The influence of poverty and corruption on the loss of life in earthquakes

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Supplementary materials

We provide here methodology and details for the assembly of materials used in the published text. A table of earthquakes accompanies this supplement.

1. Mean Corruption Perception Index and its uncertainty

see http://www.transparency.org/policy_research/surveys_indices/cpi/2010/in_detail#4

One of the difficulties in quantifying corruption is that what is legally defined or perceived to be corrupt differs between different countries: a political donation legal in some jurisdiction may be illegal in another; a matter viewed as acceptable tipping or 'pourboire' in one country may be viewed as bribery in another. The causes and consequences of, and solutions for, corruption tend to be intertwined and there are numerous special cases for which the lack of long-term observational data prevents the derivation of general rules (Jain, 2001).

Because the CPI index is based on data from the past two to three years it is by nature only an index and its values for different years are not necessarily comparable. This means that a change in perceptions of corruption for a particular country would only emerge in the index over longer periods of time (see Transparency International 2010). Year-to-year changes in a country's score result not only from a changing perception of a country's performance but also from a changing sample and methodology (Wilhelm 2002). Each year, some sources are not updated and must be dropped from the CPI, while new, reliable sources are added. With different respondents and somewhat differing methodologies, a change in a country's score may also relate to the fact that different viewpoints have been collected and different questions been asked, so it is often difficult to improve a CPI score over a short period, such as one or two years.

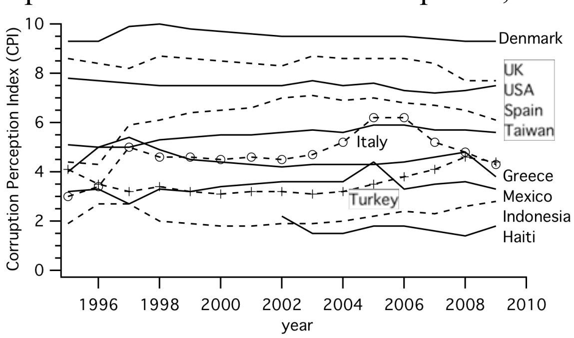

Figure S1 Variation of the annual Corruption Perceptions Index (CPI) for eleven countries for the period 1995 to 2009.

The variation of individual CPI estimates for a particular year is the result of the differences in the number of the sources used for their assessment, so that the greater the number of surveys to which a particular country has been subjected, the more reliable is the assessment of CPI. The greater the variance of the annual mean, the greater the differences of perceptions of a country among the sources, indicating a high degree of deviating opinions, which is typical for corrupt or poor countries that need more surveys. On the other hand a small variance indicates an almost perfect concordance.

Since changes in CPI for a particular country emerge over periods longer than one year the assessment of CPI index depends on the length of time considered. This allows its values to be averaged over a period of time which is more stable than annual estimates. CPI estimates are available for more than 150 countries. An example of the variation of CPI with time for a number of selected countries is shown in **Figure S1**.

Figure S2 shows the distribution of the standard deviation of the average CPI estimates for 153 countries over the period 1995-2009, which is less than 10% and is not significant. The uncertainty of CPI increases for countries with decreasing transparency, most clearly evident in the plot of CPI vs the ratio CPI/Standard Deviation CPI. An interesting insight of the regional and national time variation of CPI in Italy can be found in Del Monte and Papagni (2007).

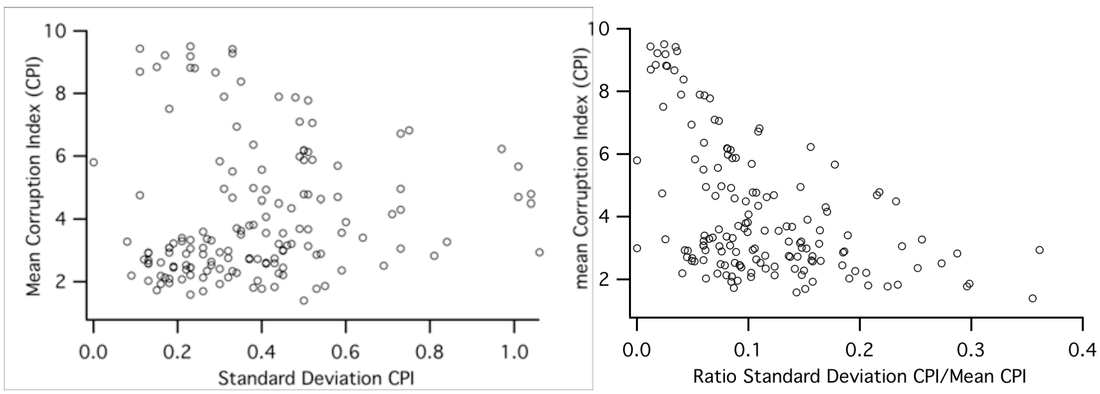

Figure S2 Standard deviations of the mean Corruption Perceptions Indices (CPI) for 153 countries. A CPI score of 10 indicates an absence of perceived corruption.

2. Gross National Income per capita GNI and its uncertainty

The World Bank uses two methods to estimate GNI, the Purchasing Power Parities method PPP and the Atlas method (A), (World Bank, 2010). In the GNI_{ppp} method conversion factors take into account differences in the relative prices of goods and services thereby providing an overall measure of the real value of output produced by an economy compared to other economies. GNI_{ppp} is measured in current international dollars which, in principal have the same purchasing power as a dollar spent on GNI in the U.S. economy. Because GNI_{ppp} provides a realistic measure of the standard of living of residents in a given economy, they form the basis for the World Bank's calculations of poverty rates at \$1 and \$2 a day. In the GNI_{Atlas} method the World Bank takes into account production in the domestic economy (i.e., GDP) and smoothes exchange-rate fluctuations by using a three year moving average, with a price-adjusted conversion factor. We compare GNI_{Atlas} and GNI_{ppp} in Figure S3. The two are comparable for high income levels but GNI_{ppp} is biased to a higher numerical value than GNI_{Atlas} for lower income levels. For the measures of wealth used in the article we adopted the GNI_{Atlas} method with data averaged over the period 1960 to 2009.

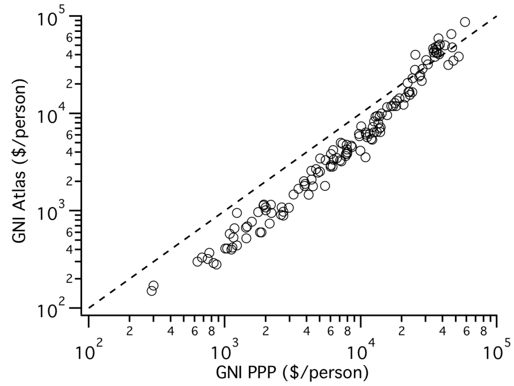

Fig. S3 Comparison of the 2008 GNI_{Atlas} ($) with GNI_{PPP} estimates for 147 countries. The dashed line corresponds to $GNI_{Atlas} = GNI_{PPP}$, revealing that the two are approximately equivalent for wealthy countries, but that lower values for GNI_{Atlas} are derived for impoverished nations.

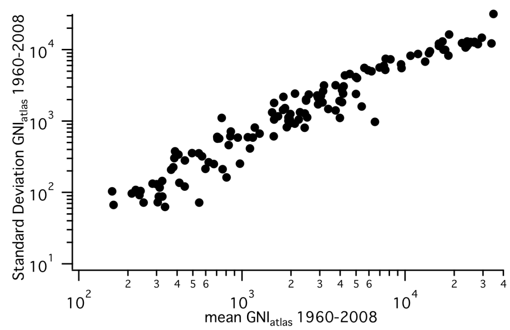

Fig. S4 Standard deviation GNI_{Atlas} vs. mean GNI_{Atlas} for 147 countries for data 1960-2008.

The standard deviation of the mean GNI_{Atlas} for each of the 147 countries considered, as shown in **Figure S4** decreases smoothly with increasing values of GNI (R^2=0.9) providing a measure of the uncertainty needed for GNI_{Atlas} to be used in other correlations. The effect of the average GNI_{Atlas} on the Corruption Perceptions Index CPI was investigated using the minimum, maximum and average values of GNI_{Atlas} for each country, adopting finally average estimates.

3. Effect of Gross National Income per capita GNI on corruption

We tested first the GNI_{ppp} data for the 27 countries of the European Union, for the period 1995 to 2008. As can be seen from **Figure S5** the data confirm beyond doubt that the wealth of a country influences the degree of corruption.

Similar results are obtained from the correlation of the average Gross National Income per capita (GNI_{Atlas}) with the mean Corruption Perceptions Index CPI for 130 countries throughout the world. **Figure S6** shows a plot of global data for the period 1960 to 2008, which leaves little doubt of the strong dependence between income (GNI_{Atlas}) and corruption (CPI).

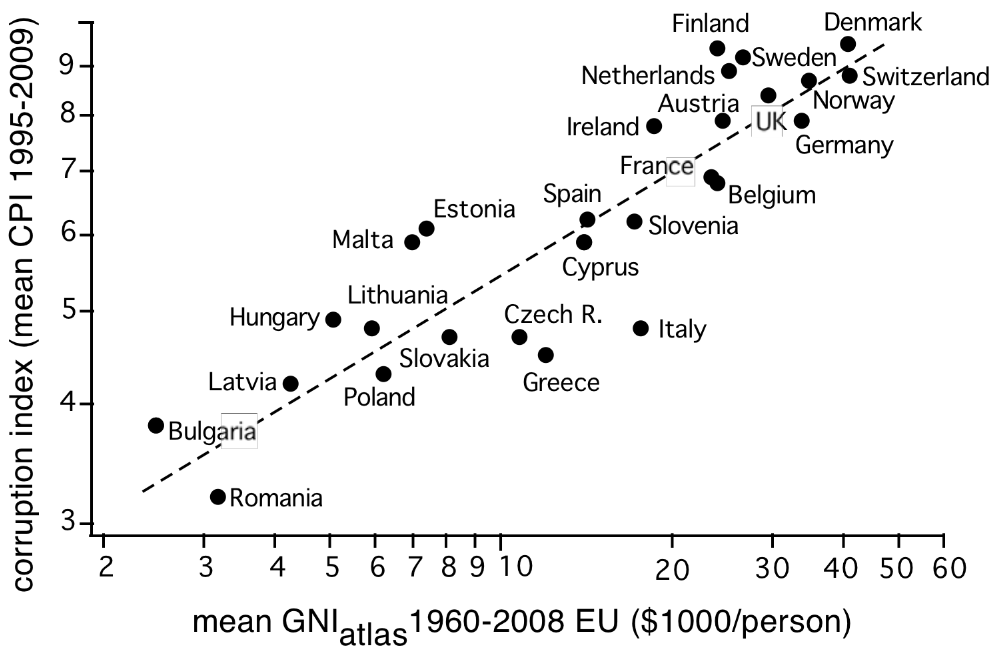

Fig. S5 Effect of average Gross National Income per capita (GNI Atlas) on the average Corruption Perceptions Index (CPI) for the period 1995 to 2008 for countries of the European Union. Dashed line least squares fit [$logCPI=(0.34\pm.03)logGNI- (0.63\pm.0.14)$]

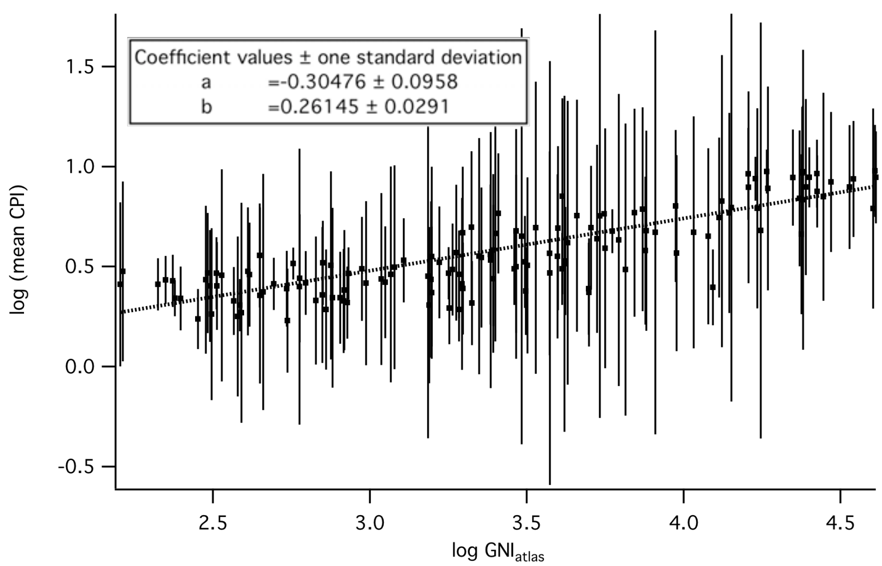

Fig. S6A Mean Gross National Income per capita (GNI_{Atlas}) vs Corruption Perceptions Index (CPI) for the period 1960 to 2009, for 148 countries world wide (showing unweighted regression coefficients). A least squares fit weighted by the uncertainties in CPI yields $log\ CPI=(0.261\pm0.03)logGNI_{Atlas}(-0.322\pm0.09)$ with slope similar to **Fig. S5**. The plot without the uncertainties, and with each data point named, is reproduced as **Figure 2** in the main body of the text. Figure 6b names each country.

Similar correlations exists between GNI_{Atlas} and other indices: education, land distribution and the rule of law **(viz. http://filipspagnoli.wordpress.com/statson-human-rights/).** Lack of information and the uncertainties involved in the assessment of the available CPI values, particularly of the actual regional distribution of CPI within a large country, does not allow the refinement of the results in a finer scale by taking into consideration other variables.

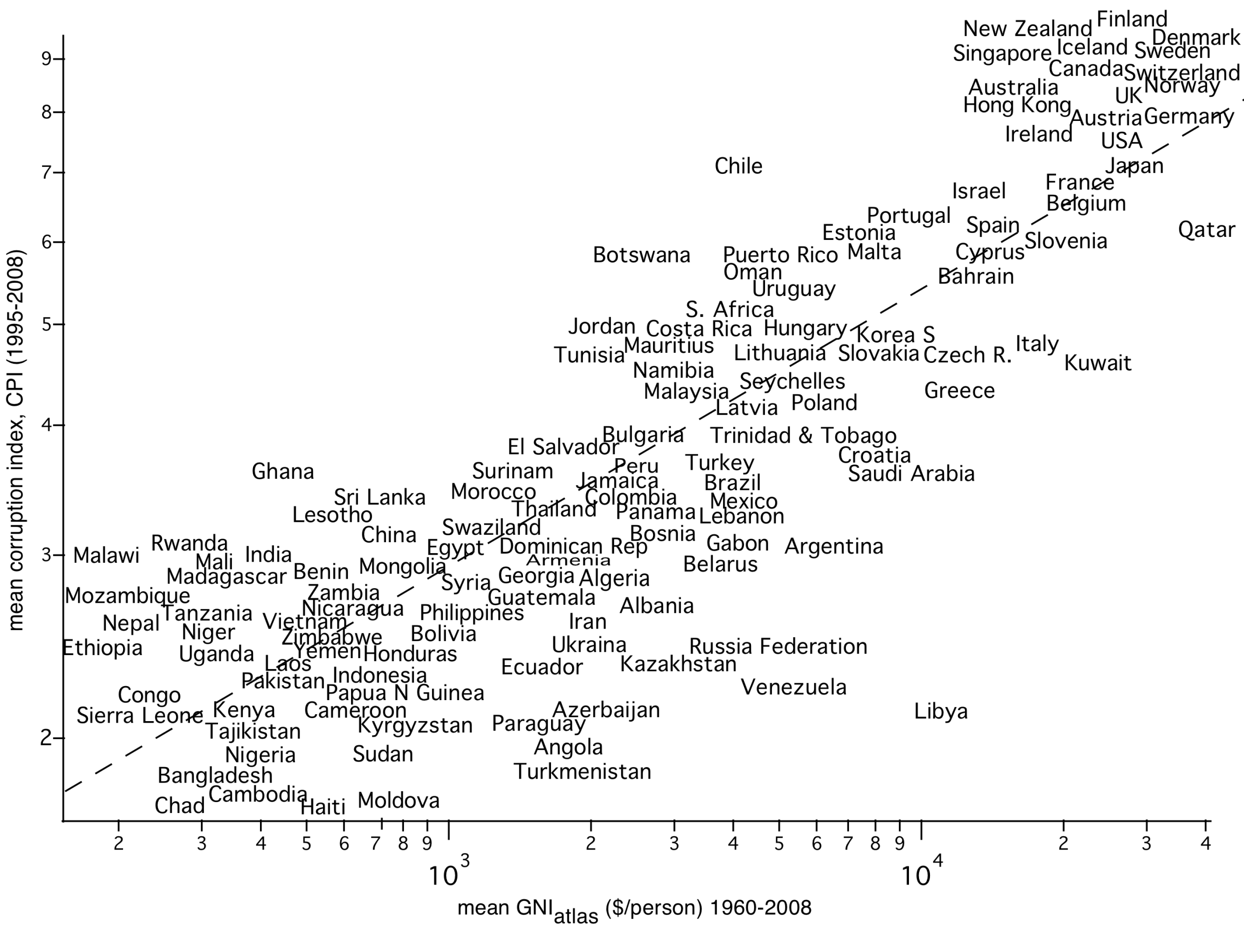

Figure S6B Same as Figure S6A but with names of countries plotted. Some have been insignificantly offset for clarity.

High indigenous corruption contributes an invisible increase to the annual income of many of its citizens, well above the income estimated by the GNI. In such countries, income from corrupt practices constitutes a second salary for work which was never done, particularly in poor countries where the value of the perceptible corruption index becomes a function of the corruption itself. Corruption thereby causes a redistribution of wealth, the magnitude of which is perceptible, but difficult to assess. In other words, in addition to economic growth rates, corruption may affect the distribution of income within a country regionally causing a skew distribution of a country's gross national income among its citizens (Jain, 2001). An extreme case is Haiti where it is alleged that 1% of its people own nearly half the country's wealth.

No refined method can be suggested at present to test the observed GNI_{Atlas}/CPI relationship (**Figure S6**) other than by testing its implications which may best be regarded only as an indication to the extent to which they are supported by actual observations.

4. Deaths from the collapse of buildings in earthquakes (DRE).

Estimates of the variation of the death toll during past centuries as a function of global population as well as of deaths as a function of earthquake magnitude are given, among others, by Cheng et al., (1988), Utsu (2002), Hough and Bilham (2006), Wyss and Trendafiloski (2009) by the reference therein. However, as we go back in time the uncertainties of the death toll in a single earthquake increase, becoming barely acceptable, while for early events such estimates are almost meaningless. The compilation of the data-set of DRE values since 1900 (Ambraseys

2010), of which a subset since 1980 is discussed here, required the examination of original sources of information that describe the effect of earthquakes, and separately a uniform evaluation of seismological and building vulnerability parameters.

In government sources and the local press we found examples where the number of fatalities had been exaggerated, presumably with the purpose of attracting attention for more generous assistance, and in some cases the opposite, a political need to downplay fatalities and economic losses. Following the 12 January 2010 Haiti earthquake, for example, on 24 January the official death toll was reported as 150,000, but by 10 February the number had been adjusted to 230,000. Subsequent guesses during media events offered numbers as high as 270,000, but these were retracted. Notwithstanding these retractions later reports, without attribution, have rounded the number to 300,000 (e.g. Crane et al., 2010). At the time that the earliest government estimates were being proposed, district by district investigative reporting (Melissen, 2010) was unable to account for more than 52,000 buried, and possibly as many 30,000 remaining beneath rubble. A death toll of 82,000 is a large number, but is one third of the number loosely cited in reports 9 months after the earthquake. The source of government information on the Haiti death toll has remained elusive, and the true death toll may never be known, but there were clear economic advantages for Haiti to inflate the death toll in the period in which international relief was being discussed. In Table 1 we adopt a death toll of 212,000 recognising that significant uncertainty in this number exists.

Similarly, examples can be found where local intensities from the earthquake have been exaggerated, allegedly to justify the collapse of an unjustifiably large number of otherwise substandard vulnerable houses with great loss of life.

The absence of an accurate census and building by building occupant listings prior to an earthquake is a serious impediment to quantifying fatalities in an earthquake. This was certainly the case for Haiti. The unavailability of census is partly due the not unnatural invasion of privacy associated with counting family members, but also by a suspicion that the census may lead to potential future tax increases or to conscription (Ambraseys 2010). For several historical earthquakes the reported death toll is clearly erroneous, especially in earlier earthquakes in some countries where there was still no accessible regional census from which to glean life losses. Equally wrong death toll figures are known where the regional census was used a pre-earthquke head count and the death toll obtained by subracting from this the number of the people who were found to be alive after the earthquake.

For some 20th century earthquakes casualty figures were unavailable due to official restrictions in the publication of life losses related to earthquakes, particularly in the USSR, in China, and to a lesser extent elsewhere, a restriction that lasted for a long time (viz. Vladimirov 1972).

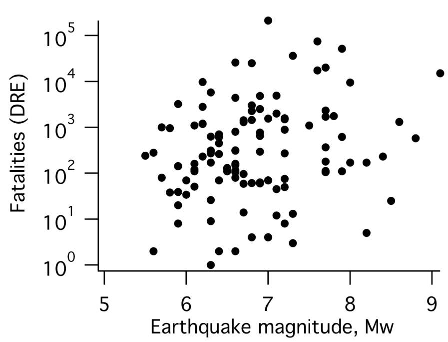

Figure S7 Range of earthquake magnitudes and associated fatalities used in this study

Supplementary Table 1 lists data used for the period 1980 to 2010. The 132 earthquakes in 37 countries in this 31-year period have caused a total loss of 568,759 or an average of 18,347 deaths/yr. The list includes only those earthquakes for which we have quantified building vulnerability parameters etc, and thus excludes numerous less significant earthquakes that are documented elsewhere. The magnitude frequency distribution of the earthquakes in Table 1 and their range in causal fatalities is illustrated in **Figure S7**.

For each earthquake the location, depth, magnitude and contribution from aftershocks were reassessed, and the vulnerability of the predominant type of affected building stock was recorded. An approximate classification of the perceived vulnerability of houses was derived from reports, recent site visits and from opinions of colleagues familiar with the affected region.

Population density at the time of the earthquake was estimated on a comparative basis and divided into four categories: (i) Regions of normal population density that included both rural and urban sites; (ii) Regions, mainly rural but with few small urban settlements of lower habitation density (SP); (iii) Areas almost entirely rural, in a few cases sparsely inhabited with no urban centres where density was considered to be even lower (SPP), and (iv) Land that did not support human habitation (SD). With few exceptions DRE values are listed from primary sources (see comments below Table 1).

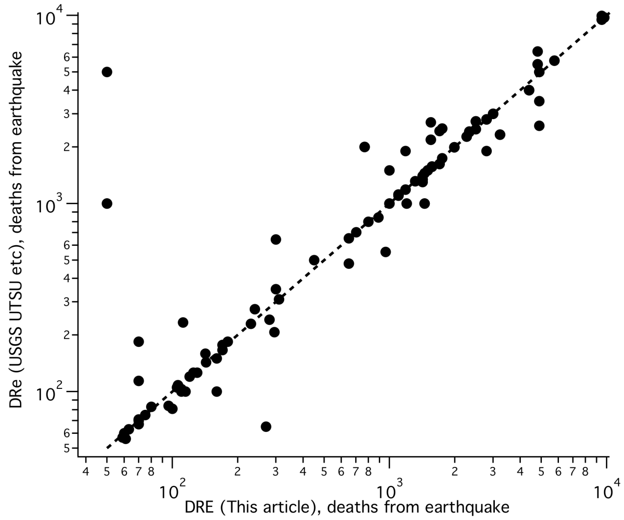

Fig. S8 DRe from various sources and compared to values of DRE estimated here. Points above the line are overestimates of fatalities directly arising from the collapse of structures, whereas those below the line are underestimates.

The data confirm that secondary effects are rarely the main cause of the death toll (Marano et al. 2009). They show, however that such effects can be dominant in some cases such as of the earthquakes of San Francisco of 1906, Messina of 1908, Tokyo 1928, and for the 2004 Andaman/Indonesia earthquake.

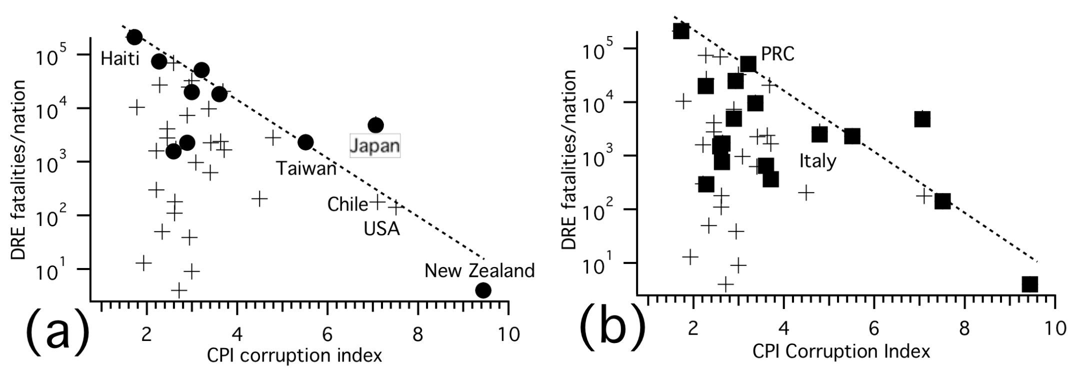

Fig. S9 Crosses indicate cumulative death toll (DRE 1980-2010) for 33 nations for all earthquakes in Table 1 as a function of the mean Corruption Perceptions Index (CPI 1995-2009). Circles in (a) indicate a selected subset of ten nations that include only shallow earthquakes on land (1995-2010) with 7.9>Mw >6.8. Squares shown in (b) extend this subset to the period 1980-2010. Selected countries are indicated.

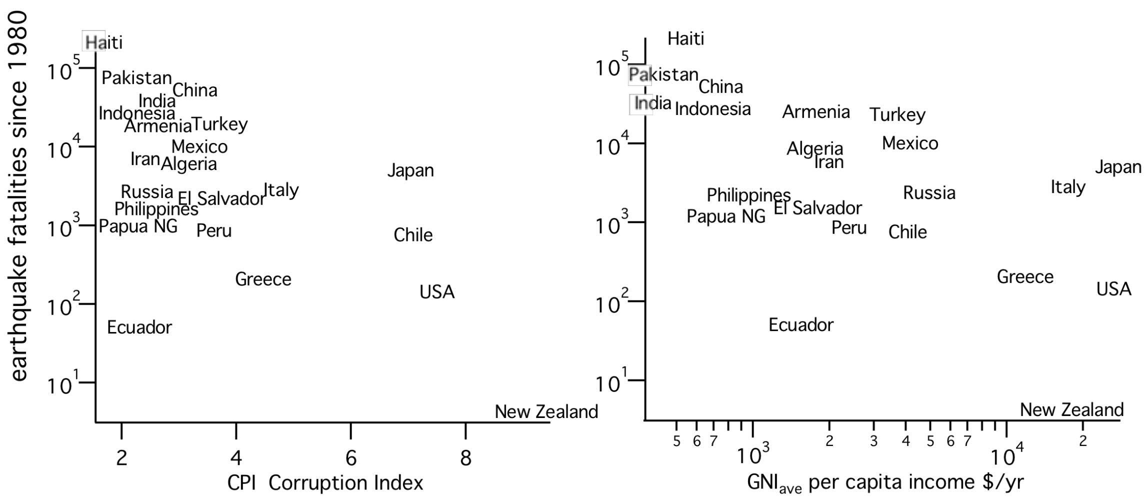

Figure S10 Cumulative death toll (DRE) caused by earthquakes in the period 1980-2010 as a function of corruption Index (left) and wealth (right).

Regressions between DRE fatalities and CPI corruption in **Figure S9** were undertaken for all the DRE data, and for a subset of data with reduced range of magnitudes 7.9 ≥M≥ 6.8, depths <35km, and for offshore epicentral distances <20 km, excluding all earthquakes with epicentral areas in very low density or sparsely inhabited regions. A magnitude range 6.8-7.9 is chosen because normal depth earthquakes in this range at epicentral of fault distances of ≤20 km would correspond to spectral ground accelerations at 0.3 sec greater than 0.35g which will guarantee the collapse of substandard constructions and houses not designed to resist earthquakes. By including earthquakes greater than 20 km offshore and in desert regions we risk biasing the sample to include distant earthquakes far from settlements. The inclusion of these distant epicenters biases the resulting regression to shallower slopes since it may not shake a region of exposed, vulnerable structures. A problem arises with subduction and very low angle fault breaks in which the epicentral location is a poor measure of macroseismic shaking. In such cases we have used macroseismic epicentres which are assessed from maximum damage. The perceived classification of vulnerability of houses and population density this was done from opinions of persons familiar with the region and from large scale maps. For a further discussion of these technical issues the reader is referred to pp. 28-31, 37-57, 820-827 and Figures 2.85. 4.4, and 4.9 in Ambraseys (2010).

In **Figure S9a** we show data for 1995 to 2010, that include DRE estimates for 10 countries derived from 12 earthquakes. A quadratic expression can be fit to these data in a least squares sense with a standard error of 0.72. These data, and the full set of data, fall largely to the lower left of a line with slope *log(DRE)≈ -0.6(CPI)*. Its numerical value has no special significance but we interpret it as representing a probable worst case bounding slope for earthquakes in which centers of population and epicentral maximum macroseismic shaking coincide. In **Figure S9b** we show data for the extended period 1980-2010 in which cumulative DRE estimates for 16 countries from 27 earthquakes are shown. A least-squares quadratic fit to these data is associated with a standard error of 0.65. This small data base is clearly biased towards countries of low transparency, where recent damaging earthquakes have occurred. Figure S10 provides quantitative evidence for a link between the perceived level of corruption in a country and the number of people killed by earthquakes.

Figure S11 shows these relationships in 3D, and in particular demonstrates that it is not only corruption, but the severity of corruption in country that has the most significant influence on earthquake deaths. We plot both GNI and the CPI Index against an *Expectation Index* defined in Figure S6 as the deviation from the least squares fit relation between GNI and CPI. A positive expectation Index is the number of CPI units a nation lies above the CPI corruption Index anticipated from their GNI per capita income.

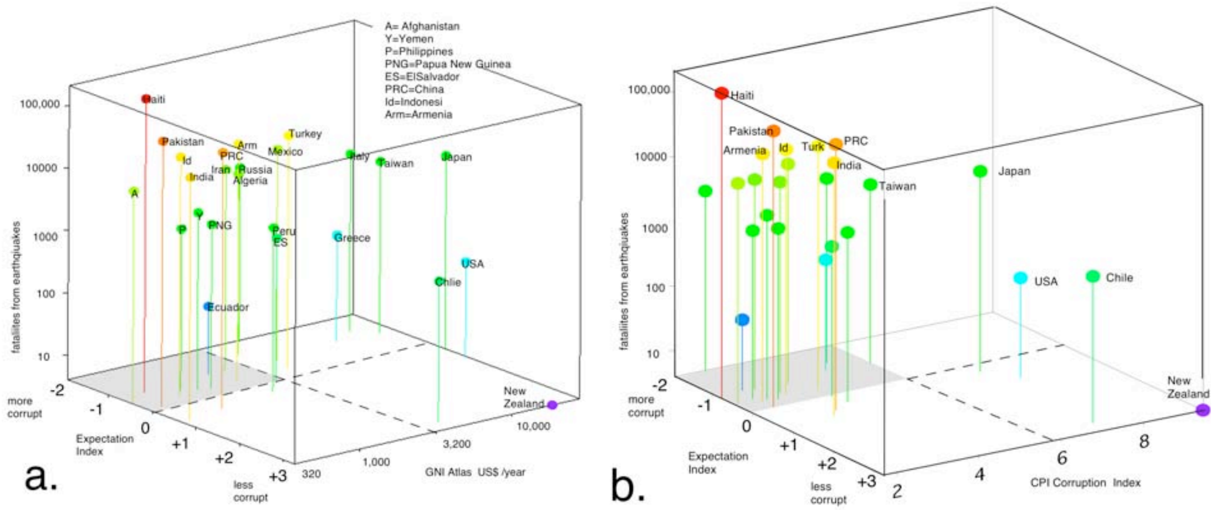

Figure S11. 3-D plots showing the influence of corruption, income and the expectation index. The expectation index is the deviation from the mean regression between *per-capita* income and corruption shown in Fig S6. In each case building collapse is largely found in countries that are more corrupt than expected from their per capita income (ie a negative *Expectation Index*). Ninety percent of these fatalities are in countries with incomes less than $3,200/yr (S11a), and 82% of these fatalities are in countries with a CPI corruption level 1-6 (S11b).

Another, less satisfactory, way of examining the effect of CPI on DRE, and one that can possibly extend the period available for analysis, is to invoke the Gross National Income per capita (GNI Atlas) as a proxy for CPI, the corruption index (from the relation established in **Figure S6)**. This was tested for the period 1980 to 2010. It shows that very similar results can be obtained using the wealth of a country in terms of its GNI as a proxy for the loss of life DRE. As expected the figure shows that the number of fatalities (DRE) do depend on the Gross National Income per capita (GNI), with similar trend and distribution, but with greater scatter. By including events before 1980 it is unlikely that the conclusions on the relationship between fatalities from earthquakes and the prevalence of corruption will be substantially changed.

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