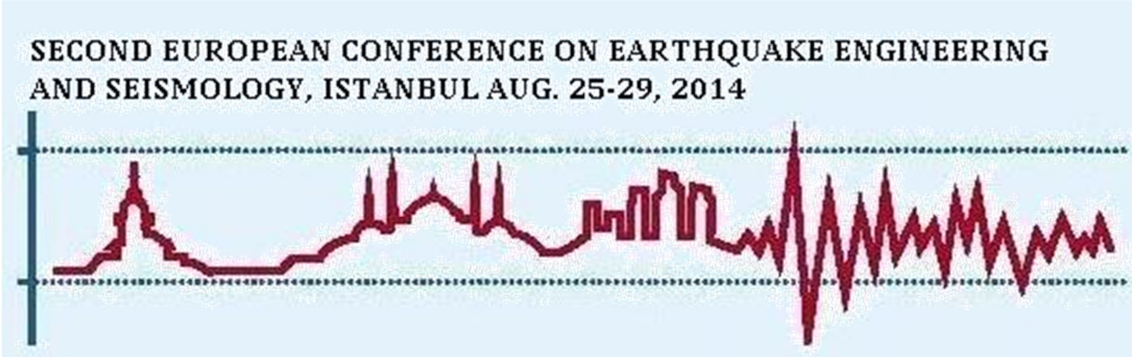

THE ECONOMICS OF EARTHQUAKES: A REANALYSIS OF 1900-2013 HISTORICAL LOSSES AND A NEW CONCEPT OF CAPITAL LOSS VS. COST USING THE CATDAT DAMAGING EARTHQUAKES DATABASE

James Edward DANIELL[1], Friedemann WENZEL[2]

ABSTRACT

The definition of economic losses within the CATDAT Damaging Earthquakes Database (Daniell et al., 2011a) as of v6.1 has now been redefined to provide three options of pricing, including reconstruction cost, replacement cost and actual loss, in order to better define the impact of historical disasters. Damaging earthquakes from 1900 to 2013 have been reassessed taking into account the historical net and gross capital stock and GDP at the time of the event, including the depreciated stock, in order to calculate the actual loss. The difference between depreciated and gross capital can be removed from the historical loss estimates which have been all calculated without taking depreciation of the building stock into account. The culmination of time series of net and gross capital stock, GDP, direct economic loss data, use of detailed studies of infrastructure age, and existing damage surveys, has allowed the first estimate of this nature. This aids rapid earthquake loss estimation of economic losses and costs. Case studies of 1948 Turkmenistan and 1995 Kobe are shown, where the reanalysed loss and cost values provide a different result from existing databases, providing a better insight into the historical loss.

INTRODUCTION

Economic loss and cost estimates from historical earthquake socioeconomic loss catalogues provide various loss estimates confused with gross capital stock and total costs calculated via insured losses. This has been the case in all major databases including EM-DAT, MunichRe, SwissRe and the author's own CATDAT database pre-2012. The CATDAT Damaging Earthquakes Database provides over 7200 earthquakes analysed with respect to country economic conditions at the time of the event and provides a method of comparing 2 events from different countries while still taking into account the major differences in CPI, wage and GDP adjustments through time. The historical economic loss values in CATDAT have been aggregated from estimates after events, as well as from various studies. However, pre-2012, depreciation of the exposed stock was not taken into account in the historical estimate, meaning that a gross capital stock loss (or replacement cost) was used, rather than the true value of the disaster.

An earthquake affects new infrastructure stocks as well as dilapidated and used infrastructure stocks; however, in the reconstruction, the total infrastructure stock is returned to a completely new infrastructure stock. Often, reconstruction costs are higher than replacement costs due to additional laws and other enactments brought in as part of the reconstruction process (Sichuan 2008) (Table 1).

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ECLAC (2003) and BTE (2001) were the first to provide context as to this difference, with a book value loss being the actual loss associated with an event. However, for this, the depreciated stock and the gross stock need to be known. It is reasonable for an insurance company to define its losses in the form of replacement costs for the portion of the stock that they are insuring; however, it does not also define "losses", but only "insured costs for replacement and repair of stock". This is a good proxy for the government to view the improvement in their stock relative to the actual loss.

METHODOLOGY

The definition of gross capital stock is given as the replacement cost of the infrastructure (without depreciation, but with price index changes). Net capital stock includes all tangible items of infrastructure (i.e. buildings, equipment, contents, non-structural, infrastructure) but also includes the depreciation rates associated with the infrastructure. Buildings that are older have less value on average (even given repair costs and retrofitting). In addition, in the case of earthquakes they have a higher damage ratio, as shown by many damage surveys (Eleftheriadou and Karabinis, 2008; Porro and Schraft, 1989; Cochrane and Schaad, 1992). When these older buildings are replaced, this gives a large difference between the actual value lost and the replacement cost, meaning that often in extreme cases building losses can be overestimated by at least 2 times, by the depreciated definition as seen in Figure 1.

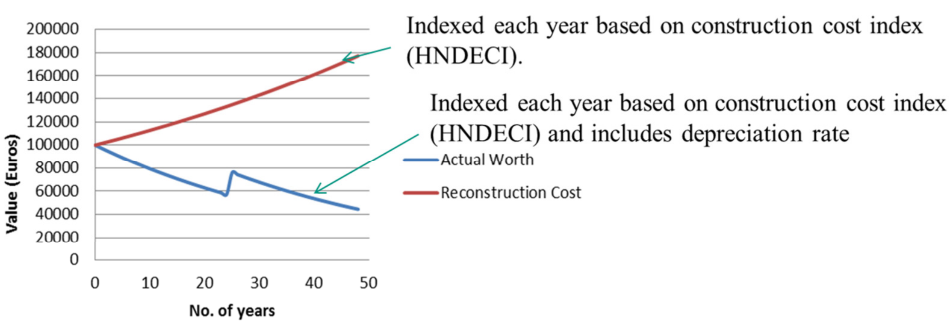

Figure 1: The difference of gross and net capital stock for an individual building

For a group of buildings, there is an averaged depreciation rate (as repairing certain components of damage adds in some value and an extension of design life) over various sectors. For an individual building, this does not work, as an average value per m^2 is generally used for gross cost and the repair cost would be underestimated in an averaged GFCF or Gross Fixed Capital Formation with index.

Table 1: Definitions for actual loss, replacement and reconstruction costs

	Economic Loss Type	Loss Metric
Actual loss to society and the country.	Contents, Infrastructure and Building Direct Losses, Production+Indirect Losses	Net Capital Stock and GDP
Replacement cost for society and the country.	Total Replacement cost	Gross Capital Stock at time of event and GDP
Reconstruction cost for society and the country (chosen by government) can be standard.	Total Reconstruction cost	New Gross Capital Stock via Gross Fixed Capital Formation increase and additional building law changes post-disaster and GDP

The present-day capital stock that is rebuilt after an earthquake incorporates an increase in building typologies and quality of typologies, which includes an increase in construction GDP and total capital value of a society. This can also be defined by the formation of gross capital stock as a percentage of GDP. This value can be defined as GFCF. The more deteriorated the building stock, the lower the standing value, and the higher the reconstruction cost needed relative to the initial value. GDP increase due to reconstruction is simply a capital stock production (gross capital formation) which is essentially, if reconstructed well, returning the location to a higher economic exposure than previously, given that as buildings become older, there is a certain depreciation associated with the stock. This reconstruction can then offset GDP losses (some of which are non-recoverable) in other sectors through growth and need for services and industry (and in some cases the entire capital stock lost). To provide a new perspective moving away from a purely reconstruction cost-based loss assessment which is synonymous with the cost for a reinsurance company of the portion of damaged stock which they insure, the following methodology in Figure 2 has been undertaken for each of the 7208 damaging earthquakes from 1900-2013 by using modelling of GDP & capital stock estimates, combined with the earthquake loss methodologies used to create the loss estimates post disaster.

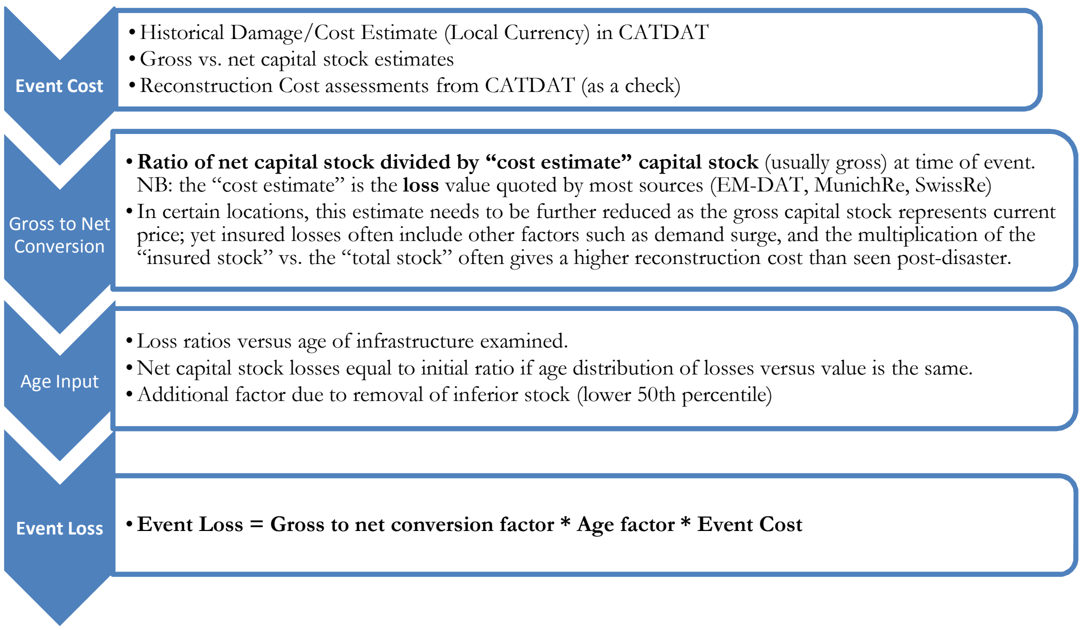

Figure 2: Process diagram for the evaluation of economic loss and cost from earthquakes

CAPITAL STOCK AND GDP ESTIMATES FROM 1900 ONWARDS.

The net and gross capital stock are the key to assessing losses worldwide. A global assessment on province level has been undertaken in the PhD of Daniell (2014) in order to characterise net and gross capital stock from 1900-2013 for each province in the world, as shown in Figure 3. In all cases, care has been taken that only structures and equipment were included in the calculation and not the addition of future mining resources, or land. This forms a slight issue when calculating losses due to liquefaction, as in the case of Christchurch, given the cost associated with land; however, this value should be adjusted on a case-by-case basis. BTE (2001) simply used the premise that the net capital stock is approximately 50-60% of the gross capital stock for Australia and New Zealand. GFDRR (2005) used a reduction factor for Pakistan vs. replacement cost (approx. 1.5 times). GFDRR (2010) used a 40% reduction factor for Haiti. World Bank (2005), in their Wealth of Nations, used a flat 5% depreciation rate worldwide.

On average over the world, this difference of gross and net capital stock does not necessarily correlate with the age of infrastructure, given that differences exist in depreciation rates and gross capital formation through time. Hofman (2000) has calculated gross to net capital stock for 6 countries from 1950-1994. Timmer and van Ark (2002) explore relationships for Taiwan and North Korea in terms of productivity and differences in capital stock. Wu (2009) explores capital stock relationships for China. A calibration of the "age of infrastructure" through time analysis and the "gross capital formation" allows for a trend to be built for gross capital stock. The value fluctuates between 1.3 and 2.4 times the net capital stock of a region. This is only applied as a fill-in where no data was sourced or directly created via the GFCF and the depreciation rates of structures, equipment etc. This has been normalised in terms of USD, using direct exchange rates. It could be argued that an additional PPP (purchasing power parity) value could be used in order to account for reconstruction differences in costs between nations. Thus, a PPP version has also been calculated using the time series for each nation.

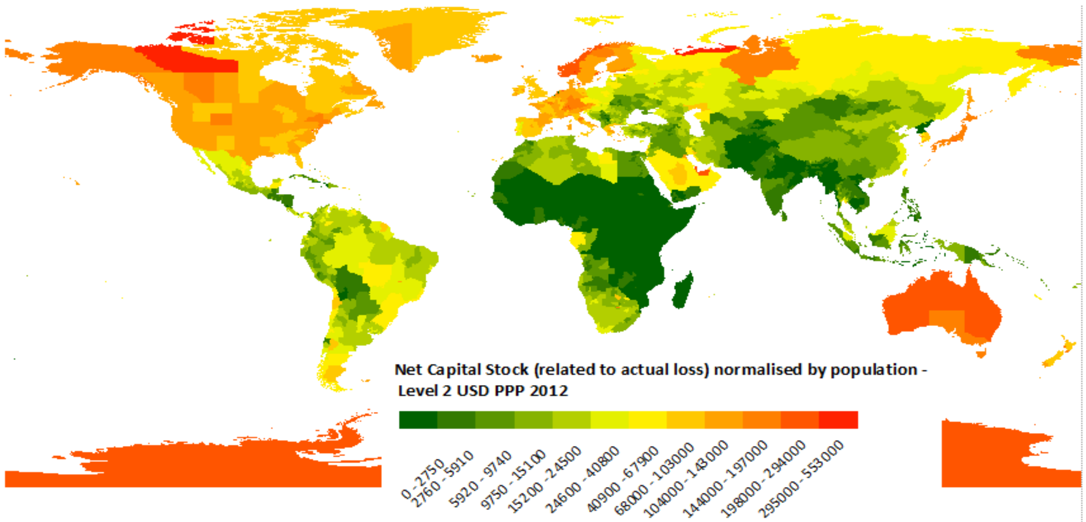

Figure 3: The net capital stock per capita as calculated for Level 2 – the actual exposed capital at any time globally is currently around 200 trillion USD (PPP 2012).

In addition, GDP has been calculated on province level. This estimate of infrastructure and contents value is central to the loss calculation. Also, the age of the infrastructure is needed to calculate the depreciation which has been collected, as shown in the socio-economic vulnerability indices paper of Daniell et al. (No. 1400). The additional "lack of losses" due to older infrastructure having higher damage ratios has also been added into the calculation. This has been calculated for each country through time using service lives of infrastructure. There are a number of reasons why net capital stock is difficult to quantify accurately. Measuring worth is often very difficult without having a selling price. For residential housing, the land is often the component which governs selling price, rather than the building. Older buildings are often torn down in place of new infrastructure, as they are completely depreciated. Depreciation rates in this study for net capital stock would be different from the tax purpose write-offs of individual infrastructure or depreciation based on the whole economy. The capital stock method uses service lives of the assets to calculate depreciation, but other methods could be used in the future to adapt the results for individual cities or locations, rather than the method used in this study.

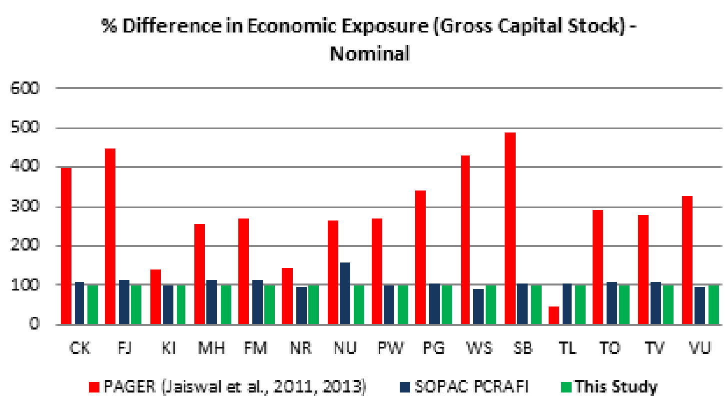

Figure 4: The difference in various models for economic exposure that have been undertaken for natural disasters in the Pacific countries.

On examining a number of existing studies, there is difference in results between the SOPAC PCRAFI (2010-2013) because of differences in the gross capital stock model used, and because it is likely that SOPAC had detailed data on the economic exposure from the individual countries. This study (my model) is based on GFCF, survival rates for various building stock and total values, and thus there is a slight difference from the values of SOPAC. The economic exposure was calculated for the year 2009 from the 2010 model of capital stock. This study seems to fit very well with the existing exposure calculations of SOPAC, NEXIS and other individual capital stock studies (Figure 4). The only country where there are some issues from the estimate is the little island nation of Niue, which does not appear to follow the usual trends, perhaps due to influx of foreign investment.

The PAGER (Jaiswal & Wald, 2011; 2013) model uses the wealth of a nation to create the economic exposure. However, the source was "The Wealth of Nations" which is not a capital stock model for exposure to natural disasters (World Bank, 2005), but is actually the resources/wealth of a country, including potential natural resources, forests etc. which have no relevance to the affected economic value (i.e. gold reserves mined in the year 2200). A better estimate would be "physical capital stock (minus land value)" (however is only based on a flat 5% depreciation). The PAGER empirical model, therefore, gives very erratic economic exposure estimates which are on average around 3-6 times too large globally, and around 2.5-4 times too large in the Pacific Islands. This is due to the difference of capital to output for small island nations, which is generally larger.
There is no net capital stock calculation for comparison in the natural disaster field or any integrated set worldwide; thus, the intention of this study was not only to evaluate the original model of construction cost, but also to improve previous loss estimates to account for the actual loss to capital, rather than the reconstruction cost.

THE CASE OF THE 1995 KOBE EARTHQUAKE

In testing this hypothesis for another major economic loss of the 20th century – the 1995 Kobe earthquake – a similar result occurs. In this earthquake, the direct cost estimate at the time of the event was based on replacement cost for new value. The relation between construction year and damage is shown below from the reconstruction plan of Kobe in Figure 6. Loss statistics were sourced from Kobe city reconstruction and damage documents and were then estimated using the work of Toyoda (2008) and subsequently by combining multiple Japanese estimates. The direct replacement cost was finally estimated at approximately 133 billion USD. For the building and infrastructure components the losses totalled approximately 94 billion USD. These were calculated using a pricing system of replacement cost per m2 for various typologies, which is synonymous with using gross capital stock. From the 94 billion USD of capital stock costs, about 58 billion USD were buildings of various typologies, as shown in Figure 5. Commercial and industrial buildings generally incur less damage than residential buildings; however, as only the total net loss is to be calculated, the relative difference of survival life and damage ratio will be assumed to be constant.

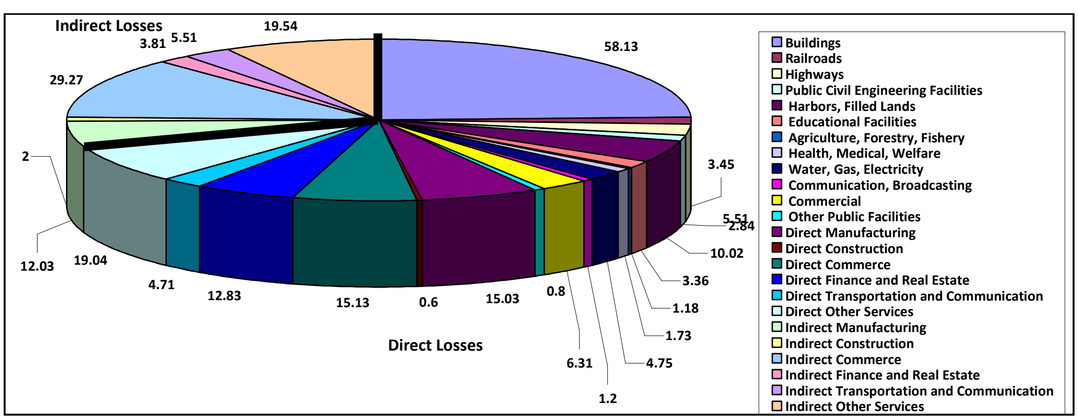

Figure 5: Sectoral distribution of losses in the 1995 Kobe Earthquake (Daniell et al., 2011b)

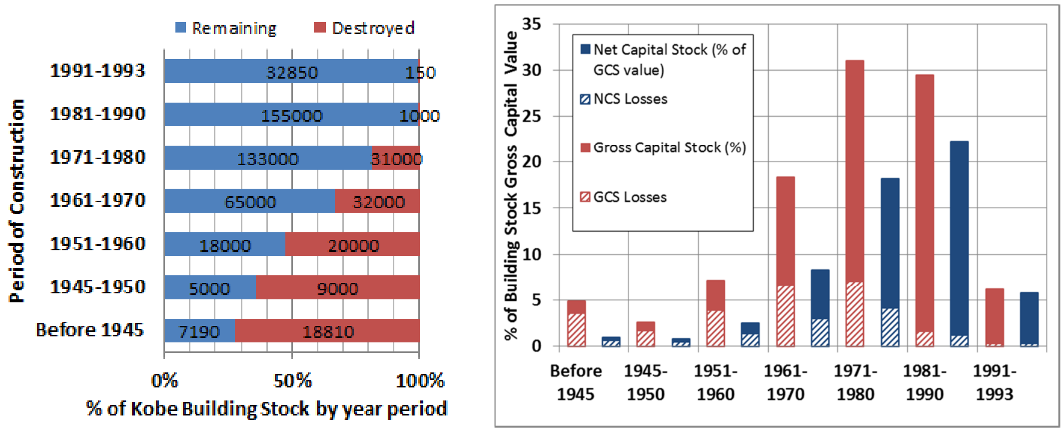

Figure 6: Left: The losses of the city of Kobe (adapted from the Japanese statistics provided by the Kobe municipal government), seen in the number of destroyed and remaining buildings after the event; Right: Calculation of the net capital and gross capital stock estimates for the dwelling portion of the losses/costs incurred in the 1995 Kobe earthquake

As depicted in Figure 6, 99% of the buildings destroyed or demolished in the Kobe earthquake were built before 1980 (as shown in red) as compared to only 64% of buildings built before 1980 from the total building stock. Using the gross capital stock to net capital stock ratio in 1995 of 1.685, the actual loss is equal to 66.5 billion USD reduced from 112 billion USD replacement cost/repair cost quoted post-disaster. In Kobe, the average net capital stock, when adding up the value of all buildings, was 1976 (19 years old), which can be seen in Figure 6. When calculating repair to all other buildings at averaging 5%, and the destroyed buildings at 100%, the loss value is about the same as that of 2008 Sichuan which had the loss value at 2.2 times less than replacement i.e. around 29% different from the net capital stock value, with the factor being 1.29 in terms of the losses vs. the net capital stock average loss expected. When using the year of construction as the basis and using the weighted losses of each building, the average year of loss in dollar values was 1966; thus, there was a 10 year difference between the average year of construction for net capital stock versus that lost in the earthquake. In smaller earthquakes, or earthquakes where equally old and new buildings incur losses, this effect will be zero. For the effect to change to the other direction towards gross capital stock, higher losses must be seen in the newer houses relative to the average net capital stock house. The actual loss value is approximately 51.1 billion USD, based on net capital stock. Table 2 shows the capital stock losses adjusted for the 3 definitions for the 1995 Kobe earthquake. Assuming the GDP losses have been correctly calculated, the GDP losses are generally not depreciation-related in many cases, as equipment is included in the capital losses.

Table 2: The capital stock losses adjusted for the 3 definitions in 1995 Kobe

Earthquake (event year billion USD)	**1995 Kobe EQ****
Actual Loss	51.1
Replacement Cost	112.0
Reconstruction Cost/Total spent on new capital	133.2
Additional Capital Impact (Improvement of Capital)	+82.1

***the reconstruction cost at Kobe was reported at 159 billion USD for all components - 19% increase on the replacement cost.*

DISCUSSION OF THE IMPACTS OF LOSS VS. COST

Regardless of the losses seen, the additional capital impact improves the location. The replacement cost is again defined as the traditional replacement calculation based on gross capital stock and a direct price per m^2 for various building types. This does not take into account service life and depreciation. The additional capital impact is calculated as the reconstruction cost minus the actual loss (direct damage at book value). The offset impact is then defined as the additional capital impact minus the actual loss. It is, however, better in many cases to retrofit, as the cost difference from the final loss value makes the repair money better spent, avoiding complete removal of the building stock and improving the offset impact. Systematic studies of this nature have been made in Japan following Kobe by looking at the infrastructure stock and calculating the buildings with and without the best earthquake standards (most buildings and infrastructure in Japan have some form of seismic resistant buildings, as the first codes came in the 1920s i.e. the earthquake disaster prevention maps with building age for Nirasaki (Nirasaki Local Government, 2013).

The real loss value of earthquakes is therefore much less than first thought, and in many cases can inspire additional productivity in terms of construction GDP, human involvement and energy, improvement of services and a much greater capital stock than before the event (Bhuj, 2001), sometimes also offsetting the GDP losses of the event. In some cases, however, the loss can be so severe that productivity decreases and the lost capital is never rebuilt, or substandard replacement of capital occurs (1988 Armenia). More studies such as those of macroeconomic effects e.g. Tatano and Nakano (2008) or the ECLAC GFDRR studies (2003) are needed in order to improve real loss functions in the future. This current study provides the first step in undertaking this on a global level.

ECLAC (2003h) has a minor comment that the stock for a capital-output ratio needs to be reduced, as otherwise the capital impact will be too high when calculating the final macroeconomic effects of a disaster. However, in the calculation of direct loss, this is still convoluted, with no clear strategy as to how to reduce the loss value. This reiterates the problem of an economic loss vs. economic cost even when defined via an in-depth methodology, such as the ECLAC Handbook, as it is not clearly set out. *"Assume replacement cost of the facility similar to the cost for reconstruction of a house with unit cost at Rp 1.6 million/m^2."* 2006 West Java Earthquake Post Disaster Needs Assessment (PDNA) – World Bank GFDRR and Indonesian Government (2006); this is also possible, but the actual loss is then not the replacement cost.

Table 3: The various components explored by PDNAs of ECLAC/GFDRR studies*****

Earthquake	**Actual Loss (mill. USD)**	**Replacement cost**	**Reconstruction cost**
1972 Nicaragua EQ	No	620 (GCS)	Higher
1976 Guatemala EQ	No	748 (468)	Same
1985 Mexico City EQ	No	3558.5 (563.4)	Unknown
1986 El Salvador EQ	No	685 (226)	Higher
1987 Ecuador EQ	No	345 (20)	Same
1992 Nicaragua Tsunami	No	25 (11.3)	Same
1999 Colombia EQ	No	1668.12 (547)	Unknown (577)
1999 Turkey EQ***	No	3640 (622)	Unknown
2001 Bhuj EQ	No	2131	2274
2001 El Salvador EQ	Unclear, 840?	840	1500
2004 Maldives Tsunami	No	Yes	Higher
2005 Pakistan EQ	Yes, 2274 depreciated	X	3503 (1.54x)
2006 Indonesia EQ*	No ?	2446	Same
2009 Bhutan EQ	No actual loss	52	Approx. same
2009 Indonesia EQ**	No	2060 (1664)	2093 (1584)
2009 Samoa Tsunami	31.46, replacement minus 30%	X	40.6
2010 Haiti EQ****	40% due to housing – not stated if reduced due to net capital stock	4506 (2333)	Ca. 6000
2011 Bhutan EQ	No (depreciation not possible)	24.46	Approx. same

* Statements that replacement = reconstruction; ** "Cost per m2 between Rp 600,000 – Rp 3,000,000 for various types of construction, applying Podes data on P/—permanent, SP/—semi-permanent and N/—non-permanent houses, for single and two floors or more" (GFDRR) – appears to be replacement – gross capital - but does not have a reduction factor in place for net actual loss.; *** 1999 - reconstruction and repairs are estimated by the World Bank MEER mission. Other values are given by UNISDR for the cost of housing ($1.1-1.6 billion USD), and reconstruction costs from $3.5-5 billion USD. Given the uncertainties in TL-USD conversions, and costs at the time of the event, much uncertainty results from this earthquake; **** 2010 Haiti earthquake – $2.333 billion loss ($1.748 bn housing, $0.585 bn contents) vs. $3.247 billion reconstruction costs based on 105369 destroyed and 208146 damaged buildings (about 25% higher than the final figures).

***** Citations: PDNAs of ECLAC (1973, 1976, 1985, 1986, 1986, 1992, 1999), World Bank - Turkey Country Office (1999), Asian Development Bank (2005), BAPPENAS (2005), Marti (2005), World Bank GFDRR; & ADB (2001, 2005), & Indonesian Govt (2006), & Bhutan Govt (2009, 2011), & Govt of Samoa (2009), & Haiti Govt. (2010)– as per PDNA

In looking through all PDNA assessments made, the actual loss is not calculated as far as can be viewed, except for the 2005 Kashmir earthquake PDNA in 2005 (ADB and World Bank GFDRR, 2005), which is the only one that attempts to solve this problem by using an approach of taking direct damages at book value, as shown in Table 3. *"To keep the estimation procedure simple, three broad assumptions have been made: (i) all buildings built in or prior to 1970 are valued at 1970's book value; (ii) taking into account the cost of construction in the affected areas and international experience, the cost escalation factor to make an asset earthquake resistant is assumed to be 5 percent of the asset's current replacement cost; and (iii) the repair cost of a partially damaged building is assumed to be 20 percent of its current replacement cost."* 2005 Kashmir (ADB & World Bank GFDRR, 2005). It is assumed that in other PDNAs the net capital effect is taken into account by giving a lower housing price for each typology by a certain percentage.
Thus, using the methodology detailed in this paper gives a chance to accurately calculate the actual loss (direct damage at book value), replacement cost and reconstruction cost (via historical knowledge). In the future, GFCF federal impacts will need to be quantified on a Level 2 or Level 3 basis, as the interactions between the province governments and federal governments will also impact on the capital stock in each location. At present this is distributed by using GDP on Level 2 and Level 3, but still uses the GFCF calculation from Level 1 in an attempt to distribute the capital stock correctly over a nation.

This work also shows the importance of damage surveys characterising the building year distribution of damage, such as is done in the CEQID database from Cambridge University (Cambridge Architectural Research Ltd., 2011) – the only damage survey database in the world. These studies can be used to estimate a damage distribution which can then be inputted into the damaging earthquakes database distribution of buildings, in order to calculate the additional multiplier from the net capital stock to the gross capital stock in terms of the affected buildings. The damaging earthquakes database only uses large scale data and does not contain any detailed ground survey data beyond the loss statistics made by governments and post-disaster damage assessments.

THE CASE OF THE 1948 ASHGABAD EARTHQUAKE AND ANALYSIS WITHIN THE CATDAT DAMAGING EARTHQUAKES DATABASE

The 1948 Ashgabad earthquake in Turkmenistan was one of the most catastrophic on record, hitting with 7.3Mw on the 6th October 1948. Approximately 1.3 million people were living in Turkmenistan at the time of the event, with approximately 200,000 affected directly in Ashgabad. This was despite the official estimates of only 132,000 people being located there, as it now appears that at least 198,000 people and an additional population in barracks around the city were also located there (Nalivkin and ed. Amanniyazova, 1989). 1948 Ashgabad was a major earthquake where the values of gross capital stock were less than the cost estimates (where a value of 359 million dollars USD (1948) was given). The loss estimates from 1948 Ashgabad range from $25 million USD from MunichRe (2009b), to $5-6 billion USD from Ashirov et al. (1994). Using Gillula (1981) for the calculation of fixed capital from 1960-1980, Turkmenistan or Turkmen SSR changed from a ratio of housing to total fixed capital of 23% in 1960, to around 14-15% in 1972.

It is expected that the 1972 levels were approximately what the Turkmen SSR had before the disaster in terms of productive fixed capital, given the Soviet Union data from Turkmenistan. The gross to fixed/net capital ratio at the time was around 1.13; however, it was expected that this was understated in terms of depreciation, given the replacement of nearly the entire Ashgabad building stock. If the 1972 value was used as a proxy versus that from the USSR, and then the non-productive fixed capital, the value in Turkmenistan was 3.683 billion roubles in 1972 roubles of which 48% was structures, 24% was machinery and equipment and 28% was all other assets (Gillula, 1981). However, the total fixed capital, including productive fixed capital, was estimated at about 9.3 billion roubles.

It is also mentioned in Ashirov et al. (1994) that “600 million roubles’ worth of industrial equipment, raw materials and finished goods were buried beneath the rubble and over 200 enterprises of all (Soviet) Union importance were affected”. It is quoted on the 25th day that 3350 people had been pulled from the wreckage and that 300 million roubles of materials had been extricated (Nalivkin and ed. Amanniyazova, 1989). At the time, Ashgabad was a centre of production. However, from the work of Kumo (2004), the stated Turkmen SSR industrial output at that time in 1948 was about 500 million roubles in 1926/27 prices from the 39,500 workers estimated in the labour force in industry or about 12,000 roubles per worker, giving a lot higher per capita measurement than other countries in the same Central Asia region. The estimated buildings destroyed in the area were approximately 90%, with the infrastructure losses being about 40-50%. The machinery and equipment lost was also calculated at around 50-60%. Water pipes only had minor problems, and electricity systems were back running within 6 days, with limited capacity (Nalivkin & ed. Amanniyazova, 1989).

In comparison, in the 2010 Haiti earthquake, where around 20% of structures were red-tagged, 24% yellow-tagged and 56% green tagged, the capital stock loss percentage was significantly less. The estimation of gross capital stock for Ashgabad (200,000 people) within the database collected was equivalent to approx. $108 million USD (1948 prices). This is slightly underestimated from some historical values. From best estimates of backward modelling of capital stock, the fixed capital (non-productive) in Ashgabad would have been around 250-300 million roubles, with an additional 450-600 million roubles in assets, and additional production and machinery. Thus, the estimate of “600 million roubles under the ruins” may not have been so far different from reality. Ashgabad was the centre of the region, and, as such, provided an important gateway to Iran as well as an important outpost with many military personnel. The estimate of loss would have been approximately 60-70% within the direct area, and an additional 50,000 people outside Ashgabad affected. Over the border in Iran, 3000 were killed, according to Berberian (2005). This would suggest an actual loss in the order of 500-600 million roubles, or around $115 million USD at the time using black market exchange rates as the Soviet Union had an inflated currency at the time of the event. The actual economic loss of the eventwhich was about 70% was capital-related and 30% GDP-related. This example of analysis is shown as a view of the CATDAT Damaging Earthquakes Database, the economic loss component of was presented in Daniell et al. (2011a) and Daniell et al. (2012b) and will not be shown in this paper.

ECONOMIC LOSSES AND COSTS FOR EARTHQUAKES FROM 1900-2013

Sectoral disaggregation of economic losses from historical events is also undertaken to show not only the relative losses from various infrastructure types, but also various production, manufacturing and social services, as well as other influences such as NaTech economic losses from the CATDAT databases. Sectoral analysis of historical earthquake economic losses reveals that residential losses are not always the greatest loss sector with respect to earthquakes. 61 major earthquakes between 1907 and 2012 around the world were split into 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 from earthquakes. By using 61 earthquakes in terms of sectoral losses, as shown in Daniell et al. (2012a), as well as additional earthquakes (ca. 250) where estimates of capital stock versus GDP-related losses have been collected in terms of gross capital stock effects, about 90% of earthquake losses have a “capital stock” versus “GDP”-related loss assessment. This gave 310 different ratios of capital stock to GDP losses for earthquakes. Secondary effect losses have been disaggregated in line with Daniell et al. (2012b) looking at each individual earthquake as per Figure 7 but have been assumed to retain the same depreciation percentages, even given events such as Tohoku 2011, where the number of completely destroyed buildings from the tsunami in comparison to the earthquake shaking was much larger and would invariably have a different age-damage relationship than for shaking.

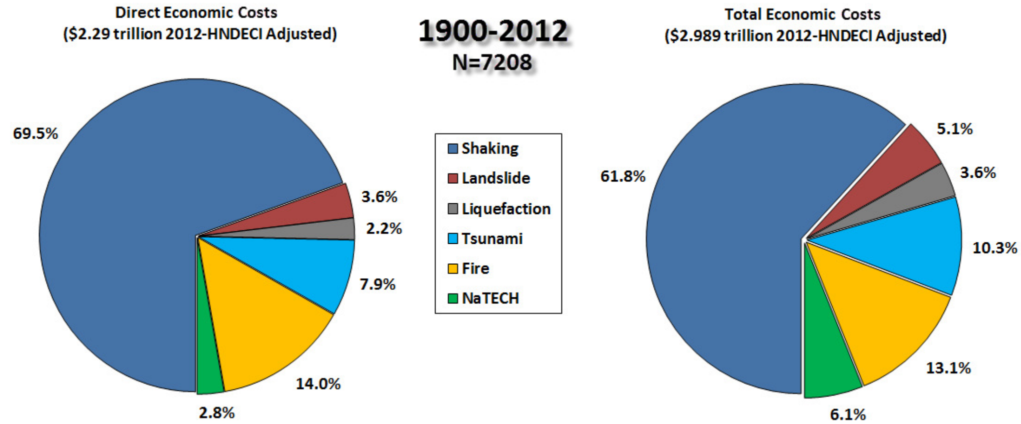

Figure 7: Disaggregation of Shaking and Secondary Effects Economic Costs from 7208 earthquakes from 1900 to 2012 – Left: Direct Economic Costs; Right: Total Economic Costs

The remaining reconstruction cost, or capital increase, is then examined versus the expected capital increase. The problem has been compounded in historical earthquake loss statistics, even compared to the expected 1.6-1.9 times average error of using gross capital stock. The difference between depreciated and gross capital can be removed from the historical loss estimates which have been all calculated without taking depreciation of the building stock into account. Thus, the traditional definition of "loss" in existing worldwide earthquake loss databases needs to be changed, as these values have all included historical loss and cost together. Historical earthquakes have been reevaluated, such as 1948 Turkmenistan.

An average has been utilised for the remaining earthquakes by using the average of the above known sectoral losses in the medium size events (from $1-$1000 million USD). This value came to 74% costs related to capital stock and 26% costs/losses due to GDP. The 26% of the direct loss was therefore not modified, due to the above method, and remains as a direct loss and direct cost. The 74% for 6900 smaller events or the observed capital stock "cost" depending on the 310 larger events were then reanalysed using the gross to net capital conversion coefficient. For the detailed cases where data were available, the age of infrastructure vs. damage was also used to calculate the age dependent factor. Detailed assessment of losses to buildings such as those contained in the CEQID database (Cambridge Architectural Research Ltd., 2011) undertaken by EEFIT (2007 Peru - Taucer et al., 2009), and Pomonis (1990; 1989) from various ground surveys, are very important for such a process, as they contain some form of age versus damage data for the following earthquakes: 2009 Padang; 2009 Italy; 2003 Greece; 1999 Chi-Chi; 1995 Aegeon; 1995 Neftegorsk; 1994 USA; 1992 Roermond; 1990 Luzon; 1989 Newcastle; 1971 San Fernando; and the AIJ studies of 2004 Niigata (Architectural Institute of Japan, 2004); 2003 Miyagi-ken; 2001 Geiyo; 2000 Tottori; and 1995 Kobe. In total for 16 out of the 64 earthquakes contained in the CEQID Database, there is building age versus damage data from surveys. In addition, data from various sources such as for 1999 Athens (Eleftheriadou and Karabinis, 2008), 1978 Albstadt (Porro and Schraft, 1989), 1923 Great Kanto (Moroi and Takemura, 2004) were used for the purposes of these functions.

In combination with the economic loss model presented in the study of Daniell (2014), new loss estimates have not only been created through the past events, but also then for current events, as shown in Figure 8. It should be noted that infrastructure, energy and economic modelling is required if forward modelling is to be undertaken and this is not within the scope of this study, given the variability of economic modelling. The loss to nations as a result of direct economic losses has been less than previously stated in literature (with the exception of the Pakistan Report of ADB & World Bank GFDRR (2005)), with the reconstruction cost undertaken improving the nature of construction and the book value of tangible assets. The impact of the disasters in terms of capital improvement essentially shows up in macroseismic assessments as a combination of GDP increase due to reconstruction, and increased "forced" spending from governments. The culmination of time series of net and gross capital stock, GDP, direct economic loss data, use of detailed studies of infrastructure age, and existing damage surveys, has allowed the first estimate of this nature.

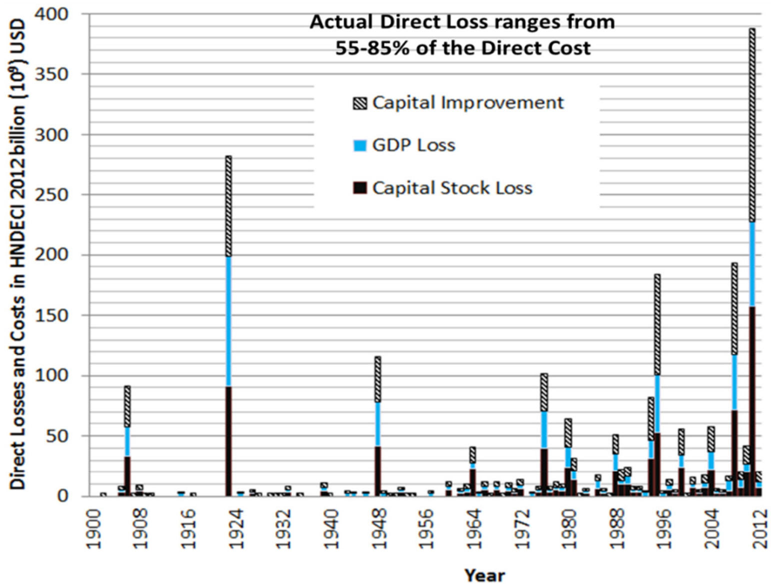

Figure 8: Actual Losses (Direct Economic Loss) as opposed to direct economic cost for 7208 worldwide damaging earthquakes from 1900 to 2012 (Dec. 31) (stacked graph). This shows a new picture of what the actual loss is to a country versus the invested gain in capital value.

CONCLUSION

The loss to nations as a result of direct economic losses from earthquakes has been less than previously stated in literature (with the exception of the 2005 Pakistan ADB Report), with the reconstruction cost undertaken improving the nature of construction and the book value of tangible assets. The impact of the disasters in terms of capital improvement essentially shows up in macroseismic assessments as a combination of GDP increase due to reconstruction, and increased "forced" spending from governments. The culmination of the large collection and production of time series of net and gross capital stock, GDP, direct economic loss data, use of detailed studies of infrastructure age, and existing damage surveys, has allowed the first estimate of this nature. This aids rapid earthquake loss estimation of economic losses and costs. It has also provided a new look at the economic losses from historical events as well as greater chances for normalisation of earthquakes and production of direct economic loss fragility functions as per the doctoral thesis of the author.

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