able to be sourced; however, a similar method is likely to have been employed for the meteorological hazards. A normalisation approach for Australian earthquakes from 1788-2010 was undertaken by Daniell and Love (2010a) using the HNDEC indexed (Hybrid Natural Disaster Economic Conversion Index) values and the current population versus historical population in the area, as well as an index of the level of vulnerability of the building stock compared to the historical building stock. The HNDECI uses a spatio-temporal combination of country-specific wages, construction costs, workers' production, GDP, CPI and other tools, to better account for the historical cost of earthquakes in today's terms explained in the paper of Daniell et al. (2012b).

2. DATA NEEDED FOR NORMALISATION OF EARTHQUAKE LOSSES

A wealth of data has been collected as part of CATDAT in the past years, in order to compare the world in each year from 1900 to 2012.

2.1. Worldwide Population and Development Modelling from 1900 to 2012.

Population has been modelled for all nations, using census data from over 1500 individual census forms from over 200 nations, forms and statistical yearbooks, and population estimation sources, in addition to demographic and health surveys from 1900 to 2012, creating a high quality dataset around the world of population changes through time (Fig. 2.1). There are existing worldwide population datasets such as CIESIN and Landscan; however, it was decided that as no public administrative boundary data was available from these sources and because of the short time period of the dataset (1990-2012), a database of cities, administrative boundaries, historical boundaries, country changes, wars and population changes was needed due the complexity of world politics and movements from 1900 to 2012. This is no trivial matter, as the boundary changes need to be taken into account when doing historical trending.

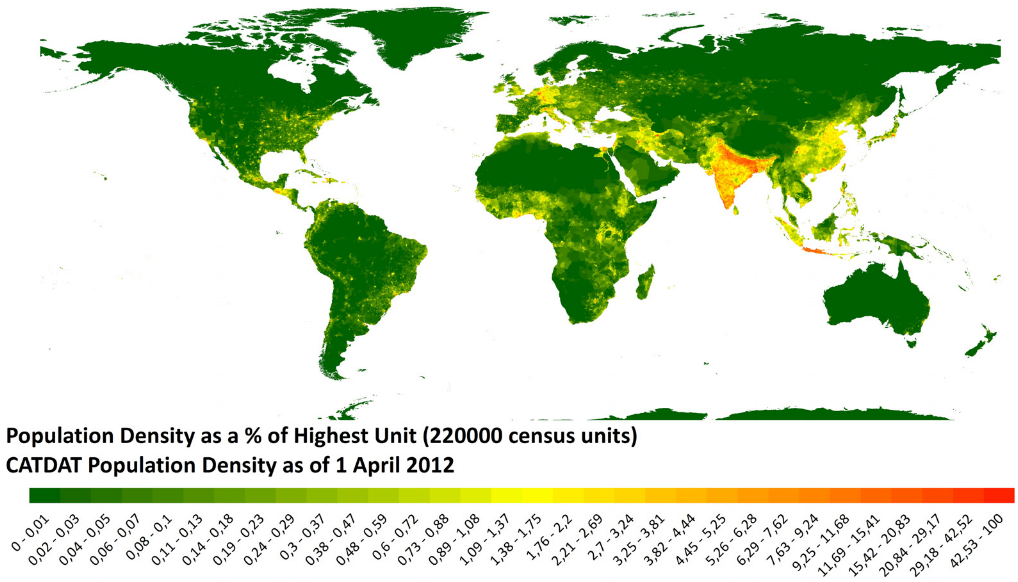

Figure 2.1. CATDAT Population in 2012 for the 220000 census units

In addition, the population in urban and rural settings and percentage of labour force was calculated and collected from 1900 to 2012, as there was a difference of occupancy and building quality of infrastructure. In a world first, a country-level human development index has been produced from 1900-2012, using a combination of life expectancy, education and literacy and GDP per capita for 245 nations. The index also takes into account historical boundaries such as the Ottoman Empire, Russian Empire and war boundaries, using data for the individual parts relative to the 2012 countries (Fig. 2.2).

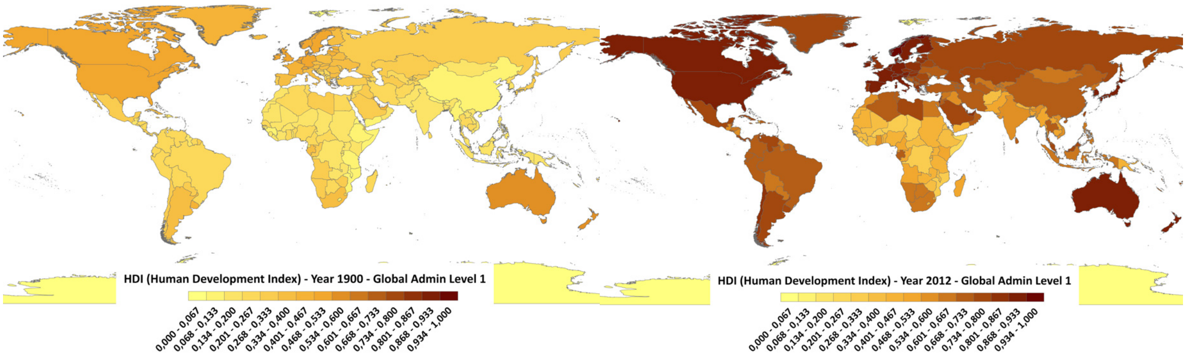

Figure 2.2. CATDAT Human Development Index in 1900 vs. 2012

2.2. Building, Infrastructure and Building Indices collected from 1900 to 2012

To analyse changes in vulnerability through time, a country-by-country global building inventory and vulnerability index has been produced for 245 nations using individual country studies rather than regionalised assumptions. The goal was to create a virtual earth of first-order building typologies for each country. In addition, a seismic code index was created in order to look at the effects of seismic codes on the building types. It can be seen that borders between countries influence the difference of corruption in building practice, seismic code implementation and cultural differences. In many countries, data exists for building typologies not previously shown in a worldwide setting (Daniell, 2010b; Daniell, 2010c; Daniell et al., 2011d).

Over 1500 individual census forms and statistical yearbooks, in addition to demographic and health surveys, United Nations data, WHE-PAGER reports (Porter et al., 2008), energy building stock reports, individual government reports, and other sources, were used on a country-by-country basis to create an urban and rural building inventory from 1900 to 2012. Parameters in the residential building database include building type (houses, apartments etc.), wall and roof type (in terms of HAZUS classes), age of the building (8 classes of year ranges), number of floors, number of rooms, building quality, number of buildings, building cost data and household size (occupancy). This database was discussed in a paper at AEES (Daniell et al., 2011d) and is not the focus of this paper.

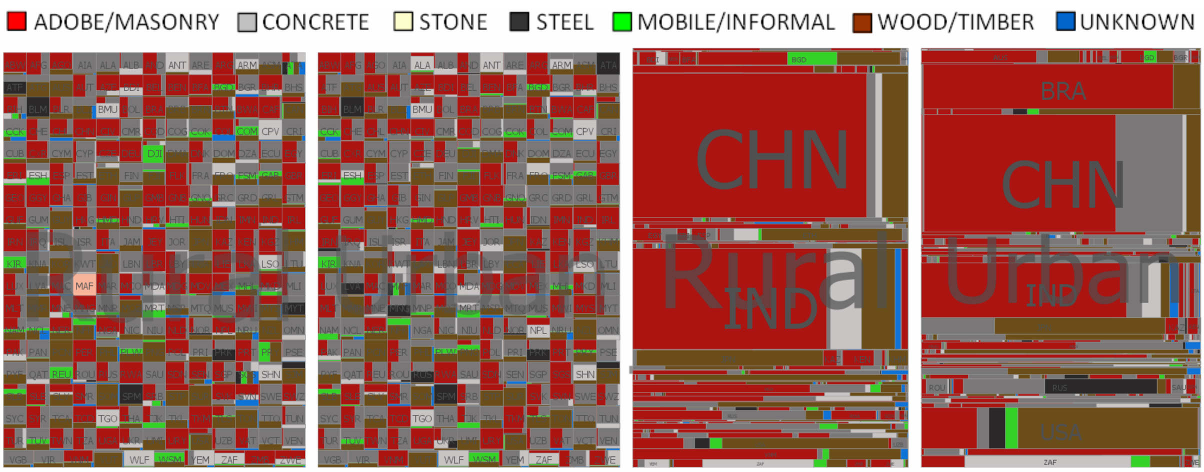

Figure 2.3. Urban and Rural Building Types in each ISO country ordered alphabetically and of equal size (left); Population living in various urban and rural building types (right) (Daniell et al., 2011c, Slingsby et al., 2011)

The most common building types in the world are unreinforced concrete blocks with about 16% of the global urban residential building stock. In addition, common wood building types have 10.67% of the global urban stock. Each country is shown in terms of building types aggregated from 95 classes to 7 classes to make viewing easier in Fig. 2.3. It can be seen that the population living in Adobe/Brick/Masonry buildings predominate worldwide and it has been proven that from 1900 to 2012 over 55% of people have died from earthquakes from collapse of various types of masonry structures (Daniell et al. 2011b).

A general building practice factor has been created using a combination of socio-economic indices such as corruption, relative income and other parameters. The building practice factor ranks the building quality in terms of corruption indices and building practice, engineering etc., allowing for comparison between countries. For earthquakes, a review of the various seismic resistant codes around the world has been undertaken, examining the level of base shear relative to hazard, seismic zoning and other parameters subjectively ranked in comparison to the relative hazard of a particular country. The seismic code index (Fig. 2.4) ranks the quality of seismic codes since 1900 in each nation, giving a score between 0 and 100. 154 nations out of 244 nations have some form of seismic resistant code, as of 2012, giving a score of 30/100 or greater. A notable change of code quality can be seen in some African nations where colonial European seismic codes have been discontinued through time and only recently reinforced.

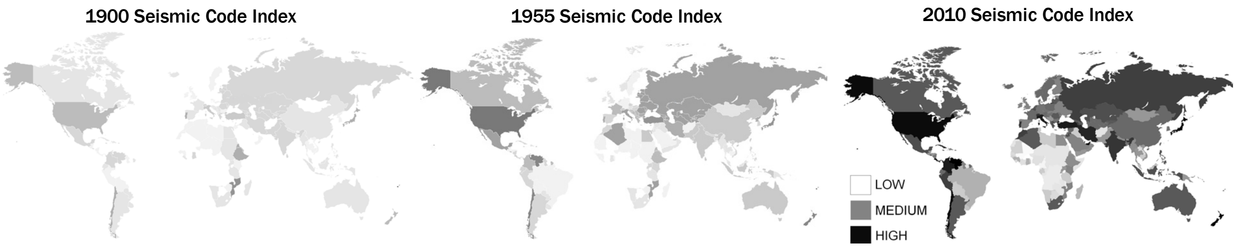

Figure 2.4. The evolution of the quality of seismic codes around the world (Level 1 shown) with range 0 (white) to 100 (black)

If countries are assumed to build equally to the hazard within the country across zones i.e. high-risk earthquake zones built to a higher standard, low-risk earthquake zones built to lower standard, then the following view can be made of the world in terms of relative vulnerability using building practice, building fragility function and seismic codes. (Fig. 2.5). By multiplying the relative quality of the building and the seismic code, this combined index gives a multiplier to show the reduction or increase of vulnerability between the event year and now.

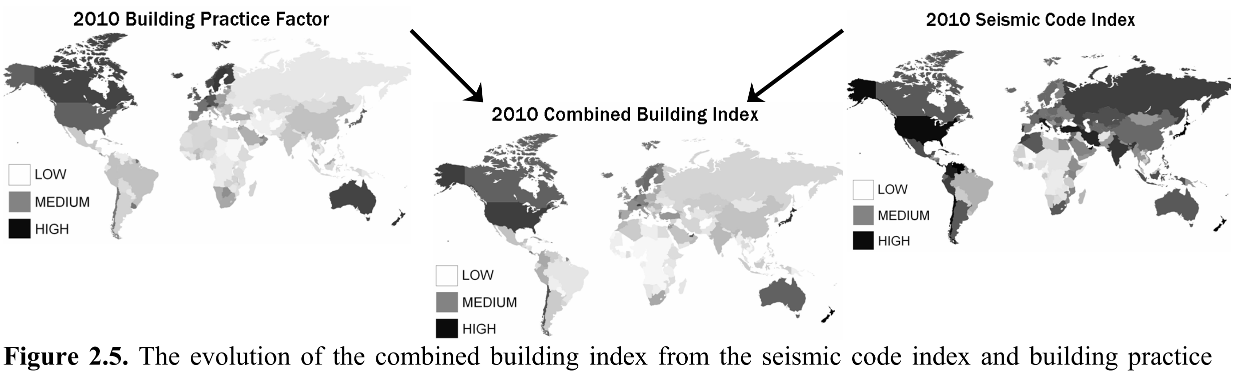

Figure 2.5. The evolution of the combined building index from the seismic code index and building practice factor for earthquakes (as of 2010) – values from 0 (white) -100 (black).

2.3. Economic Indices pertaining directly to infrastructure and sectoral losses from 1900 to 2012

Economic Indices pertaining directly to infrastructure and sectoral losses have been derived from 1900 to 2012, in order to look at the economic difference from the event year to today's terms. A detailed dataset of worldwide GDP (nominal and PPP-adjusted) and Capital Stock (net-depreciation and gross) data from 1900-2012 has been produced allowing for a better worldwide dataset than ever before. Economic values have been collected on the Level 1 (Country, 245 values), Level 2 (Province, 3000+ values), Level 3 (Sub-Province, 8000+ values) data have been produced for 245 nations (including the newly formed South Sudan), as well as for the largest 900 cities worldwide (Daniell 2009-2012, Daniell 2011a). Additional data on a lower level has been derived where census and bank data is available for smaller spatial resolution. An example is shown in Fig. 2.6. with Level 2 capital stock per capita shown on the right, and the net capital stock for the largest 900 cities in nominal USD shown on the right.

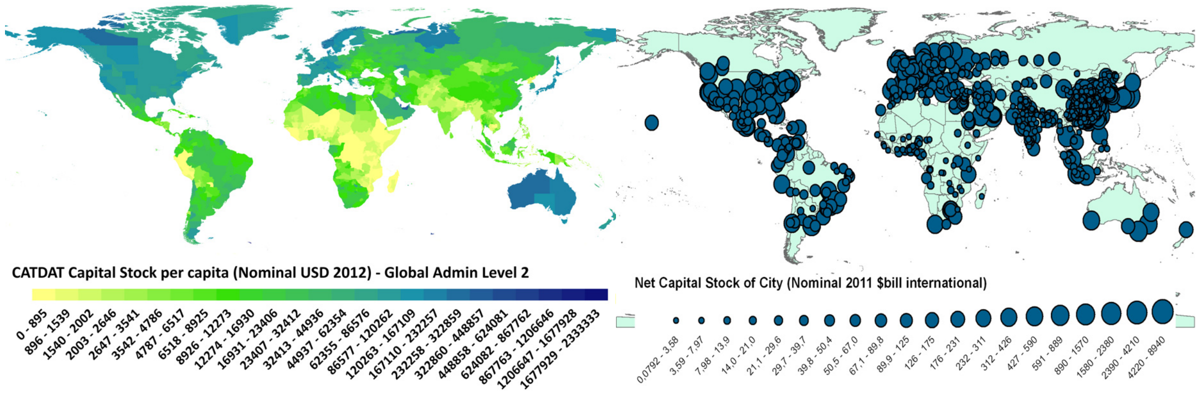

Figure 2.6. Left: CATDAT Capital Stock per capita (Level 2); Right: Net capital stock of City in 2011 $bill international (Daniell, 2009-2012)

Detailed economic analysis studies using the CATDAT dataset show that the adjustment from event-year loss to current-year loss utilised by historical databases using simple inflation via Consumer Price Index greatly underestimates the impact of historic earthquakes, giving less significance to historic events. Therefore, we have decided not to use the Vranes et al. (2009) version of normalising losses.

Many other economic indices have been derived, including exchange rate from 1900 to 2012, unskilled wage data, CPI data, inflation, sectoral changes and governmental regimes, as part of the CATDAT Damaging Earthquakes Database, as is discussed in Daniell et al. (2012c). These are essential for correlation of historic earthquake losses to today's terms, and post-disaster work (Wenzel et al. 2012).Using a combination of the vulnerability, wealth, population and adjusted event economic loss, a rapid prediction of socio-economic loss from each damaging historic earthquake in CATDAT since 1900 is presented.

3. WORLDWIDE EARTHQUAKE NORMALISATION STRATEGIES - METHODOLOGY

Given the level of data collected and the multitude of possible normalization methodologies, 2 methodologies are proposed using 2 different types of economic losses (direct and total) and 2 different historic earthquake disaggregation models (shaking and total).

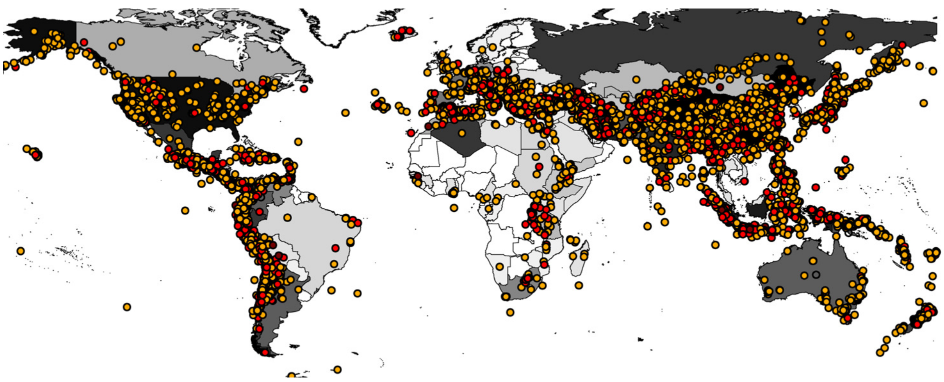

Figure 3.1. The 7103 damaging earthquakes from 1900 to 2012 used for normalisation.

There have been 7103 damaging earthquakes between 1 January 1900 and 17 April 2012, which have been reanalyzed for today's loss. It should be noted that non-damaging earthquakes during this time may also cause damage today due to changes in location of infrastructure but these are expected to be negligible given the level of damaging earthquakes collected within the CATDAT Damaging Earthquakes Database. The population within the damaging area was calculated via Shakemap data from USGS, historic earthquake intensity maps from over 500 sources and, where intensity maps were unable to be sourced, from produced shakemaps (Daniell 2011a). To simplify the population change between the event year and 2012, the total population within the VI+ intensity bound was chosen.

3.1. Discussion of Methodologies

The equations 3.1 to 3.4, below, denote the various factors used within the Daniell and Love (2010a) methodology of normalisation. The following method is used to normalise CATDAT earthquakes to the economic conditions of 2012, if the earthquake were to occur today. The normalised 2012 damage for a certain location ($NormD_{2012,loc}$) is characterised by the following equation:-

$$NormD_{2012,loc} = D_{2012,loc} \times PD_{y,loc} \times V_{y,loc} \times CW_{y,loc} \qquad (3.1)$$

2012 Event Adjusted Damage:
The 2012 HNDECI adjusted damage ($D_{2012,loc}$) is used as the initial input of the normalised damage calculation. The HNDEC Index converts the event-year-dollar earthquake damage to 2012-dollars through time via a hybrid index of GDP, wage and CPI, as per Daniell et al. (2012b) and this allows for the exact conversion to today and a much better calculation of earthquakes in today's terms.

Population-Dwelling Factor (PD):
The first factor used in the normalisation is the population-dwelling factor ($PD_{y,loc}$). It is assumed that the number of people in each dwelling has remained constant through time, or that the proportion of construction cost is constant per population (in countries where the former are not available). These assumptions have been explored within Daniell (2011a). In the area most affected in terms of damage, the population has been calculated in the region of the earthquake at the time of event, and in 2012 to indicate the relative difference in exposure. This difference is determined as a multiplier:-

$$PD_{y,loc} = Pop_{2012,\ location} / Pop_{year\ of\ event,\ location.} \qquad (3.2)$$

Building Vulnerability Factor (V):
The second factor is the change in vulnerability based on building code changes on a worldwide basis and the change in building types used in terms of earthquake resistance, in an attempt to evaluate the difference in damage to infrastructure as a result of the same earthquake occurring in the present year (2012). A building code will not lead to all damage from infrastructure being prevented, and is only there to reduce damage and for life safety. Using code work undertaken in HAZUS for example, code enforcement does play a major role to the losses that would be incurred in the retrofitted or newly built stock... This factor differs between 0.01 and 0.5 for full code enforcement, depending on the world location for those buildings built after the quake.

Loss studies, such as Giovinazzi (2005) for Italy, Durukal et al. (2006) for Turkey, Barbat et al. (2008) for Spain, provide a useful basis for the varying vulnerability factor in relation to losses for the building components. However, when looking at the percentage of buildings that are subjected to the code, this value reduces. Thus, the building age data collected in the building inventory was very important. In some cases where construction materials of buildings have moved from timber to masonry, the vulnerability of these buildings to earthquakes could actually increase over time.

Each update to the code in each country usually gives an increase in quality of the buildings built after the code enforcement. 479 code changes in 154 nations have been made from 1900-2012, as explored. As explained above, the combined building index of the building practice factor multiplied by the seismic code index from 1900 to 2012 was integrated against the building age percentages. Different locations have different building ages, such as Tokyo which has changed significantly, and individual studies have been undertaken for the major cities as part of Daniell (2011a). Further research will be undertaken in the future. The vulnerability factor is:-

$$V_{y,loc} = 1 - \int_{Year1900}^{Year2012} (BuildingStock\%Age, BPF, SeismicCodeIndex, Xfactor) \tag{3.3}$$

where the Xfactor is the relative loss factor associated with each seismic code change (used as 0.5 where data has not been sourced); BPF = building practice factor.

Community Wealth Factor (CW):-
This factor shows the difference in community output between the year of the event and 2012. This is the change which comes about as GDP and wealth increases faster than the HNDECI given industry changes in a region; hence it accounts for the increase through time of transportation, utilities and production per head of population. The difference in sector loss can be seen in Daniell et al. (2012b) showing the huge difference between losses from historic quakes. Currently, this factor takes into account country and province-based changes in wealth and output through the difference between the historical GDP (with the removal of inflation) and a reduction factor based on historic data. The community wealth factor is as follows:-

$$CW_{y,loc} = (GDP_{2012,loc}/GDP_{y,loc})/(HNDECI_{2012,loc}/HNDECI_{y,loc}) \times 0.2 + 1 \tag{3.4}$$

Table 3.1. The normalisation methodologies tested within this study

Method	Normalisation Parameters	Disaggregation	Economic Loss Type
1	Daniell and Love (2010a)	Total	Direct
2	Capital Stock method	Total	Direct
3	Daniell and Love (2010a)	Total	Total
4	Capital Stock method	Total	Total
5	Daniell and Love (2010a)	Disaggregated	Direct
6	Capital Stock method	Disaggregated	Direct
7	Daniell and Love (2010a)	Disaggregated	Total
8	Capital Stock method	Disaggregated	Total

The following equations (3.5 and 3.6) denote the methodology of the capital stock method to adjust losses to today's terms.

$$NormD_{2012,loc} = D_{y,loc} \times CSF_{y,loc} \tag{3.5}$$

Capital Stock Method Factor (CSF):-
This methodology simply uses the loss at the time of the event multiplied by the infrastructure wealth factor change of the area from the time of the event to today, using the multi-level CATDAT capital stock database from 1900-2012.

$$CSF_{y,loc} = \text{Capital Stock Value}_{2012,\ location} / \text{Capital Stock Value}_{year\ of\ event,\ location.} \tag{3.6}$$

3.2. Disaggregation of Economic Losses and the use of Direct vs. Total Economic Losses.

In Daniell et al. (2012b), it was shown that around 61% of economic losses from the 7103 earthquakes from 1900-2012 have been due to shaking. Other losses due to liquefaction, landslides, tsunami, NaTech and fire have been shown to total around 39% of economic losses from earthquakes. Liquefaction, landslides and tsunami losses should not be changed within the normalisation process, despite some economic loss mitigation measures in locations such as Japan. However, despite fire losses (totalling about 5% of the total economic losses) due to Great Kanto 1923 and San Francisco 1906, it can be argued that although fires will occur for an earthquake occurring today, the losses will be significantly lower from fire. Thus, fire losses have been reduced in the "Disaggregated" method to the levels of recent earthquakes such as Northridge 1994, Kobe 1995, Sichuan 2008 and Tohoku, 2011. The total values are representative of the Annual Average Loss (AAL) that has actually been lost; yet the disaggregated values give a better example of the future losses and the AAL of today.

In addition, due to the new impact of losses from industry, it has been decided that a direct economic loss version, and total (direct and indirect) loss version will be used for comparison in the final results.

4. WORLDWIDE EARTHQUAKE NORMALISATION STRATEGIES - RESULTS

From the normalisation study, it has been seen that there is a trend in economic losses when using direct or total losses from the disaggregated version. Reducing the major fire losses indicates that the total losses from earthquakes are increasing given the relative change in losses versus the worldwide losses. It can be seen that USA, Chile, China and Japan have the highest normalised losses in Fig. 4.1. from historic earthquakes for absolute earthquakes.

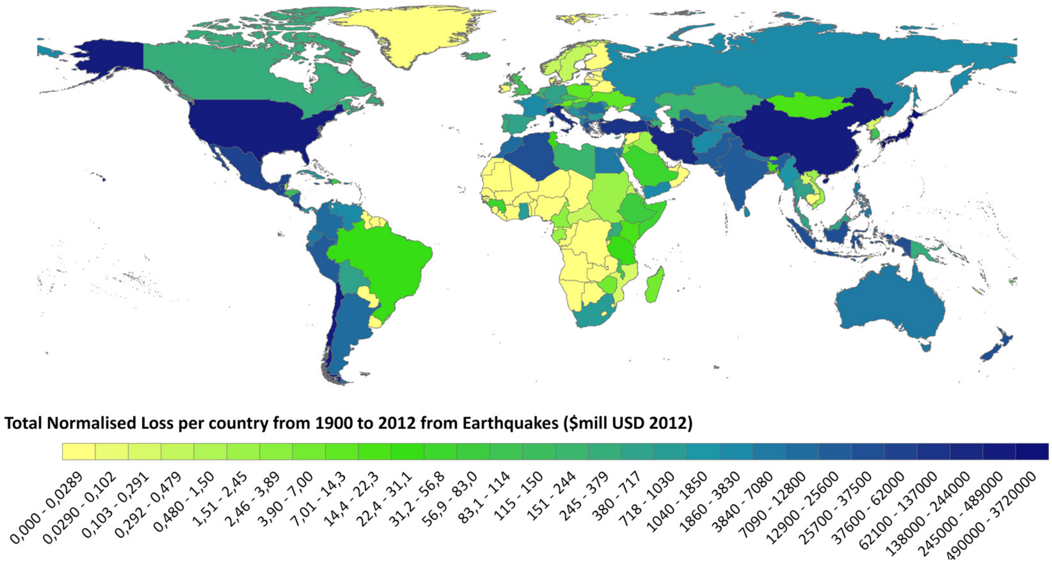

Figure 4.1. The preferred normalised loss (Option 5) in terms of disaggregated direct losses from 1900-2012

When looking at relative AAL losses (Fig. 4.2) from normalisation, Central Asia and Central American countries are generally the highest ranked due to the country size vs. the earthquake risk.

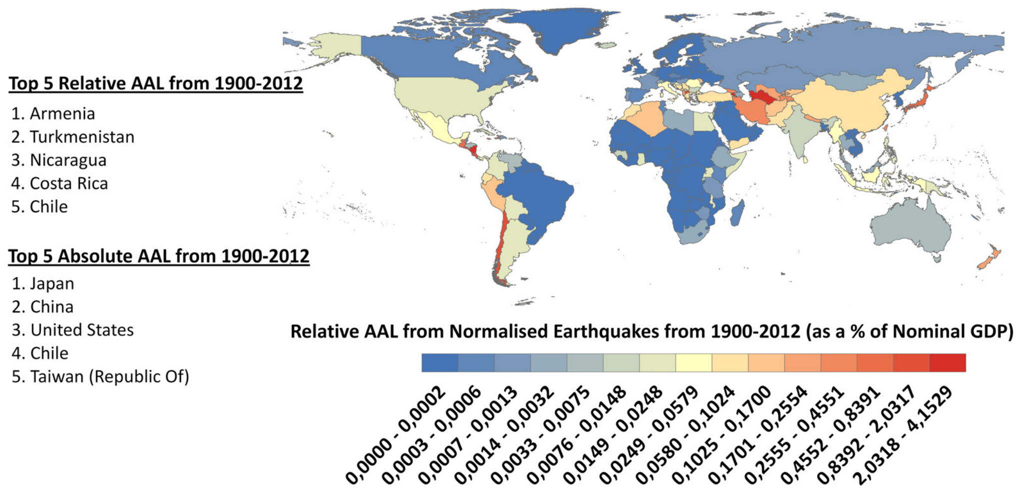

Figure 4.2. The relative annual average loss from normalised worldwide earthquakes (Option 5) in terms of disaggregated direct losses from 1900-2012

The difference between San Francisco 1906 in the disaggregated version (around $200 billion USD) and the non-disaggregated version (around $720 billion USD) shows the major difference given the fact that it is unlikely that a fire would destroy so many city blocks in the next earthquake. Due to the disaggregation of economic losses from historic earthquakes, this allowed for better normalisation than ever before. As per the RMS (2006) report on San Francisco losses, it is expected that the future damage will be $260 billion, which is 30% greater than the disaggregated value. Further comparisons can be made with historic studies, also agreeing well.

The AAL derived (Table 4.1) correlates well to the expected GDP (PPP) worldwide shown in Daniell et al. (2012b), at around 57 billion USD for direct losses and 71 billion USD for total losses.

Table 4.1. Total and AAL calculated worldwide via the normalisation methodologies (2012-dollars)

Method	Total Loss over 113 years	Normalised AAL Worldwide
1	$10.357 trillion USD	$92.2 billion USD
2	$9.612 trillion USD	$85.6 billion USD
3	$11.240 trillion USD	$100.1 billion USD
4	$11.149 trillion USD	$99.3 billion USD
5	$6.382 trillion USD	$56.8 billion USD
6	$6.409 trillion USD	$57.1 billion USD
7	$7.229 trillion USD	$64.4 billion USD
8	$7.945 trillion USD	$70.7 billion USD

5. CONCLUSION

The normalization of earthquake losses in today's terms from this study allows for better trends of economic losses from earthquakes than ever before. Using a statistically significant dataset, a realistic value of annual loss worldwide has been derived for the population of 2012. The production of many worldwide indices, including historical population, building inventory, seismic code index, building practice factor, capital stock values and other socio-economic details such as CPI, wage, GDP and HDI from 1900-2012, has been undertaken to create the normalisation. It has been seen that the economic losses from the normalisation strategies are very close to modelled losses from firms like RMS.

The Tokyo 1923 event can be seen to be the main loss event from 1900 to 2012; however, many other earthquakes such as San Francisco 1906, Kobe 1995 and Tangshan 1976 will also cause significant losses given a repeat event. Normalisation of earthquakes serves an important purpose for AAL; however, it should be noted that it should only be used for trends analysis and does not replace full earthquake loss estimation procedures.

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