The worldwide economic impact of historic earthquakes

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SUMMARY:

The CATDAT Damaging Earthquakes database contains economic damage and historical impact data on over 7000 earthquakes worldwide since 1900 with not only single values, but also ranges of possible losses for each earthquake. This paper details the trends in economic losses (direct, indirect and insured) with many economic loss values not reported in existing databases. Historical GDP, exchange rate, wage information and insurance information have been collected globally to form a hybrid index to compare earthquake losses. Additional work on the trends of indirect to direct loss ratios in developing economies show higher losses in recent years. Sectoral analysis of historic earthquake losses demonstrates that residential losses only make up around a quarter of direct economic losses in most cases. The disaggregation of secondary effect losses from historic worldwide earthquakes is also shown for tsunami, fire, landslides, liquefaction and fault rupture and Natech in comparison to direct earthquake shaking.

Keywords: Economic Loss, indirect, direct loss, HNDECI, insured loss.

1. INTRODUCTION

Economic losses (both direct and indirect) due to earthquakes have occurred in over 154 nations out of 245 as a result of earthquakes since 1900. Of these, none has been harder hit than Japan, due to a combination of not only earthquake shaking, but also secondary effects. The CATDAT Damaging Earthquakes database contains economic damage and historical impact data on over 7000+ damaging earthquakes worldwide since 1900, with not only single values but also upper and lower ranges of possible losses for each earthquake. This paper details trends in economic losses (direct, indirect and insured) in this database, as many economic loss values are not reported in existing databases.

An extensive global database of exchange rates, capital stock, wage, CPI and GDP (nominal and real) information was produced to allow the adjustment and comparison of foreign earthquake loss estimates. Global databases of wage rate and other parameters such as PPP were also created as part of the study from sources such as Maddison (2003), Officer and Williamson (2010), World Bank (2010), IMF (2010) and many individual national banks etc. as these details are required to effectively convert loss estimates from around the world into present-day costs. The concept of the HNDECI (Hybrid Natural Disaster Economic Conversion Index), which has been developed as a new method to accurately bring the historical losses to today's dollar amount, is also explained given the natural tendency of any CPI (Consumer Price Index) to underestimate losses in the past. (Daniell, 2011a) Globally, a slightly increasing trend in economic losses due to earthquakes is not consistent with the greatly increasing exposure. This could show the improved impact of better building practice due to earthquake building codes but also could be simply due to the lack of major earthquakes in urban and economically influential areas in the past few decades.

2. CONVERTING ECONOMIC LOSSES IN THE PAST TO TODAY'S DOLLARS

In order to compare the economic losses of two historic earthquakes, they need to be brought forward to present value. It is important to note that this is not simply an inflation adjustment but actually the values that would be paid in today's dollars for the event-year earthquake effects. In addition, each country has grown differently and thus will have different indices to bring dollar values forward.

The CPI is not the same in every country and can give very different results. Thus, economic trending must be done on a country-by-country basis. If the value is to be homogenised into international dollars (US dollars), then the individual country index must be used rather than that of the United States to bring the dollar amount forward, even if the original loss was recorded in US dollars. This is explained in greater depth in Daniell et al. (2010a); however, the concept is that because the disaster occurred in the country and not in the United States, then the exchange rate must be used at the time of the event, to produce the index to bring the value forward, and then the present exchange rate used to convert back to international dollars. Through the exchange rate database created within this study, this can be undertaken for any country globally from 1900-2012.

There are many indices that can be used to measure a historic loss parameter in today's dollars. For buildings, construction cost indices are commonly used; however, this data is also notoriously difficult to collect through time for each of the 245 nations worldwide. Table 2.1 shows inflation adjustment measures for economic costs commonly used worldwide.

Table 2.1. Details of common inflation adjustment measures for economic costs

Adjustment Parameter	Explanation
Consumer Price Index	CPI –Most common method. It is a cost comparison of consumer goods and services. Forms the basis for a country's inflation rate. Earthquake economic loss is generally not related to food and electrical goods costs – not reasonable!
GDP Deflator	A measure of average prices – not just consumer goods, also includes housing etc.
The Consumer Bundle	This is the average annual expenditure of a family or household – refers to how much goods are used as well as cost of the goods.
Unskilled Wage	Wage of an unskilled worker. Unskilled work remains constant through time – so is a good measure of wage.
Worker's Production Index	An index based on the wage of a production worker in manufacturing (i.e. in a specific job) - earnings as well as the increase in added benefits through time.
The Average Wage	Average of all wages in the country. Influenced by changes in the composition of the workforce towards more skilled labour and also higher wages on the top end. Not as good a measure through time – difficult to know what was included in 1900!
Project Escalation Index	A combination of construction materials, wages, inflation and other measures - attempting to account for the cost of an engineering project over a number of years.
GDP per capita	Gross Domestic Product produced per capita is also a good measure of the general output of a single person and has a good correlation with average income.
Gross Domestic Product	The Gross Domestic Product is the market value of all goods and services produced in a country in a year. This overestimates greatly the cost of a natural disaster in current terms, due to the large increase in population and associated infrastructure.

Thus, a hybrid index is designed to better account for the historical cost of earthquakes and other natural disasters in today's terms, using a combination of wages, construction costs, workers' production, GDP, CPI and other tools which change for each country. In the Hybrid Natural Disaster Economic Index (HNDECI), components of the earthquake loss (direct and indirect) are assigned an inflation adjustment measure to bring the loss to present day value in much the same way as a project escalation index for an engineering project. Using the HNDECI, more accurate comparison than ever before was produced for historic earthquakes. An example of the conversion of various components of a historic earthquake are shown in Table 2.2.

Table 2.2. The assumptions for adjustment within the Hybrid Natural Disaster Economic Index

Natural Disaster Parameter	Adjustment to future terms	Reason
Property Loss (commercial,	Country-based unskilled wage	Historical trends have been matched to

industrial and public buildings)	index	property loss with good correlation
Reconstruction Cost of Residential Buildings	Country-based PhD Building Inventory analysis and historical material databases	Building costs analysis via historical components of houses gives closest value.
Crops, pastures, livestock	Using historical databases – if not, CPI.	CPI is most likely closest to the cost of crops and livestock.
Life Insurance and Intangible costs (Deaths, Injuries, Disability)	Proxy on premiums. Country-based average wage or Worker's Production Index or 1.5 times an unskilled wage.	BTE (2001) trended most of this cost to above an unskilled wage trend – with increasing GDP playing a role.
Indirect Losses via business interruption	Consumer Price Index	Economic values should be CPI adjusted (or interest rate)
Clean-up	A combination of material costs (CPI) and demand surge wage. This is constant through time.	A 50-50 combination of CPI and unskilled wage.
Utilities and Transport Damage	Unskilled wage index.	Tied closer to construction materials and labour.

The reconstruction material cost assumption is difficult to produce as datasets for all parameters are not readily available. Historical datasets have been surveyed to build a global adjustment for construction cost; however, for the moment a value directly between the CPI and the unskilled wage is chosen where data is lacking. A good assumption on a sliding scale is that the economic loss of an earthquake should be brought forward using a value slightly greater than the unskilled wage.

3. A COMPARISON OF EARTHQUAKE ECONOMIC LOSSES FROM 1900 ONWARDS

Using the HNDECI and the full damaging earthquake database, all 7000 earthquake event losses have been brought forward to 2012 dollars. Unsurprisingly, it can be seen that developed countries dominate the economic losses, given the influence of historic Japanese (over $1 trillion) and China (over $400 billion) earthquakes. Major events such as Tohoku 2011, Sichuan 2008 and Great Kanto 1923 have had the largest influence on the overall losses in absolute terms. The key earthquakes, causing over $75 billion in losses (2012-HNDECI adjusted), are shown by year in Fig. 3.1.

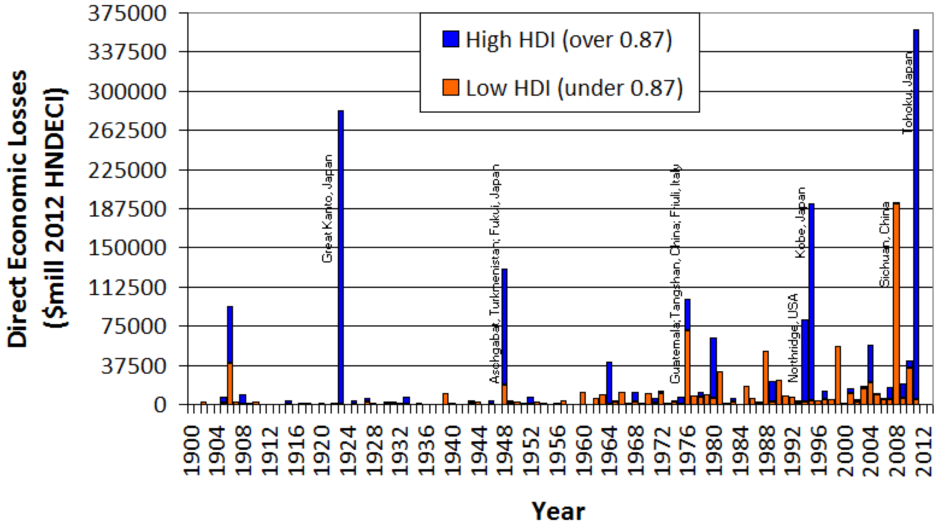

Figure 3.1. Historic earthquake economic losses per year in 2012-HNDECI Adjusted Dollars

However, earthquakes with lower economic losses can have a major impact on smaller countries as compared to the event-year GDP of the country. Using Purchasing Power Parity to take into account the relative cost of goods in countries, the following annual average loss as a percentage of GDP (PPP) is undertaken for each country. This shows the relative impact of each individual earthquake, giving a better understanding of the economic risk of each individual nation in relation to GDP. A list of the highest losses from individual events is included in Daniell et al. (2011b). It can be seen in Fig. 3.2 that Chile, Armenia, Turkmenistan, Haiti, Nicaragua, Costa Rica, Japan and New Zealand have high exposure, as expected, to economic losses as a % of GDP.

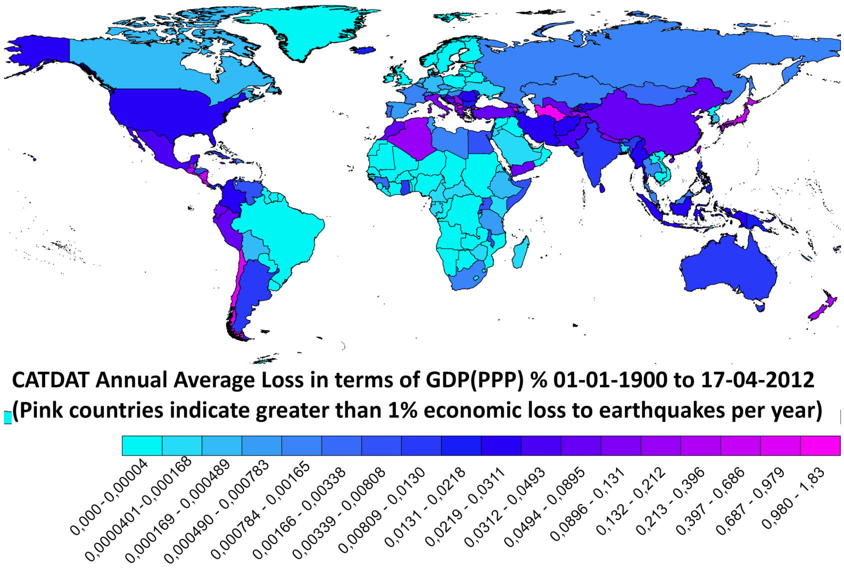

Figure 3.2. Annual Average Loss (in % GDP (PPP)) from earthquakes over 112 years from 245 nations

The highest absolute economic losses have resulted from the earthquake/tsunami/powerplant disaster of Tohoku 2011 (Table 3.1). This showed the economic impact of cascading effects of earthquakes. In terms of relative loss to a country, the Armenian earthquake of 1988, although technically occurring under the former USSR, occurred at a point where the effects were borne mostly by the country of Armenia. The central American countries also show a large relative exposure to earthquakes.

Table 3.1. The highest 10 direct economic losses in terms of nominal GDP at the time of event since 1900 and also absolute losses as per the 2012 HNDECI-Adjusted US Dollar direct economic loss value.

Rank	Earthquake	Relative (% of Nominal GDP)	Earthquake	Total Economic Loss ($bn 17 April 2012-HNDECI)
1	Armenia (*SSR) 1988	358.9	Tohoku 2011	324.0
2	Managua 1972	67.1 to 105	Great Kanto 1923	271.3
3	Cartago 1910	90.0	Sichuan 2008	189.8
4	Concepcion 1906	55.0 to 82.9	Great Hanshin 1995	187.6
5	Haiti 2010	70.0	Fukui 1948	111.8
6	Wallis/Futuna 1993	54.0	Northridge 1994	79.1
7	Great Kanto 1923	52.8	Irpinia 1980	58.0
8	Guatemala 1976	50.3	Tangshan 1976	57.8
9	Nicaragua 1931	51.0	San Francisco 1906	55.1
=10	Maldives 2004	46.0	Niigata 2004	35.5
=10	Jamaica 1907	45.9		

*Accounts for a partial Soviet Union response – doubling the 1990 Nominal GDP and GDP (PPP) of Armenia. Hyperinflation and devaluation made it very difficult to properly determine the GDP of the time; thus, a range has been given incorporating different sources from 1988-98 using an average value through this period, consistent with the reconstruction payout through time. Modelling leads to values as high as 594% of nominal GDP.

Insurance takeout for earthquakes differs worldwide; however, historic earthquakes have generally had a minor impact in comparison to the total losses. In the future, insurance losses will take a more major role. It should be noted that when using the HNDECI, the Great Kanto in 1923 gave the biggest insurance loss of up to $55 billion as compared to Tohoku 2011, which gives the highest insured loss using country-based CPI. The insurance takeout within New Zealand is the highest insured loss as a proportion of GDP, with event insured losses for the first time exceeding 10% of GDP (Table 3.2).

Table 3.2. List of highest insured losses (1900-2012) in 2012 Country CPI adjusted $ international

Rank	Earthquake	Country	Date	Insured Loss Range	Pref. Source for Loss
1	Tohoku	Japan	11.03.2011	$33.9bn-$38.75bn	Industry Estimates
2	Northridge	USA	17.01.1994	$23.53bn	Industry Estimates
3	Christchurch	NZ	21.02.2011	$10.97bn-$16.46bn	Industry Estimates
4	Great Kanto	Japan	01.09.1923	$8.46bn-$14.58bn	Daniell (2010b)
5	Maule	Chile	27.02.2010	$8.39bn-$13.30bn	Industry Estimates
6	Kobe	Japan	16.01.1995	$6.56bn	Industry Estimates
7	San Francisco	USA	18.04.1906	$6.14bn	Daniell (2003-2012)
8	Izmit	Turkey	17.08.1999	$3.63bn-$8.46bn	Industry Estimates
9	Darfield	NZ	03.09.2010	$2.19bn-$4.94bn	Industry Estimates
10	Sumatra	Many	26.12.2004	$2.375bn-$4.224bn	Daniell (2003-2012)
10	Loma Prieta	USA	18.10.1989	$2.58bn	Daniell (2003-2012)

4. RELATIVE IMPACTS ON ECONOMIES FROM EARTHQUAKES

Capital Stock has changed around the world with development through time from 1900-2012, and this is quantified for each of the 245 nations by using much data on infrastructure, depreciation rates and the other CATDAT Exposure databases. The relative loss as a % of capital stock from 1900 to 2012 is shown in Fig. 4.1 for each country. It can be seen that the annual average loss of New Zealand or Japan is about 0.05% loss of the total capital stock.

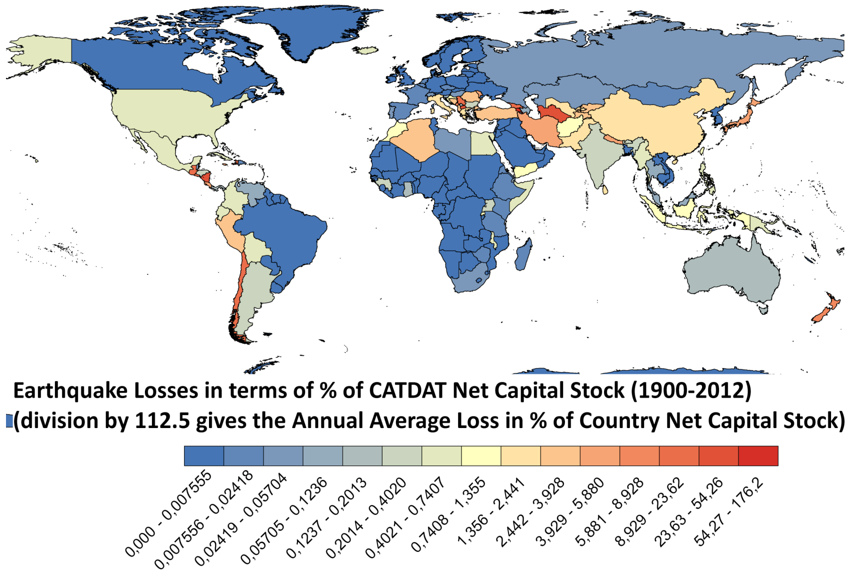

Figure 4.1. Cumulative Net Capital Stock Loss (in %) from earthquakes over 112 years from 245 nations

4.1. Indirect Losses

A split between indirect and direct losses has been undertaken for each earthquake where data was available. Indirect losses are notoriously difficult to quantify; however, existing studies such as Toyoda (2008), CEPAL (1987) and 200+ other studies have been used in addition to our own studies.
Additional work on the trends of indirect to direct loss ratios in developing economies has shown that higher indirect losses generally occur with the size of economic loss and with a decreasing development index. This is in some respects counter-intuitive, with the size of business interruption in developed country economies exhibiting a much higher absolute value; however, because of the lack

of redundancy in production sector practices in developing country economies, the relative influence of indirect losses is higher. This can be demonstrated by the 50 example earthquakes in Fig. 4.2.

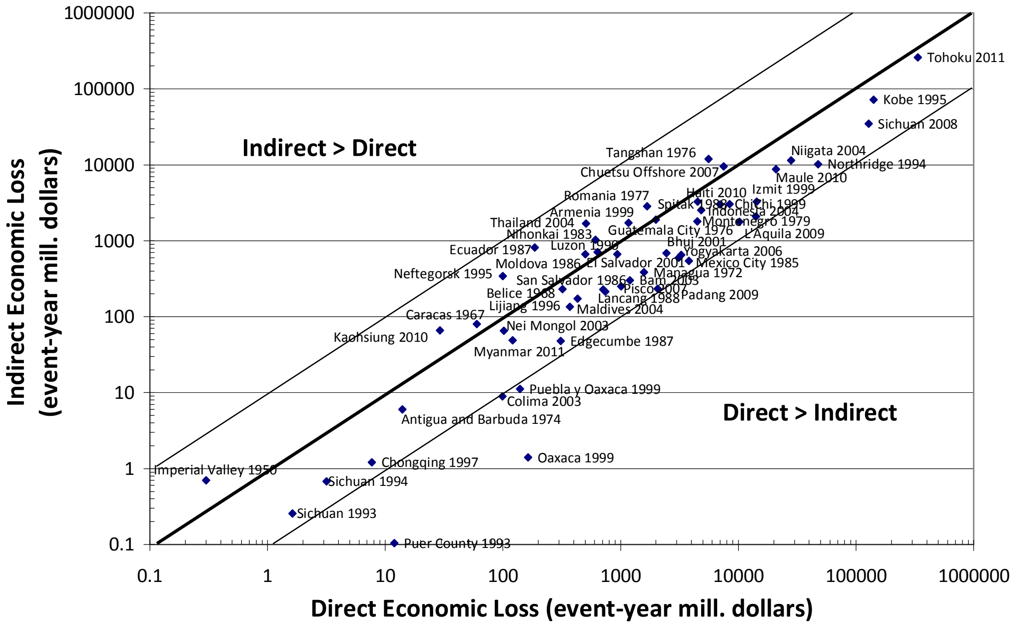

Figure 4.2. Direct vs. Indirect economic loss from selected events in event-year mill. US dollars within the CATDAT Damaging Earthquakes Database

Indirect losses will continue to increase with production of various items being shared across countries, such as cars being produced from car parts from 2 or more countries, or microchips being produced in other locations than the end-electrical products' location. The Ecuador 1987 earthquake is also a famous example of downtime of destroyed pipelines in oil-dependent nations where a lack of redundancy meant that although 33km of pipelines were destroyed and the pipeline damage was $122 million (1987 US), the associated losses with lack of supply totalled $766 million (1987 USD). Other sectors such as tourism are commonly greatly affected. Further reanalysis will be undertaken using socio-economic indicator processes, such as that of Daniell et al. (2010a), for indirect losses in the Asia-Pacific region.

4.2. Disaggregation of Secondary Effect Economic Losses

Disaggregation of secondary effect economic losses demonstrating the relative influence of historical losses from direct earthquake shaking in comparison to tsunami, fire, landslides, liquefactions, fault rupture and other type losses is important if we are to understand the key economic loss causes post-earthquake. Existing studies have attempted to look at the key causes without putting dollar values on the losses e.g. Bird and Bommer (2004) studied 50 earthquakes between 1980 and 2003 for all secondary effect types, Keefer (1984), Rodriguez et al. (1999) studied landslide losses, and NGDC (2010) looked at tsunami losses. Although most historical losses have been earthquake shaking related, the influence of the recent 2011 Tohoku earthquake has changed the historical percentages significantly for tsunami, as have the Kobe 1995 and Christchurch 2011 earthquakes with regard to liquefaction. Liquefaction has occurred in many earthquakes but this is also difficult to disaggregate for older historic earthquakes. Fire in San Francisco 1906 and Great Kanto 1923 caused a proportion of losses, but since then important losses have also occurred in many earthquakes.

A detailed study of all 7103 damaging earthquakes from 1 January 1900 to 17 April 2012 has been undertaken by examining the original sources, descriptions and expert opinion where exact dollar amount losses with regard to disaggregation have been calculated. The results in Fig. 4.3 are depicted for direct losses and total economic losses from earthquakes. Around 70% of direct economic losses have come from direct earthquake effects, whereas 30% have occurred due to secondary effects of earthquakes. For total economic losses, taking into account the indirect losses, this percentage increases to 38%. This has many implications for our earthquake research. The focus on just shaking losses should be changed to one of holistic strategies for shaking and secondary effects losses.

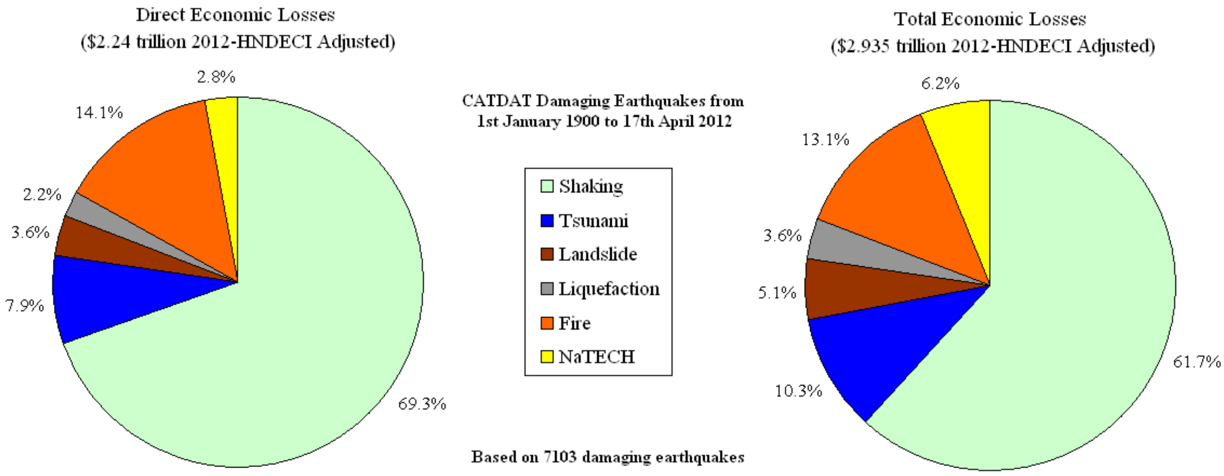

Figure 4.3. Disaggregation of Shaking and Secondary Effects Economic Losses from 7103 earthquakes from 1900 to 2012 – Left: Direct Economic Losses; Right: Total Economic Losses

Landslides can be seen to cause over 5% of economic losses currently and this has only been low due to the relatively low populations living worldwide in mountainous areas exposed to earthquakes since 1900. China has experienced major losses through the Haiyuan 1920 and Sichuan 2008 earthquakes. Khait 1949 and Ancash 1970 were also major landslide-bearing earthquakes causing major economic losses to their respective countries. The Tohoku 2011 and Indian Ocean 2004 earthquakes have both caused most tsunami economic losses in recent years; however, many tsunami-bearing earthquakes have caused much damage e.g. Chile 1960, Alaska 1964 with over 10% of total losses due to tsunami and additional NaTech (Natural Hazards triggering technological disasters) losses via the powerplant disaster in Tohoku.

4.3. Sectoral Losses from Historic Earthquake Events

Sectoral disaggregation of economic losses from historical events is also undertaken to demonstrate not only the relative losses from various infrastructure types, but also various production, manufacturing and social services losses, as well as other influences such as NaTech economic losses from the CATDAT databases. Sectoral analysis of historic earthquake economic losses reveals that residential losses are not always the greatest loss sector with respect to earthquakes. 60 major earthquakes between 1907 and 2011 around the world are shown in Fig. 4.4 splitting direct earthquake losses into the various social (buildings-private, health, educational etc.), infrastructure (bridges, pipelines etc.), production and cross-sectoral (banking etc.) losses. In total, 47 classifications have been used for sectors for direct losses for earthquakes. As expected, around 50% of earthquake direct losses were from various types of buildings (around 45% on average being from residential buildings, and the other 55% consisting of governmental, educational, cultural, health and inventory of the buildings). Further reanalysis will attempt to be undertaken in the future to split non-structural and structural loss within this sector, with an example earthquake being the 1978 Albstadt earthquake in Germany where 44% of the residential damage was non-structural.

Around 30% of the direct losses come from infrastructure losses (transport/communications, pipelines, energy supply systems etc.). Generally, about 15-20% of direct economic losses came from the production and cross-sectoral sectors where economic effects and goods and services are counted. In these sectors there are generally large indirect losses associated with them and this has not been shown on this diagram but is included in the CATDAT Damaging Earthquakes Database v5.1001 (Daniell et al. 2011b). A good example of large direct losses from the goods and services sector came from the loss of the banana stock ready for export in the Limon, Costa Rica, earthquake in 1991.

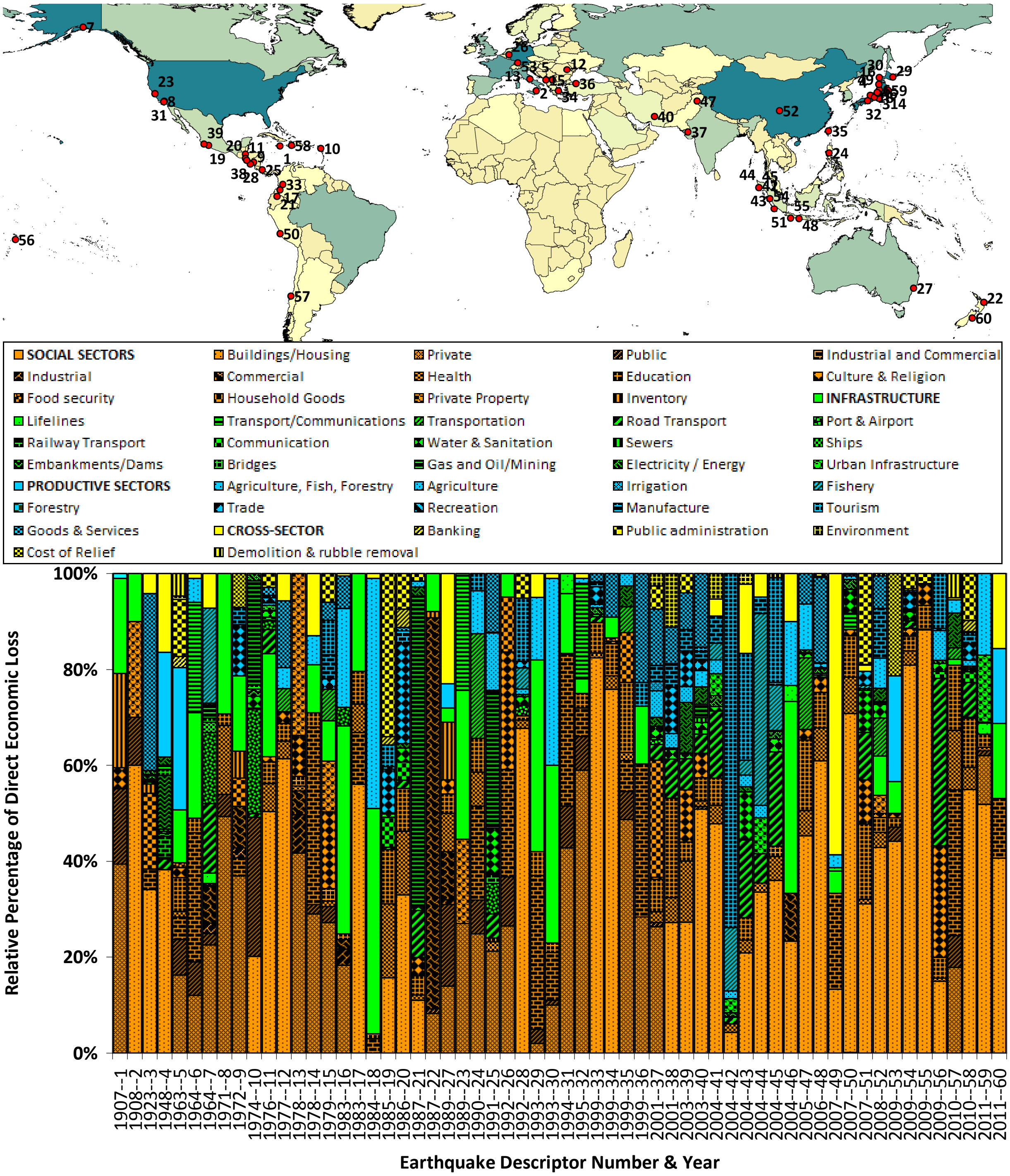

Figure 4.4. Disaggregation of direct economic losses of 60 selected major earthquakes into 47 economic sectors of loss. (Numbers correlate to earthquake locations in the above diagram)

4.4. How has the world changed since 1900?

Showing the cumulative worldwide socio-economic trends of GDP and population over the last 113 years, it can be seen that the Gross World Product (GWP) has increased relative to population (as seen left in Fig. 4.5). Meanwhile, deaths due to earthquakes have been steadily decreasing relative to the population of the world. This is due to many factors, including better building practices, seismic resistant codes in 150+ nations, early warning systems, earthquake risk awareness, non-megacity affecting earthquakes and a wealth increase. However, when compared to the worldwide death rate from 1900 to 2012 (Daniell, 2009-2012) a slight increase can be seen in earthquake deaths as a percentage of total deaths, meaning that perhaps greater efforts have been made to reduce human death tolls in other fields when compared to earthquakes.

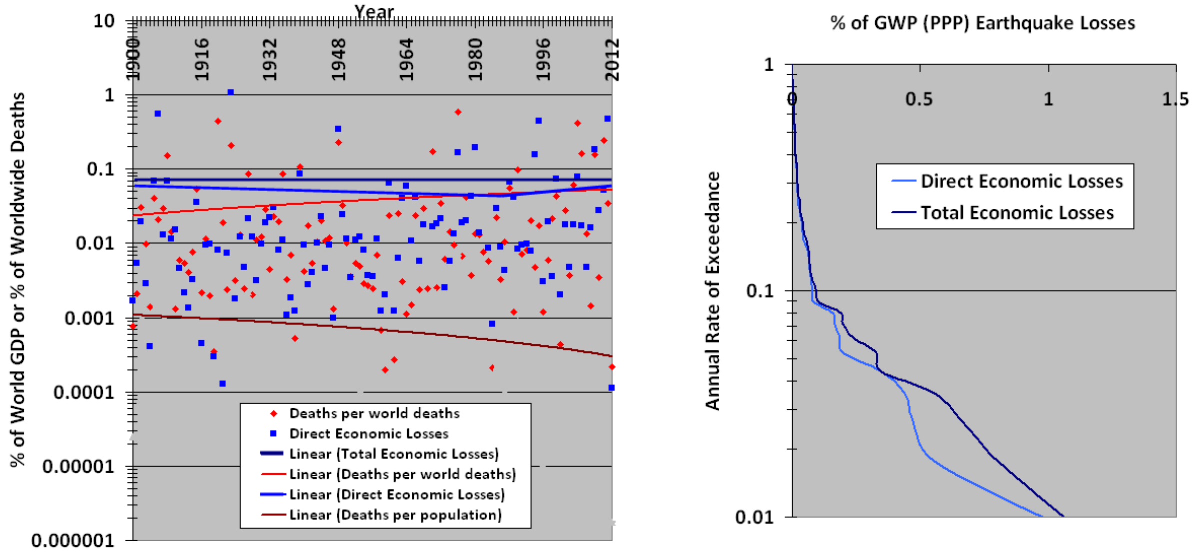

Figure 4.5. Left: The worldwide trend of population, deaths and GDP (PPP) in fatalities and economic losses from 1900 to 2012; Right: Exceedance curves in terms of economic losses as a % of GDP (PPP) p.a.

The direct economic losses from earthquakes as a percentage of GWP (PPP) of the world has fluctuated over time, peaking at 0.1% in 1949, and has reduced to about 0.047% of GWP (PPP) with a slight increase in recent years. Over the time period, wealth and population have increased, and the absolute value of loss is therefore increasing despite the reduction in relative losses. This has also held for the period from 1800-1899 with 0.055% of GWP. Using a cumulative annual average loss over 213 years, the average annual loss is 0.0505±0.007%. For the year 2013 (projected GWP(PPP)=87.3 trillion USD), it can thus be expected that the annual loss will range (± 1 standard deviation) from 38-50.2 billion USD with a median 44.1 billion USD from earthquake effects worldwide. This is a useful value for a globally distributed portfolio over a number of years.

Of course, there is much variability in an individual year that is not taken into account in an annual average loss sense. Only 9 years of 113 have seen over 0.1% of GDP(PPP) losses from 1900-2012 as seen right in Fig. 4.5. A lognormal distribution fits very well showing a median of 0.01% of GDP in any 1 year. There is a 16% chance of the loss exceeding 0.043% in any year, and about once in 10 years over 0.075% in economic losses is expected (around 65 billion USD in the year 2013). It can be seen that total economic losses are increasing due to greater business disruption, and other associated indirect losses with time due to the more globalised nature of business.

5. CONCLUSION

In this paper, a view of historical worldwide economic losses due to earthquakes has been presented using the CATDAT Damaging Earthquakes Database. It has been demonstrated that correct use of indices, such as country-adjusted CPI, GDP and wage, is essential to convert historical losses into today's dollars. This can be undertaken using the newly developed HNDECI (Hybrid Natural Disaster Economic Conversion Index). With over 2.9 trillion US dollars damage due to earthquakes occurring between 1900 and 2012, earthquake economic damage has shaped certain parts of the world (Central Asia, the Pacific rim etc.) as shown through the relative and absolute views of losses presented.

Through collecting and analysing this in-depth information, three key aspects of economic losses from historic earthquakes have been introduced in this paper:

1) Indirect losses in earthquakes cause a large proportion of damage in some cases (Tohoku 2011, Kobe 1995), due to the effects of business interruption, lost revenue etc. Historic earthquakes such as Ecuador 1987 had up to 7 times greater indirect losses than direct losses.
2) Disaggregation of secondary effect economic losses is presented in the paper, demonstrating the relative influence of historical losses from direct earthquake shaking (61%) in comparison to tsunami, fire, landslides, liquefactions, fault rupture and other type losses (39%).
3) Direct economic losses have also been disaggregated into the relative economic sector losses for 60 selected earthquakes, showing the relative losses in the social, infrastructure, productive and cross-sectoral sectors through use of the CATDAT Databases.

Finally, the trend of worldwide economic losses has been compared to the socio-economic status, showing that losses are increasing worldwide, though not as markedly in some previous studies. Many other trends can be produced from the significant number of parameters and indices produced in CATDAT. Refer to Daniell et al. (2010a, 2011b, 2012) for additional information.

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