# *Earthquake Fatalities: The Interaction of Nature and Political Economy*

Nejat Anbarci Monica Escaleras Charles A. Register*

June 2004**

***Abstract***: To say that the level of fatalities resulting from an earthquake is inversely related to a country's per capita level of income is hardly novel. What makes our approach novel is that we relate fatalities to both per capita income and the level of inequality that exists within a country through their joint impact on the likelihood of collective action being taken to mitigate the destructive potential of quakes. We first develop a theoretical model which offers an explanation as to why, in some environments, different segments of society prove incapable of arriving at what all parties perceive to be an agreeable distribution of the burden of the necessary collective action, causing the relatively wealthy simply to self-insure against the disaster while leaving the relatively poor to its mercy. Following this, we test our theoretical model by evaluating 269 large earthquakes occurring worldwide, between 1960 and 2002, taking into account other factors that influence a quake's destructiveness such as its magnitude, depth and proximity to population centers. Using a Negative Binomial estimation strategy with both random and fixed estimators, we find strong evidence of the theoretical model's predictions. That is, while earthquakes themselves are natural phenomena beyond the reach of humankind, our collective inaction with respect to items like the creation and enforcement of building codes, failure to retrofit structures and to enact quake-sensitive zoning clearly plays a part in determining the actual toll that a given quake takes. And, it is through these and other examples of collective inaction that limited per capita income and inequality couple together with a given quake's natural destructive power in determining the actual fatalities resulting from a quake.

*JEL Classification(s)*: D31, H41, P16

* *Nejat Anbarci*: Florida International University, Department of Economics, University Park, DM 316, Miami, Fl 33199.

*Monica Escaleras*: College of Charleston, Department of Economics and Finance, 66 George Street, Charleston, SC 29424.

*Charles A. Register*: (Corresponding Author) Florida Atlantic University, Department of Economics, 777 Glades Road Boca Raton, Florida 33431, email: register@fau.edu, phone: 561-297-3222, fax: 561-297-2542.

** We would like to thank Jesse Bull, Rachel Davidson, Sebastian Edwards, Suman Ghosh, Jonathan Hill, Cem Karayalcin, Dani Rodrik, Dimitrios Thomakos, Mehmet Ulubasoglu and the seminar participants at the Florida Atlantic University for their comments and suggestions, and Eric Chiang for his assistance in developing this project. We are grateful to MCEER (in particular to Sofia Tangalos), Mississippi State University Libraries (in particular to Marybeth Grimes) and NOAA/NESDIS National Geophysical Data Center (in particular to Paula Dunbar) for the data they provided on earthquake preparedness indices.

## *1. Introduction*

Until recently, a country's level of inequality has been viewed as an outcome of its general economic performance, rather than an input into that performance. This began to change in the 1990's with the publication of a number of papers that addressed the impact that inequality itself might have on a country's economic performance, especially on its growth rate. Galor and Zeira (1993), Bertola (1993), Alesina and Rodrik (1994), Persson and Tabellini (1994), and Benabou (1996) have been among the frontrunners of this literature. The initial impulses in this strand of research concerned the political economy implications of inequality (especially tax selection by the median voter) and capital market imperfections (which limit the investment options for the relatively poor) as the main channels through which inequality might impact the overall efficiency and growth of an economy.

Another strand of related research extends these outcomes by suggesting that inequality can be linked to economic performance in other ways. Examples include the role that inequality can play in political instability, as evidenced by greater social conflict, which can lead to reduced investment levels (Alesina and Perotti (1996)) and limit a country's ability to effectively respond to external shocks (Rodrik (1999)). Further, such social conflict inevitably leads to increased violence and crime, which also can reduce the overall economic performance of a country through its direct costs in lives and property damaged and through its indirect costs in terms of medical resources required to treat those injured, lost productivity from those injured or killed and the resources needed for policing that must be diverted from other, arguably more productive, activities to mitigate, if not prevent, these criminal activities (see Fajnzylber et al (2002) and Bourguignon (2001)).

Social unrest and the resulting criminal activities, however, are not the only factors leading to unnecessary loss of lives and property damage. Each year, throughout the world, natural disasters claim tens of thousands of lives, injure several times more, and cause billions of dollars in property damage. Earthquakes alone claim thousands of lives a year (in some cases, more than a hundred thousand lives in a single quake). Some natural disasters can be foreseen (or predicted with some probability) and thus measures can be taken to limit their severity. In many instances, these measures require collective action by society.[1] For instance, in the case of earthquakes, the potentially devastating effects of the quakes can be limited through communal preparedness and mitigation activities such as the creation and enforcement of rigorous building codes, retrofitting of bridges, highways and other structures, zoning regulations (i.e., land-use controls which limit construction near fault lines), proper licensing requirements for contractors, engineers and architects as well as proper training of search-and-rescue professionals.

The ability of a country to pursue such collective action is, however, limited by its income and the ability of the population to arrive at an agreeable distribution of the economic burden of the actions.[2] Given this, we analyze the impact of a country's per capita income and level of inequality on earthquake fatalities. To be sure, others have considered the link between per capita income and quake deaths (see, for example, Dunbar, Bilham, and Laituri (2003)). But the theoretical and empirical links between inequality and quake fatalities have, to date, not been considered. As such, we first develop a theoretical model which shows both how per capita income and inequality are related to the actual death toll resulting from a given earthquake. Further, the theoretical model offers an explanation as to why, in some environments, different segments of society prove incapable of arriving at an agreeable distribution of the burden of the necessary collective action, causing the wealthy simply to self-insure against the disaster while leaving the relatively poor to its mercy. Our theoretical model indicates that collective action is an increasing function of per capita income and a decreasing function of a country's degree of

[1] Worldwide collective action in earthquakes in the form of pooling data started as early as 1899 (Howell, Jr. (1990, p. 29). Furthermore, international relief aid following catastrophic earthquakes has intensified in the last few decades.

[2] Alesina and Drazen (1991) consider a framework in which stabilization entails tax increases to eliminate a budget deficit; in that case, socioeconomic groups may shift the burden of stabilization onto each other (see the references therein for other works that report similar results).

inequality. To test these predictions, we analyze empirically 269 6+ Richter-scale quakes occurring worldwide between 1960 and 2002. The results of this analysis strongly support the theoretical predictions. That is, while potentially devastating quakes are acts of nature, the actual death toll arising from them is very much the result of the interaction of political-economic institutions and nature.

The next section considers examples of some recent, potentially catastrophic earthquakes. Some of these quakes proved to be worst-case scenarios, while others led to relatively few fatalities. This anecdotal evidence clearly shows that mitigation activities, such as high-level building codes, are absolutely essential in alleviating the effects of severe quakes. Equally important, however, is enforcement of these codes, or other mitigation activities, which all too often is lacking, especially in developing countries. The reason for the absence of or failing to enforce high-level building codes and aggressively retrofitting structures is obvious: These activities can be extremely expensive and building a consensus to finance such activities often proves problematic. Too often, when necessary collective action fails to occur, the cause is either that society's per capita income is simply too low to generate the necessary resources or due to conflict between different segments of society who cannot agree on the distribution of the relative burden of the high costs of effective regulation.

As mentioned above, Section 2 considers examples of some recent earthquakes. Section 3 provides rationale for collective action. Section 4 presents the theoretical model and results. Section 5 discusses data and contains univariate empirical results. Section 6 presents multivariate empirical results. Section 7, which contains 'further empirical considerations', pertains most importantly to the link between income/inequality and earthquake preparedness. Section 8 concludes.

## *2. Differential Effects of Potentially Catastrophic Earthquakes*

The difference in the outcomes of earthquakes in countries with varying degrees of collective action can be quite astonishing. Noji (1997, p. 139) provides such a comparison between the 1988 earthquake in Armenia and the 1989 earthquake in Loma Prieta, California (which is commonly known as the San Francisco earthquake) by pointing out that the former had half the energy release of the latter and yet caused 25,000 deaths while the Loma Prieta quake resulted in less than 100 deaths. Noji rightfully concludes that "[t]he differences in impacts between these two earthquakes is directly related to differences in the degree of disaster-mitigation and disaster-preparedness measures taken in those areas. Strict adherence to building codes (as well as zoning ordinances during the past few decades) in the latter region undoubtedly saved many lives and kept thousands of buildings from collapsing."

Perhaps more enlightening are actual post-quake reconnaissance reports from the Multidisciplinary Center for Earthquake Engineering Research (MCEER) which analyze severe quakes and regularly point to the positive effects of collective action and, unfortunately, the dire consequents of their lack. For example, the MCEER report which followed the devastating, 6.8 Richter-scale quake, that occurred in Algeria, May 27, 2003, claiming 2,700 lives, concludes that the death toll from the quake was greatly exacerbated by the lack of high-level construction regulations for privately-built housing (though such regulations exist for government-built housing), the absence of licensing for contractors, engineers and architects and the heavy demand for housing arising from a rapidly growing population which enticed many unqualified individuals into construction trades. While this case is extreme in that building codes, to the extent that they existed, did not apply to privately constructed housing and since there was a lack of proper licensing of contractors, the mere existence of these types of collective action, in and of itself, is not sufficient. There must, of course, be rigorous enforcement. This is apparent in the 6.4 Richter-scale earthquake occurring in Changureh, Iran on June 22, 2002, which claimed 261 lives. The MCEER report on that quake notes that while Iran has building codes which are comparable to those existing in the United States, they tend to be enforced only in the country's larger cities. In smaller villages where most of the deaths from the quake occurred, effectively no seismic-related building codes exist which, when coupled with relatively low levels of income in those areas, had lead many to build their homes with poor design/construction and with low-quality materials.

The MCEER's report on the 7.4 Richter-scale earthquake in Marmara, Turkey on August 17, 1999, which claimed about 17,000 lives is also informative. The report's most important conclusion for the present study is "the dismal performance of the reinforced concrete frames, virtually ubiquitous in the region. The collapse of thousands of these buildings transformed this earthquake from a damaging event to a catastrophe." This is despite the fact that "[d]esign and construction of reinforced concrete frames to withstand strong earthquake motions ... are well understood by Turkish engineers."[3] Cost-saving concerns in the relatively poorer regions of Turkey lead to a fateful under use of relatively expensive building materials: "Steel, being by far the most expensive construction material in Turkey, has been used rather sporadically in construction." Furthermore, zoning codes were, at best, unevenly enforced as many people built their homes—and firms (even some state-owned enterprises) built their plants—on land made relatively cheap by its proximity to dangerous fault lines although the code strictly rules out any kind of development around fault lines. Clearly, the society did not or was not able to regulate

[3] Not surprisingly, in the history of earthquake fatalities, by far the greatest proportion of victims have died because of the collapse of adobe, rubble-stone, and rammed earth (i.e., the unreinforced masonry (URM)) buildings and other types of masonry buildings (such as unreinforced fired-brick masonry and concrete block masonry buildings). Reinforced concrete-frame houses, on the other hand, are generally less likely to collapse. When they do collapse, however, they are substantially more lethal and kill a higher percentage of their occupants than do masonry buildings. Reinforced concrete requires much more sophisticated and elaborate construction techniques than URM. Despite that, reinforced concrete is often used in communities around the world where either technical competence is inadequate or inspection and enforcement are lacking (the earthquakes in Armenia (1988) and Turkey (1999) provide examples of these various points). Furthermore, whereas the debris of building of adobe, rubble masonry, and brick can be removed with primitive tools, reinforced concrete entails severe problems for rescuers especially where specialized heavy equipment cannot be used for one reason or another.

the rapid urbanization in that region.[4] The conclusion of this reconnaissance report highlights the importance of collective action: "Unfortunately, the rapid development of the region overtaxed the ability of the society to assure that these principles were followed. The result was inadequate buildings, when there need not have been, and a tragic catastrophe. The ultimate lesson therefore is that building and development is simply not a physical process—governmental institutions and social processes must develop in parallel, to keep up with the physical demands and assure minimum acceptable standards of construction and public safety."

These few examples clearly show that the potentially devastating effects of major earthquakes are, if not preventable, at least subject to significant mitigation by collective action. In the following sections, we first offer a discussion of the potential for collective versus private action and then develop a theoretical model of the interrelations between a country's per capita income and level of inequality, the likelihood of collective action and the fatalities resulting from a given earthquake.

## *3. Collective vs. Private Action*

As the anecdotal evidence shows, there seems to be significant rationale for collective action directed at mitigating the effects of significant earthquakes. At their base, collective earthquake preparedness and mitigation activities aim to protect people from the consequences of their own ignorance.[5] Few potential homeowners (or renters) are technically capable of

[4] Perhaps the most vulnerable areas are the informal housing sectors on the periphery of many rapidly growing cities in developing countries, which are built on soft grounds. Lomnitz (1999) states that in the 1985 Mexico City earthquake "buildings collapsed on soft ground and nowhere else" (p. 9) and that this soft ground has "a density of 1.1, which is only 10 percent higher than water" (p. 11).

[5] Lagorio (1990, p. 249) describes people's ignorance of the potential consequences of earthquakes and their failure to personalize the consequences of an actual event when the probability of its occurrence is not an immediate threat: "Lack of earthquake hazards mitigation programs and preparedness plans are commonly due to a community's failure to grasp the potential impacts of seismic activity in the area. By misunderstanding the probable recurrence intervals of earthquakes, say one that is said to have a 100-year return period or that is beyond the life expectancy of the average person, there is a tendency to rationalize that 'one will not occur during my life time'. Such rationalization ignores the possibility that two 100-year-recurrence earthquakes may occur within the same year or two." As a matter of fact, as

evaluating fully the potential hazards inherent in a commodity as complex as a family dwelling. In the housing market, major information asymmetry exists between the sellers and buyers. The consequences of such adverse selection problems have been well studied since Akerlof (1970). Often the end result is another version of Gresham's law, which in our context can be summarized as "bad buildings will drive out the good" if there is no regulation or no effective enforcement of the existing regulation.

As an alternative, one may consider the presence of a market for the information provided by 'structural experts' who inspect properties and provide an impartial assessment about them to potential buyers. The performance of such a market, however, will be inefficient from society's point of view since most houses will be considered by a number of potential buyers leading to needlessly redundant inspections. Alternatively, the seller may provide an inspection report. But then, even though duplication of effort is avoided, the potential collusion between the seller and structural expert may reduce the value of the inspection report's information content.

Of course, a well-functioning insurance market that offers buyers protection from earthquake hazards could eliminate the rationale for collective action. Many studies, however, report that such an insurance purchase typically depends on the subjective risk perceived by the homeowners. Should all potential buyers or owners perceive the same level of risk, such a market could effectively function. This is highly unlikely, however, when the issue at hand is something with relatively low frequency, like a major earthquake. In this situation, buyers and owners are likely to have widely divergent beliefs as to the likelihood of a devastating quake,

---

Noji (1997, p. 138) reports "[a] series of three great earthquakes (estimated magnitudes 8.6, 8.4, and 8.7) ... occurred during a 3-month period in the winter of 1811-1812 near the town of New Madrid, Missouri."

Lagorio (1990, p. 249) also comments on the 'Act of God' syndrome which suggests that "nothing can be done to stop it, so why bother? This echoes the feeling that a disastrous event that is about to happen is so big that nothing can be done to help - we are all doomed and in the hands of God anyway, so let nature take its course. On local government's part, there is always the excuse that there aren't enough resources or funds available for earthquake hazards mitigation. Consequently, there are always more important things to worry about. And finally, when there is lack of data or inadequate information on the subject, confusion results and preparedness efforts lag. Of course, after a damaging earthquake, all of those excuses are forgotten, and at that point the community has a tendency to ask, Why wasn't something done 10 years ago to prevent this?"

especially over a relatively brief period of time (Kunreuther et al (1978), Hogarth and Kunreuther (1985), Palm (1995)), leading to Lagorio's (1990, p. 164) observation that, "when there is lack of data or inadequate information on the subject, confusion results and preparedness efforts lag".

A final rationale for regulation may be found in its external benefits. A home that is earthquake-unsafe imposes some costs on adjacent properties as well. In many circumstances, structurally unsound buildings collapse on other buildings that otherwise could have escaped the earthquake undamaged.[6]

At one end of the spectrum, are countries such as the U.S. in which very stringent building and zoning codes are enforced effectively and even very costly retrofitting of pre-code buildings is achieved to some extent within the confines of collective action.[7] Further, in the U.S., an earthquake insurance market exists, though it is relatively weak since regulation arising from collective action has proven very effective in minimizing the fatality, injury and damage risks. At the other end of the spectrum, are countries such as Algeria in which no regulation exists (and therefore no measures against earthquakes can be enforced) and, making matters

[6] As Lagorio (1990, p. 164) elaborates on this issue "considerations for a single isolated building are very different from those involved for a building in a neighborhood setting of an entire block, where multiple buildings sit side by side. ... As seen in the 1985 Mexico earthquake and the October 1989 Loma Prieta earthquake, corner buildings are particularly vulnerable to damage, as they have nothing to lean on at the open street side. ... Unfortunately, there is no simple solution, and the matter is still being debated by design professionals. Some have asked the questions: "What value is it to upgrade an individual URM [i.e., unreinforced masonry] building when in fact all the buildings on the block not retrofitted might act in concert and impact the strengthened building negatively?"

[7] In the U.S., historically, the traditional approach to improving the performance of structures and upgrading building code provisions has focused on the advancement of design standards for new buildings. However, since the construction of new buildings only accounts for an addition of about 2 percent per year to the existing total building stock, retrofitting of buildings that were designed under the previous less restrictive code standards became a critical issue about a quarter century ago. Quoting Lagorio (1990): "It was not until 1978 ... that the problem associated with upgrading the seismic performance of older, existing structures was identified as a critical one to be addressed seriously by design professionals, researchers, and public policy officials" (p. 139). According to the 1986 tax legislation, the investment tax credit offers a one-time 13-20 percent write-off on income taxes in exchange for a written agreement to keep the exterior facades of older, existing buildings in their original forms (see pp. 152-153 of Lagorio (1990)). In addition, "recent California state legislation ... requires local governments at municipal and county levels to identify, quantify, and assess older, existing hazardous buildings located within their jurisdictions. Further, they are encouraged to submit appropriate programs and plans for earthquake mitigation efforts dealing with the buildings so identified" (p. 155). There are also triggered ordinances in cities and counties that are seismically very active. "When a building owner wishes to do substantial remodeling or renovation that exceeds a certain percentage level of cost and/or floor space additions, the rehabilitation work must include seismic upgrading in order for a building permit to be obtained. [A] triggered ordinance only applies to buildings undergoing renovation, whereas the retroactive ordinance applies to all hazardous buildings across the board" (p. 157).

worse, such countries typically also lack a functioning earthquake insurance market.

Somewhere between the US and Algerian examples, are countries such as Turkey. Following the 1999 earthquake in Turkey that killed 17,000 people, its parliament decided that measures such as enforcing the existing building code effectively and retrofitting the structurally unsound private buildings were well beyond the means of the taxpayers of the country. Even though many earthquake experts insisted that installing some of the above-mentioned measures were crucial, the parliament mandated only a modest earthquake insurance program, which, despite the government's mandate, has commanded a very weak following.[8]

While it is true that the dynamics of a specific quake, such as its magnitude, its depth, and proximity to population centers are the primary determinants of a quake's level of devastation, collective action of the sort that we have been discussing can effectively limit this devastation. As such, consider the following theoretical model of these interrelations.

## *4. Theoretical Model*

There are two types of households: L-types (low-income households) and H-types (high-income households). We assume the measure of all households is one. Within society, the fraction of low-income type households is L and thus the fraction of high-income households is H = 1-L.[9] Income of an L-type household is denoted by $y_L > 0$, and that of an H-type by $y_H > 0$ such that $y_H = k\, y_L$, where $k \geq 1$. That is, k denotes the extent of income inequality in society (observe that k = 1 implies that society has no income inequality).

---

[8] However, the current government decided on partial retrofitting of public buildings and bridges. This happened since the present government intends to start entry negotiations with the European Union within a year, and in order to qualify to start those negotiations, the country's regulations in various areas - including a minimum earthquake preparedness of public buildings and bridges - have to comply with the European Union's regulation in them.

[9] We allow all possible cases L > H, L < H and L = H. But to prevent cases, where despite, say, there are more low-income households than the high-income households (i.e., despite L > H), the high- income individuals constitute the majority by having larger household sizes, we assume that each household in the society has the same size; that will ensure that when, say, L > H, the low- income individuals will definitely constitute the majority.

A major earthquake occurs with probability $p \in (0,1)$ and, thus, does not occur with probability 1-p. Society decides whether to take collective or private action against the quakes based on majority voting. Importantly, we assume that those with relatively more at stake in the outcome of a particular vote also have a greater probability of voting than those with less at stake (this will be expanded upon below). If society, based on a majority vote, decides to take collective action against earthquakes, a tax will be imposed to fund communal earthquake preparedness and mitigation activities that benefit both types of households uniformly. If, on the contrary, private action is opted for, individual households take their own precautions against earthquakes.

### *A) Collective Action*

In the case of collective action, for simplicity, we assume a proportional tax rate, t. Observe that $(L + (1\text{-}L)k)y_L$ is the per capita income of society, denoted by $\underline{y}$. Let $C_c$ be the per capita amount of public funds that are necessary to ensure each household's full preparedness, given collective action. To simplify our notation, we use the normalization $C_c = 1$. We also assume $\underline{y} \geq C_c$.[10] Let $t \in (0,1/\underline{y})$.[11] With collective action, per capita tax revenue will be $t\underline{y}$. Let q denote the probability of surviving a given earthquake. With the normalization $C_c = 1$, per capita tax revenue, $t\underline{y}$, as a fraction of $C_c$ can then represent, q, the probability of surviving for a household, given an earthquake. Then we have $q = t\underline{y} = t(L+(1\text{-}L)k)y_L \leq 1$.[12]

With collective action, the expected utility function of a type i household is

[10] Per capita income in society, $\underline{y}$, is assumed to cover at least $C_c = 1$; thus, perfect coverage via public action against earthquakes is within reach of society, even though this may require society to spend its entire income (which becomes the case at the lower bound of $\underline{y}$. This, however, will never be an equilibrium as Proposition 1 below will imply).

[11] Observe that the assumption $\underline{y} \geq C_c = 1$ also ensures that the maximum possible tax rate $t = 1/\underline{y}$ never exceeds 1.

[12] Clearly, with the maximum possible tax rate $t = 1/\underline{y}$, we have $t\underline{y} = 1$ which will not have to exceed $C_c = 1$; i.e., even with the maximum possible tax rate $t = 1/\underline{y}$, society will not end up collecting more in taxes than needed to provide complete coverage.

$u_i^c = p\,(1\text{-}t)y_i\,(t\underline{y}) + (1\text{-}p)(1\text{-}t)y_i$.

Thus, if the tax rate resulting from a majority vote is t, a type i household is able to spend $(1\text{-}t)y_i$ on goods and services when either a major earthquake does not occur or when communal earthquake preparedness and mitigation activities have been undertaken perfectly. The latter holds if $q = t^*\underline{y} = 1$, which amounts to perfect coverage against a major earthquake. If the tax revenue $t^*\underline{y}$ and thus the probability of surviving a major earthquake (when such an earthquake occurs) is less than one, then $(1 - t^*\underline{y})$ fraction of households will lose their lives (and thus will earn no income and be unable to consume any goods and services).[13]

For collective action to be more beneficial on average than private action for individuals, the cost of private earthquake preparedness and mitigation, $C > 0$, should be greater than 1, otherwise, collective action would not be advantageous for at least one segment of society (this will be made more precise below). With private action, the expected utility function of a type i household is

$u_i^p = p\,y_i + (1\text{-}p)\,y_i - C = y_i - C$.

Suppose i types win the majority vote. For i types in order to decide whether or not to support collective action, they have to first assess whether or not their expected utility with collective action, $u_i^c = p\,(1\text{-}t)y_i\,(t\underline{y}) + (1\text{-}p)(1\text{-}t)y_i$, would be greater than it would be with private action, $u_i^p = y_i - C$. Making this assessment requires knowledge of the tax rate needed to implement collective action. For i types to make the most out of the collective action, the necessary tax rate, $t_i$, should maximize their expected utility when collective action is chosen, $u_i^c = p\,(1\text{-}t_i)y_i\,(t_i\underline{y}) + (1\text{-}p)(1\text{-}t_i)y_i$.

***Proposition 1***: *With the tax rate, $t_i$, that maximizes i types' expected utility in collective*

[13] We do not model grief for the deceased family members since, even without grief, our results hold, while with grief our results are strengthened, albeit at the expense of needless additional notation.

*action, q increases in $\underline{y}$ as long as $\underline{y} < 1+1/p$, and q becomes 1 when $\underline{y} = 1+1/p$. Thus, given any level of p, the probability of surviving a major quake increases in $\underline{y}$.*

Proof of Proposition 1:

$u_i^c = y_i\,[p\,(1-t_i)\,t\underline{y} + (1-p)(1-t_i)]$.

$\partial u_L^c/\partial t = y_i\,[p\underline{y} - 2pt_i\underline{y} - (1-p)] = 0$.

Thus, $t_i = ½ - (1-p)/2p\underline{y}$. (1)

Then q becomes $t_i\,\underline{y}$. That is, $q = (½)\underline{y} - (1-p)/2p \leq 1$. (2)

Trivially, $\partial q/\partial \underline{y} = ½ > 0$. Simple algebra yields that $q = 1$ when $\underline{y}^* = 1 + 1/p$. (3)

Thus, q increases in $\underline{y}$ up to $\underline{y}^*$ and $q = 1$ when $\underline{y}^* = 1 + 1/p$. This completes the proof of Proposition 1.

First, note from the above proof that the same $t_i$ will be levied on both types of households if they opt for collective over private action. Also note that $t_i$ decreases in $\underline{y}$. Observe that the condition of $t_i$ entails $\underline{y} = 1 + 1/p$ when $q = 1$ (i.e., when there is perfect coverage against a major earthquake). Suppose i types prefer collective action. When p is very low, a very high per capita income (e.g., approaching infinity) would induce i types to obtain perfect coverage. When p approaches 1, on the other hand, even a very low per capita income (e.g., $\underline{y} = 2C_c$) would induce them to obtain perfect coverage.

Note that, if the majority decides on $q = t^*\underline{y} = 1$, a household obtains the same level of utility regardless of whether the earthquake occurs. That utility level will be $u_i^c = (1-t^*)y_i$. But since $t^*\underline{y} = 1$ implies $t^* = 1/\underline{y}$, we obtain

$u_i^c = y_i - y_i/\underline{y}$. (4)

Thus, each $u_i^c$ increases in the household's income, $y_i$, but decreases in the household's relative income, $y_i/\underline{y}$.

### *B) Private Action*

Will L-types and H-types support collective over private action? By definition, the cost of private earthquake preparedness and mitigation, C, is greater than 1. For L-types, clearly $u_L^c = y_L - y_L/\underline{y} > u_L^P = y_L - C$ since $C > 1 > y_L/\underline{y}$. Thus, L-types will always vote for collective action. On the contrary, H-types may or may not support collective action. The following result indicates that the outcome of this decision for H-types depends on the level of income inequality, k, existing in society.

***Proposition 2***: *Consider any set of parameter values $L > 0$, $C > 1$ as well as any $\underline{y} \geq 1$ and any $k \geq 1$. There will be some threshold level of k below which a majority vote will lead to collective action since both L- and H-types will support it, while above this level of k, H-types will vote for private action.*

Proof of Theorem 2: Let $\Delta_H = u_H^p - u_H^C = y_H/\underline{y} - C$. That is, when $\Delta_H > 0$, H-types will vote for private action; otherwise they will join L-types in supporting collective action. $\Delta_H$ can be simplified as $k/(L+(1-L)k) - C$. Note that, when $k = 1$, $\Delta_H < 0$. Also note that $\Delta_H$ increases in k strictly monotonically. Thus, by the Intermediate Value Theorem, there will be a specific threshold level of k at or below which collective action will be supported by all[14] while above that threshold, H-types will vote for private action. This completes the proof of Proposition 2.[15]

[14] In this paper, whenever there is a tie (or indifference), for simplicity the tie-break favors collective action.

[15] Our analysis in this section (and in the next section) compares the perfect coverage outcomes of the collective and private action cases. The most interesting case is $1 < C < (t^*_{q=1})y_H$ where $t^*_{q=1}$ is the tax rate in the collective action case with $q = 1$. Now, consider the imperfect coverage case $q < 1$ with collective action (which is significantly more complicated and lengthy than $q = 1$). Observe that our results will still hold with $q < 1$, since in the private action case, the imperfect coverage will cost qC, and thus the counterpart of the above case will entail $qC < (t^*_{q<1})y_H$ where $t^*_{q<1}$ is the tax rate in the collective action case with $q < 1$.

### *C) The Majority Vote with Probabilistic Voting*

In the remainder of our theoretical analysis, we will focus on the interesting case in which $1< C < y_H/\underline{y}$. Here, H-types will always vote against collective action since $u_H^c = y_H - y_H/\underline{y} < u_H^p = y_H - C$. Since L-types always support collective action, in this case collective action will only be chosen if L-types win the majority vote. Should L > ½ and every agent votes, the outcome of the majority vote will be collective action. But as MCEER reports noted earlier indicate, most developing countries do not exhibit collective action in earthquake preparedness. This would seem to be inconsistent with what we have just outlined given that, in most (if not all) developing countries, L-type households compose the majority of the population. To allow for the possibility that H-types may win the majority vote, or at least control the elected government following a vote, despite their composing less than half of a country's population, we take advantage of a majority voting model. The key to this model is that it assumes that differing segments of a population have differing probabilities of voting, based on their subjective evaluations of what is at stake for them in the vote.[16]

Our main premise is that segments in a society that have more at stake in an election are more likely to vote, or alternatively, they (and consequently the politicians and political parties representing them) are likely to secure a larger portion of seats in any government than the portion of society that they compose would suggest.[17] As detailed by McMillan and Zoido (2004), Peruvian politics of the 1990s provides a prime example of this situation. During that period, the sitting President's chief of secret police methodically bribed at least 1600 people, including politicians, judges and the news media (some TV channels received $2 million monthly

[16] We are grateful to an anonymous referee for suggesting the use a probabilistic voting model.

[17] In some developing countries, suspecting a significant loss in the popular vote in coming elections, incumbent parties have changed election laws so as to maintain their majority in the government. For example, the ruling party in Turkey led by the then prime minister, Turgut Ozal, implemented an unparalleled 10% popular vote threshold at the country-level for each party to be represented in the parliament. This new election system led to Ozal's party receiving 35% of the popular vote but controlling 65% of the seats in the parliament following the 1987 parliamentary elections.

each) to secure their support.[18] In 2000, the President's party held 51 of the congress' 120 seats, thus, a majority coalition could be secured by gaining the support of ten opposition party members. Leaving nothing to chance, the President's chief of secret police successfully bribed twelve congressmen to change parties and another five to serve as informants, while remaining in the opposition.[19] Given the resulting, comfortable 63/57 split, no single former oppositionist held power against the regime. Doubtless, the most remarkable aspect of the explicit bribery was the audacity of the plan and its principle proponent, the country's chief of secret police, who not only had the negotiations video-taped, but took care to ensure that the tapes documented the bribe-takers actually accepting the money (see McMillan and Zoido (2004, pp. 1-5)).

In addition, voting, especially in developing countries can be quite cumbersome as, among other problems, long lines are common and rolls or eligible voters are not well maintained or even purposely corrupted.[20] Further, outright fraud is not uncommon, taking the form of 'vote early, vote often' campaigns, votes being cast by deceased individuals or situations in which opposition party ballots are 'lost' or unjustly disqualified.

Given these types of problems which often surround majority voting, especially in lesser-developed democracies, we assume that segments of voters with more at stake are the ones most likely to successfully vote, that is, those with the most at stake in an election will prove to be the portion of the electorate most likely to have their vote both cast and accurately counted. As such, it is this portion of society that will end-up, in many if not most circumstances, holding a share of the legislature that is disproportionate to their share of the population.

[18] Such retrogressing of democracy is not unique to Peru, for cross-country data showing that it is typically associated with low levels of per capita income (see Przeworsky et al., 2000).

[19] "Each of these congressmen signed three documents: a receipt of the bribe; a letter asking Fujimori to admit him or her into Fujimori's party, Peru 2000; and, on congressional letterhead paper, a *compromiso de honor* (a promise on one's honor, a gentlemen's agreement)" (McMillan and Zoido, (2004, p. 7)). Also see Docquier and Tarbalouti (2000) on parliamentary vote purchases in developing countries.

[20] Even in developed countries, rolls may leave some eligible voters aside; in the U.S. state of Florida, for instance, as of late May 2004 many eligible voters were not yet on the rolls for the presidential elections taking place in November 2004 (see Fineout, 2004, p.1).

In our setup, there are only two possible outcomes from majority voting, collective or private action. When $y_H/\underline{y} > C > 1$, the subsequent utility rankings of the two types are diagonally opposed to each other. That is, $u_H^p > u_H^c$ and $u_L^c > u_L^p$. The difference between the higher and lower utility levels for a type (namely $u_H^p - u_H^c$ for H-types and $u_L^c > u_L^p$ for L-types) is key in determining what is at stake for each type.

Let $m_i$ denote the probability that each i type will vote. To be precise, the likelihood that an H-type will vote relative to an L-type is $m = m_H/m_L = (u_H^p - u_H^c)^\beta/(u_L^c - u_L^p)^\beta$, where $\beta > 1$; in other words, each agent's voting probability will respond to whatever he/she has at stake, at an increasing rate.[21] Then, given $u_H^p$, $u_H^c$, $u_L^c$, and $u_L^p$, m will reduce to $(y_H/\underline{y} - C)^\beta/(C-y_L/\underline{y})^\beta$. So, the expected outcome of the majority vote will be $E(m,L) = (m_H/m_L)\ H/L$. If E(m,L) is greater than one, H-types will be the expected winners, while the contrary holds if it is less than or equal to one.

Consider the following example: Let $\underline{y} = 9$, and $p = 1/8$, so that, if L-types win the majority vote, they pick $q = 1$ (by Equation (3) in the proof of Proposition 1). In addition, let $L = 3/5$, and $H = 2/5$ and $\beta = 3$. Further, assume that $C = 11/10 < y_H/\underline{y}$. In case (1), assume that $k = 3$. Then $y_L = 5$ and $y_H = 15$ will hold, which in turn will yield $y_H/\underline{y} > C$ (since $y_H/\underline{y} = 5/3$ and $C = 1.1$). Then observe that $m_H/m_L = (y_H/\underline{y} - C)^3/(C - y_L/\underline{y})^3 = (1.66 - 1.1)^3/(1.1 - .55)^3 = 1.06$. That is, each type will have almost the same likelihood of voting. But since L-types have a three to two ratio of potential voters, they will be the expected winners of the majority vote; i.e., $E(m,L) = 1.06\ (2/3) = .70$. In case (2) assume that $k = 6$; thus, $y_L = 3$ and $y_H = 18$ will hold, which again will yield $y_H/\underline{y} > C$ (since $y_H/\underline{y} = 2$ and $C = 11/10$). In this case, $m_H/m_L = (y_H/\underline{y} - C)^3/(C - y_L/\underline{y})^3 = (2 - 1.1)^3/(1.1 - .333)^3 = 1.62$. That is, each H-type will vote with twice the probability of each L-type. Thus, although $L/H = 3/2$, H-types will be the expected winners of the majority vote; i.e., $E(m,L) = 1.62\ (2/3) = 1.08$.

---

[21] When $\beta \leq 1$, it is straightforward to show that L-types will always win the majority vote whenever $L > ½$. So, to consider the interesting possibility of H-types winning the majority vote despite $H < ½$, we consider the case $\beta > 1$.

The next result simply follows from $\partial m/\partial k > 0$.

***Proposition 2***: *Consider any set of parameter values $L > 0$, $C > 1$ as well as any $\underline{y} \geq 1$ and any $k \geq 1$. Given this, the likelihood of H-types winning the majority vote will increase in k.*

Propositions 1 and 2 lead to the next result which summarizes our theoretical findings in terms of k's effect on collective action.

***Theorem 1***: *With any set of parameter values $L > 0$, $C > 1$ as well as any $\underline{y} \geq 1$ and any $k \geq 1$, the likelihood of collective action being chosen by majority vote decreases in k.*

Finally, we also need to illustrate that L-types will have less than perfect coverage with private action. Recall that with collective action $q = 1$ is achieved with $\underline{y} = 1 + 1/p$. Suppose collective action with $q = 1$ (i.e., perfect coverage) is the winning outcome. With private action, perfect coverage is more expensive to achieve, since $C > 1$. Even when we suppose that $C = 1$, the utility maximization problem of L-types will yield a lower coverage $q = gy_L$, where $g \in (0,1]$ is the fraction of an L-type household's income that will be spent to achieve earthquake preparedness. Consider an L-type household's utility maximization problem:

$u_L^p = p(1\text{-}g)y_L\ gy_L + (1\text{-}p)(1\text{-}g)y_L$.

The level of g that maximizes the above expected utility function turns out to be $g = ½ - (1\text{-}p)/2py_L$. Thus, $q = gy_L = 1$ can be achieved with $y_L = 1 + 1/p$. But since $y_L < \underline{y}$, with private action, $q < 1$ will hold for L-types. (Alternatively, to see this, consider the following: With collective action, an L-type household is able to obtain perfect coverage by paying $y_L/\underline{y} < 1$. Suppose that it is not able to afford more than that. Since with private action it has to pay $C > 1$, perfect coverage will not be feasible.)

### *D) Predictions of the Theoretical Model*

Proposition 1 states that collective action will save more lives as y, that is, per capita income, increases. But whether collective action will take place or not is a different issue. Propositions 1 and 2 allude to this. Theorem 1, which summarizes these results, states that collective action will be less likely as inequality increases. Consequently, L-types, when left alone, will be able to afford less for their earthquake preparedness and mitigation. Thus, earthquake fatalities will increase in k, inequality, as well.

## *5. Data And Univariate Empirical Results*

From the theoretical model and past research on the destruction caused by earthquakes, the key variables in determining fatalities are those related to 1) the dynamics and location of the quakes, 2) country specific factors such as population, geographic size and income, and 3) unspecified regional factors (see, for example, Schulze, Brookshire, Hageman, and Rschirhart (1989), and Dunbar, Bilham, and Laituri (2002)). The unit of observation in the sample is an individual earthquake measuring at least 6 on the Richter-scale, occurring anywhere in the world, between 1960 and 2002. The sample selects from all such earthquakes those for which complete data is available. This leaves 269 observations, arising from 26 countries. These come from all parts of the world: 6 are from Africa, 7 from Asia, 5 from Europe, and 8 from the Americas.

Information on the dynamics and location of the earthquakes (latitude, longitude, depth, magnitude, fatalities and geographic location where damage was reported) were obtained from the National Geophysical Data Center's (NGDC) Significant Earthquake Database. A key factor in determining fatalities, of course, is a quake's magnitude. We measure this by using the common Richter-scale, as noted above. Another important factor concerns the distance between the epicenter and the affected geographic region, which we estimate by first determining the coordinates of the affected region and the surface coordinates of the epicenter, along with its depth from the surface. Then, we calculate the direct distance, known as the focal distance, by taking the square root of the sum of the squares of the depth and surface-distance, that is, we complete the triangle formed by the surface-distance and depth (this makes extensive use of the ESRI ArcView Geographic Information (GIS)).[22]

Country specific factors include obvious items such as the population of the province(s) affected, the land area, in square kilometers, of those provinces and the frequency with which a country suffers through major quakes.[23] We measure frequency by taking the ratio of the number of 6+ quakes that a country endured during the 1900-1959 period, to 60. The key country specific factors arising from the model relate to a country's income level and degree of inequality. Our measure of the level of income is GDP per capita, in constant (1995) U.S. dollars, which was taken from the World Bank's *World Development Indicators* (WDI). Inequality is typically measured through the use of Gini codes.

Two Ginis are commonly available, one based on the distribution of income and the other on the distribution of land. While we use both in our empirical analysis, for the reasons discussed below, we choose the land-based Gini as our primary measure of inequality. That is, to account for differences in inequality levels, we use a Gini code taken from the decennial FAO *World Census of Agriculture*, which measures a country's initial distribution of the operational holdings of agricultural land. As with the more common income-based Gini, the land Gini ranges from 0-100, in percentage terms, with inequality rising with the Gini.

According to Deininger and Squire (1998), this variable is appealing, relative to the income-based Gini, for the several reasons. First, and for our purposes most importantly, the

---

[22] The latitude and longitude of the affected regions were collected from the Getty Theasurus of Geographic Names online (www.getty.edu). Also, we would like to thank Brian Anyzeski for assisting us in calculating the distance between the affected regions and the epicenters.

[23] Population and land area come from several sources: (1) The World Gazetteer (www.world-gazetteer.com), (2) GeoHive (www.xist.org), and (3) Population Statistics by Jan Lahmeger (www.library.unn.nl).

land-based Gini has a much lower correlation with GDP per capita than does the income-based measure. This is important in the present application because we will be using both the Gini and GDP per capita as independent variables in our regressions. Consequently, by using the land-based Gini, we can effectively control for inequality while minimizing any negative effects arising from multi-colinearity between the income-based Gini and GDP per capita might cause. Second, the possession of land can be a major determinant of an individual's productivity and investment capacity, especially in agrarian economies. Third, there are serious inconsistencies in the way in which income-based Ginis are calculated between countries (such as wage versus total income, individual versus household income and the like). And, finally, data on land distribution is available for earlier years than estimates on income distribution, and for countries in which data on income inequality are either not reliable or available.

Table 1 provides summary statistics for the variables used in the primary analysis while Appendix 1 provides formal definitions and sources for these variables. The mean value in the sample for the number of earthquake Fatalities is 884 with a rather broad range of 0 to 50,000. Population and Square Kilometers of the affected province(s) have means of 8,952 (in thousands) and 189,048, respectively. The direct Distance from the epicenter and the affected region has a mean value of 133 and ranges from 5.94 to 811.61. Magnitude has a mean value of 6.81 and it ranges from 6.0 to 8.5 (the sample was purposely limited to the rather severe, 6+ quakes). Frequency of earthquakes varies widely across countries from 0.01 to 1.15, with a mean of 0.47. The mean value in the sample for GDP per capita is $7,672, varying widely from just over $100 to $44,774.71. Inequality has a mean value of 62.97 and it ranges from 37 to 87. Finally, the distribution of quakes across the continents can be seen by considering the continental dummy variables.

________________________Insert Table 1 About Here____________________________________

To get a first glimpse at the predictions embodied in the theoretical model, we pool the sample and break the data of Table 1 into the two panels of Table 2 which relate Fatalities, Magnitude, GDP per capita and Inequality. Panel 2a compares countries according to whether or not they have a GDP per capita above or below $1,874, the sample's median value. Promisingly, as the theoretical model predicts, there does seem to be a negative relation between earthquake fatalities and income levels. More specifically, while the relatively poor countries tend to be hit by earthquakes of nearly identical mean Magnitudes as do the relatively wealthy, resulting Fatalities are, on average, 85% greater in the poorer countries.

It is important to note, however, that the univariate difference in means test does not suggest that these two values are statistically significant. Three points are important here. First, the difference in means tests were conducted following difference in variance tests, which showed that, in the case of Panel 2b, with respect to Fatalities, the underlying variances were unequal. Thus, the results reported in Table 2 are standard, equal variance, difference in means outcomes, with the exception of Fatalities in Panel 2b, which was conducted assuming different variances. Second, while not statistically different, the divergences in Fatalities reported in Table 2 are clearly of practical significance. Third, and of more importance to the multivariate analysis that follows, it should be noted that the lack of significance seems to arise from the extremely large standard deviations of Fatalities for both sub-groups of the sample.

________________________Insert Table 2 About Here___________________________________

Panel 2b compares Fatalities when the sample is broken into sub-groups based on the median of Inequality. Once again, there is evidence, even if statistically insignificant, suggesting that inequality may well be positively associated with Fatalities from earthquakes. Specifically, while the relatively equal and unequal sub-groups tend to endure earthquakes that are almost precisely equal in Magnitude, resulting Fatalities are 167% greater, on average, in the relatively unequal countries.

While not statistically significant, each of these outcomes suggests two things of importance relative to the multivariate analysis that follows. First, there is reason to suspect that both a country's levels of income and inequality play a role in determining the impact that an earthquake has, in terms of Fatalities, as predicted by our theoretical model. Equally important, however, Table 2 indicates that care must be taken in the multivariate analysis to deal with the extreme skewness of some of the key variables, especially Fatalities.

## *6. Multivariate Empirical Results*

The theoretical model predicts that, holding constant reasonable control variables (such as magnitude, population, land area, distance from the epicenter, frequency of major quakes, as well as other, unexplained regional factors), fatalities from a quake should be an decreasing function of both a country's levels of per capita income and equality. And these predictions do find some support in the univariate analysis offered in the data section. To more formally test these relations, we estimate:

$$\begin{aligned} FATAL_{it} = \alpha_0 + \alpha_1 DIST_{it} + \alpha_2 MAG_{it} + \alpha_3 POP_{it} + \alpha_4 SQKM_{it} + \\ \alpha_5 FREQ_{it} + \alpha_6 GDPPC_{it} + \alpha_7 INEQUALITY_{it} + \varepsilon_{it} \end{aligned} \quad (5)$$

where *FATAL* is earthquake fatalities in country *i* at time *t*, *DIST* is the direct distance from the epicenter, *MAG* indicates the magnitude of the earthquake, *POP* represents the population of province(s) in the affected area, *SQKM* is the land area of province(s) in the affected area, *FREQ* is the frequency of 6+ Richter quakes locally, *GDPPC* indicates the GDP per capita of the country, and *INEQUALITY* represents the country's land-based Gini.

Estimation of equation (5) involves two obvious complications. The first is the dataset's panel nature. While the data do include quakes occurring in 26 countries, over the 42-year time period 1960-2002, giving an average of about 10 quakes per country during the period, the distribution across countries varies greatly. At one end are particularly quake-prone countries (such as Indonesia, the United States and Peru) which experienced more than 25 quakes of magnitude 6 or greater during the survey period. At the opposite end of the distribution are places such as Ethiopia, Canada and Honduras that appear in the sample only once. Along with these differences, it may well be that other region-specific factors play a role in determining an earthquake's destructiveness. These factors might include geological issues such as soil/sub-surface composition and density, whether local fault lines tend to lead to quakes that result in lateral, rather than the typically more damaging vertical scrubbing of tectonic plates, or, perhaps, local building and location customs. With these issues in mind, and lacking prior knowledge as to the specific nature of any existing region-specific effects, equation (5) was estimated with both random and fixed effects procedures, at the continent level. The reported regressions are a mix of the two estimators, where the choice was based on the results of Hausman tests. In each case, the employed estimator is identified in the results Tables.

The second complication in estimating equation (5) concerns the nature of the dependent variable, Fatalities arising from an earthquake. Fatalities are, of course, a non-negative count of deaths. The basic model for count data is the Poisson specification. This specification is best suited for counts with low variation since the model explicitly assumes the conditional mean and variance of the dependent variable to be equal. As shown in Table 2, with a standard deviation 5.5 times greater than its mean, the assumption of equal mean and variance does not appear to fit this data. Over-dispersion of this order can cause a downward bias in the standard errors resulting from Poisson estimation, arguing in favor of the Negative Binomial Regression model. This model generalizes the Poisson by expressly relaxing the assumption of equal conditional mean and variance through the introduction of a parameter that reflects the unobserved heterogeneity between observations in the sample. The regressions reported below use this procedure. That is, the reported results, as discussed above, are based on Negative Binomial models that control for random/fixed effects, at the continent level.

While the Negative Binomial is designed to handle situations in which the dependent variable has a rather broad, non-negative distribution, it remains suspect to extreme outliers.

Again, a check of Table 2 suggests evidence of just such outliers, with respect to Fatalities. The mean number of fatalities from a 6+ Richter quake, worldwide, between 1960 and 2002, is 884, while the standard deviation of that variable is nearly 5,000.

A closer inspection of the data shows that, in fact, relatively few of the 269 quakes in the sample, only 25 to be precise, involve fatalities in excess of the mean. This suspicion of skewness was confirmed, with a formal test resulting in a Chi-Square value that was significant beyond the .001 level. This degree of skewness in the dependent variable leads us to be concerned about the potentially misleading effects of outliers and, as such, to provide a sensitivity test for the estimation of equation (5), we estimate and include 3 variants of the basic model: (1) the full 269 quake sample with its maximum death toll of 50,000, (2) a 264 unit sub-sample of those quakes that yielded no more than 15,000 fatalities, and (3) a 259 unit sub-sample of those with no more than 5,000 fatalities. In the 259-unit case, we have eliminated roughly the 4% of the quakes leading to the greatest number of casualties. More importantly for the issue of outliers, this subtraction yields a mean number of fatalities of 164, with a standard deviation of 556. Thus, while the full sample has a standard deviation to mean ratio of 5.5, by the time the top 4% of the sample is eliminated, this ratio falls to 3.3. By considering the results of the three estimations, in tandem, a clearer picture of the relations embodied in equation (5) should be attainable.

Finally, as is customary, all variables in the estimation are entered in natural logs. These estimations are presented in Table 3. In each case, the likelihood-ratio test showed positively that the probability of these estimates arising from a pooled estimator (that is, a Negative Binomial model with constant dispersion) to be virtually zero for the random-effects models, with Chi-Square values each significant beyond the.01 level. Finally, in each case, the Wald Chi-Square for the full-model log-likelihood test is also highly significant, beyond the .001 level, indicating that the likelihood of the included independent variables being jointly equal to zero to be virtually nil.

__________________________Insert Table 3 About Here_____________________________

Consider first the key variables arising from the theoretical model, *GDPPC* and *INEQUALITY*. Recall that in that model, collective action designed to mitigate the effects of earthquakes was an increasing function of per capita income and a decreasing function of inequality. Each specification confirms this prediction, significantly, for both variables. That is, with a high degree of confidence, and after taking into account the possible effects of outliers and continent–specific effects, it is clear that *GDPPC* is significantly and negatively related to earthquake fatalities. It is equally clear that *INEQUALITY*, across specifications, is significantly and positively related to fatalities. Taken together, these results reflect rather favorably on the theoretical model. Our interpretation, intuitively, is that as per capita income and equality increase, the likelihood of collective action serving to mitigate the fatalities from a given quake increases. And, given the skewness issue we addressed above, it is particularly reassuring to note that, the results hold even as the outliers, in either the 264 or 259 unit sub-samples, are eliminated from the sample.

To give these results practical meaning, the marginal impact on fatalities, for a standard deviation change in the key independent variables, is calculated. For example, holding all else constant, relative to a mean value of $7,763, an absolute value change of about $11,000 in *GDPPC*, would be expected to lead to a change of about 28% in fatalities from a given earthquake, in the opposite direction, of course. That is, holding all else constant, an earthquake of the average magnitude, about 6.8 on the Richter scale, can be expected to cause roughly 46 fewer fatalities in a country where *GDPPC* is $18,763 than it would in a country with the sample mean *GDPPC* of $7,763. Similarly, the marginal effect for *INEQUALITY* is about 45%.[24] As expected, a country's levels of per capita income and inequality play very important roles in determining earthquake fatalities, both from statistical and practical perspectives.

Several of the control variables are also quite interesting. Consider first, the dynamic

[24] The marginal effects are calculated from the 259-unit sub-sample, where both key variables have high levels of significance and the effect of outliers is minimized, though similar values hold across the specifications.

nature of the quakes themselves, as measured by the Richter-scale magnitude, *MAG*, and the distance to the epicenter, *DIST*. As would be expected, fatalities are very strongly and positively related to *MAG*, while being strongly negatively related to *DIST*. Importantly, these results hold, regardless of specification. Similarly, total population of the affected regions, *POP*, is consistently positively and significantly related to fatalities, across specifications. Of course, this should not be surprising as it reflects little more than the fact that the more people who are at risk, all else constant, the more will die from an earthquake of a given size. Less consistent are the results for the square kilometers of the affected area, *SQKM*, which, while being of the expected negative sign in each estimation, is only significant, at conventional levels in the 269 unit and 259 unit sub-samples. However, it should be pointed out that while not significant at conventionally accepted levels, in the 264 unit sub-sample, *SQKM*'s t-value of 1.53 is clearly strong enough to indicate some degree of practical importance.

The only control variable that behaves poorly in the estimations is the frequency with which quake's strike a given region, *FREQ*. It would be expected that in areas where quakes are relatively more common, comparatively less damage would be suffered simply as an outgrowth of a local population's 'learning by doing'. We find only very weak evidence of this. Specifically, while *FREQ* is of the expected negative sign in the 264 and 259 unit sub-samples, it is consistently insignificant.

## 7. *Further Empirical Considerations*

As is true with any empirical modeling, the results reported above are not without potential shortcomings that should be addressed. The two of these that seem most likely to be problematic are the use of the land-based Gini as our primary measure of inequality and the lack of any empirical link between income/inequality and earthquake preparedness. In this section, we offer evidence on each of these matters.

First, while an income-based measure of inequality is somewhat more commonly employed in empirical work than a land-based measure, we provided above our arguments, actually those of Deininger and Squire (1998), as to why the land-based measure of inequality is superior in this application, so we will not repeat them here. Rather, to address this issue, we re-estimated the models reported in Table 3 replacing its measure of *INEQUALITY* with an income-based Gini taken from Deininger and Squire (1998). Other than this, the estimations are identical. Results of these estimations are reported in Table 4. Again, as was true above, the choice of whether the estimator was random or fixed was based on a Hausman test and is noted in the table.

Insert Table 4 About Here

As was true with the models of Table 3, the models using the alternate definition of *INEQUALITY* are quite strong, offering, in each case Wald Chi-Square values significant beyond the .01 level, indicating that the likelihood of the included independent variables being jointly equal to zero is virtually zero. And, for the random-effects specifications, Chi-Square values for the likelihood ratio test of panel versus pooled estimators clearly show that, in each case, the panel estimator is preferred, beyond the .001 level. Of greater importance, however, are the results for the key variables, *GDPPC* and *INEQUALITY*. *GDPPC* shows the same very strong negative correlation with fatalities as when we used the land-based Gini. The story is a bit less clear, however, for the income-based measure of *INEQUALITY*. When this definition is used, while *INEQUALITY* exerts a consistently positive influence on fatalities, the coefficient is only significant, at conventional levels, in the 264 unit sub-sample. Two points should be considered here. First, while not significant at the standard, lower-bound .1 level in the 269 and 259 unit sub-samples, the coefficients on *INEQUALITY* are reasonably strong, being significant at the .16 and .13 levels, respectively. So, while not consistently significant, these outcomes do clearly suggest that there is a positive relation, though not as strong as we would like to find, between fatalities and *INEQUALITY*, when the alternate definition of the latter is used.

Second, and perhaps of even more importance, it should be recalled that one of the primary arguments in favor of the land-based measure of *INEQUALITY* is that it shows a rather lower correlation between *INEQUALITY* and *GDPPC* than does the income-based measure. Given that our models, both theoretical and empirical, require each of these key variables to appear as independent variables in the regressions, using the income-based measure subjects the models to possible multi-colinearity, of at least some degree. Of course, the expected outcome from multi-colinearity is inflated standard errors and the resultant fall in levels of significance. As evidence of this possibility, consider the simple correlations between *GDPPC* and the alternate definitions of *INEQUALITY*. When the land-based measure of *INEQUALITY* is used, the correlation with *GDPPC* is -0.14. When we switch to the income-based definition of *INEQUALITY*, the correlation rises to -0.44. While we can not definitively conclude that such correlation is responsible for the rather weaker relation we find when the income-based measure of *INEQUALITY* is used, it is certainly consistent with such an outcome.

Finally, with respect to the remaining variables in these models, it should be noted that the alternate definitions of *INEQUALITY* do not lead to pronounced differences in outcomes. That is, both the preferred land-based and income-based measures of *INEQUALITY* provide evidence of a positive relation between *INEQUALITY* and fatalities and do so without introducing any noticeable instability in the models.

The second issue that deserves attention concerns a key part of the theoretical model which can only be inferred in the empirical model, namely, the correlation between *GDDPC/INEQUALITY* and earthquake preparedness. The primary argument of the theoretical model is that income and equality work together to determine a country's level of collective action, in the form of earthquake preparedness. Ideally, we would like to have data on preparedness, by country, over the entire time period to show this point. Unfortunately, such data do not exist.

As a second-best solution, however, we have identified three indices of preparedness, by country, each of which is available for one year in the middle-1990s. The first is, Regulations for

Seismic Design, *RSD*, which is taken from the International Association for Earthquake Engineering's (1996) *Regulations for Seismic Design: A World List-1996*. *RSD* is based on a country's compliance with earthquake design codes and regulations and takes into account such factors as seismic design criteria, zones and loads. *RSD* is available for each of the 26 countries in our sample. Each country is assigned a value of zero (failing to satisfy the criteria) or one (compliance).

The second index of earthquake preparedness is taken from Paz's (1995) *International Handbook of Earthquake Engineering*, *IHEE*, and, while similar to *RSD* in that it considers a country's compliance with earthquake design codes, it is a bit more restrictive in that it also takes into account a country's main recent developments in seismic code activity. *IHEE* is also available for each of the countries in our sample and is coded as is *RSD*.

Our third index of collective action in terms of quake preparedness, Earthquake Disaster Preparedness Index, *EDPI*, is from the *World Seismic Safety Initiative* (WSSI) (available at http://www.wssi.org/). *EDPI* offers a rather unique look at preparedness in that it reflects the subjective opinions of those involved with the International Association of Earthquake Engineering's WSSI. That is, expert seismologists representing each of 18 countries provided their subjective opinions as to their own county's level of preparedness, after having participated in the WSSI's 1999 Bangkok workshop. This index ranges from 0 (effectively no preparation) to 10 (maximal preparation) and is available for 10 countries in our sample. Descriptive statistics and correlation information for these indices are presented in Table 5.

____________________________Insert Table 5 About Here____________________________

Given the limited nature of these three indices of collective action, the primary evidence we can take from them reflects the simple correlations between them and the key variables, *GDPPC* and *INEQUALITY* (using values from the middle-1900s for each, so as to be consistent with the preparedness measures). In each case, though admittedly limited in scope, the correlations do show the link between *GDPPC/INEQUALITY* and preparedness that can only be implied by our empirical models. That is, the correlations between *GDPPC* and *RSD*, *IHEE* and *EDPI* are, as expected, each positive and rather strong, ranging from 0.39 to 0.81. Conversely, the correlations between *INEQUALITY* and *RSD*, *IHEE* and *EDPI* are, also as expected, negative and reasonably robust, ranging from -0.32 to -0.43. In an attempt to determine the strength of these relations, Table 6 provides difference in means tests for each of these indices, relative to *GDPPC* and *INEQUALITY* (the *EDPI* index is divided at its median to allow for the test and is labeled *EDPIX*, while *RSD* and *IHEE* are already coded zero-one, as noted above).

Insert Table 6 About Here

Given the coding of each, those with a value of zero can be thought of as reflecting the countries in the sample that have invested relatively little in earthquake preparedness while those with a value of one have invested relatively more. While these tests are on rather small samples, it is clear from them that *GDPPC* and *INEQUALITY* are strongly correlated with earthquake preparedness. Specifically, Table 6 indicates that earthquake preparedness is significantly greater in countries that have higher levels of *GDPPC* and lower levels of *INEQUALITY*. And the differences, in addition to being statistically significant in every case, are rather dramatic from a practical perspective: being in the relatively quake-prepared portion of the sample is associated with a mean difference in *GDPPC* of just over $10,000 relative to those countries that are relatively unprepared while the mean difference in *INEQUALITY* between the two groups amounts to a bit more than seven Gini points, on average.

Finally, in an attempt to offer some multivariate evidence regarding the link between earthquake preparedness and income and inequality, we estimated a simple probit model using the relatively restrictive preparedness index, *IHEE*, as the dependent variable and including *GDPPC* and *INEQUALITY*, along with a constant, as independent variables. Consistent with the univariate presented above, this model not only shows a good fit with a pseudo R-Square of 0.53, but also yields coefficients on *GDPPC* and *INEQUALITY* that are both significant, beyond the .05

level, and of the expected positive and negative signs, respectively.[25]

While, obviously, a complete time series of preparedness would provide more persuasive evidence, these indices and the resulting empirics, at a minimum, are strongly suggestive of our contention that per capita income and equality are strong determinants of collective action, as it relates to earthquake preparedness. This is especially true given that the three indices of collective action are methodologically different from one another and are produced by different organizations of seismic experts. Given the continuing work of organizations like MCEER, the International Association of Earthquake Engineering and WSSI, in time, sets of complete time series for these and other preparedness measures allowing for more thorough analysis of the question will be available. As for now, however, inference from such admittedly simple empirics is the best evidence available.

## *8. Conclusion*

Earthquakes and other natural disasters claim tens of thousands of lives worldwide each year, not to mention the accompanying billions of dollars in property damage. Too often there is a tendency to ascribe such events to uncontrollable "acts of nature," releasing humankind of any role in the tragedies. In this paper, we develop and test a theoretical model that suggests that, in fact, political-economic institutions are at least partly responsible for earthquake fatalities. That is, we develop a theoretical model which shows that collective action in the form of creation and enforcement of building codes, appropriate professional licensing, earthquake-sensitive zoning and, if needed, retrofitting of structures can significantly reduce the devastation of major earthquakes. More importantly, this model shows that the probability of collective action is an

[25] There are two obvious shortcomings of this model that limit our ability to offer more complete multivariate evidence. First is its rather limited sample size of just 26 countries. Equally important, however, both given a lack of available data to estimate a complete model of preparedness and the degrees of freedom necessary to estimate such a model, were the data available; we offer these results only to provide the reader with a sense that the univariate analysis presented in Table 6 likely is, at least to some extent, supportable in a multivariate framework, should the necessary data exist. These results are available from the corresponding author, upon request.

increasing function of a country's per capita level of income and degree of equality. We test these predictions by considering, in a Random/Fixed Effects Negative Binomial framework, 269 major earthquakes occurring worldwide between 1960 and 2002. The results strongly support the predictions of the theoretical model. Thus, policies designed to improve per capita income and reduce inequality can be expected to, through their impact on the likelihood of collective action, mitigate the effects of major quakes. Of course, such policies are easier recommended than developed and implemented. And, unfortunately, improvements in these areas, in and of themselves, cannot be expected to fully alleviate the devastation done by severe quakes. Yet, it is our hope that this analysis provides yet one more reason to work toward policies that serve to increase per capita income and equality, especially in the developing world, where natural disasters such as earthquakes impose their greatest costs.

## *References*


Akerlof (1970), "The Market for Lemons: Quality Uncertainty and the Market Mechanism," *Quarterly Journal of Economics*, 89, 488-500.

Alesina, A. and A. Drazen (1991), "Why are Stabilizations Delayed?" *American Economic Review*, 81, 1170-1188.

Alesina, A. and R. Perotti (1996), "Income Distribution, Political Instability, and Investment," *European Economic Review*, 40, 1203-1228.

Alesina, A. and D. Rodrik (1994), "Distributive Politics and Economic Growth," *Quarterly Journal of Economics*, 109, 465-489.

Benabou, R. (1996), "Inequality and Growth," in B. Bernanke and J. Rotemberg, ed.s, *NBER Macro Annual 1996* (MIT Press: Cambridge, MA).

Bertola, G. (1993), "Factor Shares and Savings in Endogenous Growth," *American Economic Review*, 83, 1184-1198.

Bourguignon, F. (2001), "Crime as a Social Cost of Poverty and Inequality: A Review Focusing on Developing Countries," In S. Yusuf, S. Evenett and W. Wu, eds., *Facets of Globalization* (World Bank: Washington, D.C.).

Coburn, A. W., A. Pomonis and S. Sakai (1980), "Assessing Strategies to Reduce Fatalities in Earthquakes," *Proceedings of the International Workshop on Earthquake Injury Epidemiology for Mitigation and Response* (Johns Hopkins University: Baltimore, MD).

Docquier, F. and E. Tarbalouti (2001), "Bribing Votes: A New Explanation to the 'Inequality-Redistribution' Puzzle in LDCs," *Public Choice*, 108, 259-272.

Dunbar, P. K., R. G. Bilham, and M. J. Laituri (2002), "Earthquake Loss Estimation for India Based on Macroeconomic Indicators," in T. Beer and A. Ismail-Zadeh, ed.s, *Risk Science and Sustainability: Science for Reduction of Risk and Sustainable Development of Society* (Kluwer Academic Publishers: Dordrecht, Holland).

Durkin, M. E., C.C. Theil, and J. E. Schneider (1991), "Injuries and Emergency Medical Response in the Loma Prieta Earthquake," *Bulletin of the Seismological Society of America*, 81, 2143-2166.

Fajnzylber, P., D. Lederman and N. Loayza (2002), "What Causes Violent Crime?," *European Economic Review*, 46, 1323-1357.

Fineout, G. (2004), "Many Voters Not Yet Back on Rolls, Miami Herald 101(225), pp. 1 and 12 (May 26, 2004 issue).

Galor, O. and J. Zeira (1993), "Income Distribution and Macroeconomics," *Review of Economic Studies*, 60, 35-52.

Hogarth, R. M. and H. Kunreuther (1985), "Ambiguity and Insurance Decisions," *American*

*Economic Review Papers and Proceedings*, 75, 386-390.

Howell, B. F., Jr. (1990), *An Introduction to Seismological Research: History and Development* (Cambridge University Press: Cambridge, UK).

International Association for Earthquake Engineering (1996), *Regulations for Seismic Design: A World List-1996* (International Association for Earthquake Engineering: Tokyo, Japan).

Kunreuther, H. R. Ginsberg, L. Miller, P. Slovic, B. Borkan, and N. Katz (1978), *Disaster Insurance Protection: Public Policy Lessons* (John Wiley&Sons: New York, NY).

Lagorio H. J. (1990), *Earthquakes: An Architect's Guide to Nonstructural Seismic Hazards* (John Wiley&Sons: New York, NY).

Lomnitz, C. (1999), *The Road to Total Earthquake Safety: The Seventieth Mallet-Milne Lecture* (A. A. Balkema: Rotterdam, Holland).

McMillan J. and P. Zoido (2004), "How to Subvert Democracy: Montesinos in Peru," CESifo Working Paper N0. 1173, Category 1: Public Finance (www.CESifo.de).

MCEER (2002), *Earthquake Reconnaissance* (http://mceer.buffalo.edu/publications/default.asp).

Noji E. K. (1997), "Earthquakes," in E. K. Noji, ed., *The Public Health Consequences of Disasters* (Oxford University Press: Oxford, UK).

Palm R. (1995) "Catastrophic Earthquake Insurance: Patterns of Adoption," *Economic Geography*, 71, 119- 131.

Paz, M., ed. (1995), *International Handbook of Earthquake Engineering: Codes, Programs, and Examples*, (Kluwer Academic Publishers: Dordrecht).

Persson, T. and G. Tabellini (1994), "Is Inequality Harmful for Growth? Theory and Evidence," *American Economic Review*, 84, 600-621.

Przeworski, A., Alvarez, J. A. Cheibub and F. Limongi (2000), *Democracy and Development* (Cambridge University Press:Cambridge).

Rodrik, D. (1999), "Where Did All the Growth Go?: External Shocks, Social Conflict and Growth Collapses," *Journal of Economic Growth*, 4, 385–412.

Schulze, W. D., D. S. Brookshire, R. K. Hageman and J. Tschirhart (1987), "Benefits and Costs of Earthquake Resistant Buildings," *Southern Economic Journal*, 53, 934-951.

***Table 1. Descriptive Statistics***

| *Variable* | *Mean* | *St. Deviation* | *Minimum* | *Maximum* |
|---|---|---|---|---|
| ***FATALITIES*** | 884.04 | 4,897.14 | 0.00 | 50,000.00 |
| ***MAGNITUDE*** | 6.81 | 0.61 | 6.00 | 8.50 |
| ***FREQUENCY*** | 0.47 | 0.28 | 0.01 | 1.15 |
| ***DISTANCE*** | 133.81 | 135.67 | 5.94 | 811.61 |
| ***POPULATION*** | 8,952.56 | 20,513.37 | 1.98 | 166,052.79 |
| ***SQUARE KM's*** | 189,048.46 | 341,145.53 | 154.00 | 1,522,595.02 |
| ***GDPPC*** | 7,672.67 | 11,025.96 | 101.58 | 44,774.71 |
| ***INEQUALITY*** | 62.97 | 12.54 | 37.00 | 87.00 |

***Table 2. Relation between Fatalities and GDPPC and INEQUALITY***

***Panel 2a. Fatalities and GDPC***

| *Variable* | *GDPC<1874 Mean* | *GDPC<1874 Std. Dev.* | *GDPC>1874 Mean* | *GDPC>1874 Std. Dev.* | *Difference t test* |
|---|---|---|---|---|---|
| ***Fatalities*** | 1,151.62 | 5,230.36 | 622.37 | 4,551.95 | 529.25 (0.88) |
| ***Magnitude*** | 6.82 | 0.58 | 6.81 | 0.63 | 0.01 (0.12) |

***Panel 2b. Fatalities and Inequality***

| *Variable* | *GINI>60.9 Mean* | *GINI>60.9 St. Dev.* | *GINI<60.9 Mean* | *GNI<60.9 St. Dev* | *Difference t-test* |
|---|---|---|---|---|---|
| ***Fatalities*** | 1280.25 | 6537.21 | 478.90 | 2158.03 | 801.35 (1.36) |
| ***Magnitude*** | 6.78 | 0.61 | 6.84 | 0.61 | -0.06 (-0.88) |

Note: T-Statistics for differences in means are in parentheses.

***Table 3. Regressions on Earthquake Fatalities***

| *Variables* | *(1)* | *(2)* | *(3)* |
|---|---|---|---|
| ***Intercept*** | -10.66** | -12.68** | -12.26** |
| | (2.697) | ( 2.886) | (2.882) |
| ***DIST*** | -0.28** | -0.27** | -0.27** |
| | (0.087) | (0.087) | (0.088) |
| ***MAG*** | 3.03** | 2.46** | 2.97** |
| | (0.968) | (0.966) | (0.974) |
| ***POP*** | 0.14** | 0.11** | 0.15** |
| | (0.055) | (0.056) | (0.057) |
| ***SQKM*** | -0.09* | -0.07 | -0.83* |
| | (0.046) | (0.046) | (0.040) |
| ***FREQ*** | 0.02 | -0.03 | -0.24 |
| | (0.039) | (0.041) | (0.040) |
| ***GDPPC*** | -0.39** | -0.37** | -0.40** |
| | (0.068) | (0.066) | (0.068) |
| ***INEQUALTY*** | 1.67** | 2.42** | 2.15** |
| | (0.443) | (0.486) | (0.489) |
| ***ESTIMATOR*** | *RANDOM* | *RANDOM* | *FIXED* |
| ***Wald Chi-Square*** | 42.41** | 45.74** | 47.28** |
| ***Number of Observations*** | 269 | 264 | 259 |

Notes: Standard errors in parentheses:** and * denote significance at the 5% and 10%, respectively.

***Table 4. Regressions on Earthquake Fatalities (Alternate Measure of Inequality)***

| *Variables* | *(1)* | *(2)* | *(3)* |
|---|---|---|---|
| ***Intercept*** | -5.55** | - 5.50** | - 5.28** |
| | (2.521) | ( 2.570) | (2.592) |
| ***DIST*** | -0.22** | -0.20** | -0.21** |
| | (0.087) | (0.090) | (0.090) |
| ***MAG*** | 2.33* | 1.50* | 2.13** |
| | (0.952) | (0.947) | (0.964) |
| ***POP*** | 0.09* | 0.05 | 0.09* |
| | (0.053) | (0.054) | (0.055) |
| ***SQKM*** | -0.06 | -0.23 | -0.04 |
| | (0.046) | (0.047) | (0.046) |
| ***FREQ*** | 0.04 | 0.14 | 0.02 |
| | (0.038) | (0.037) | (0.037) |
| ***GDPPC*** | -0.27** | -0.22** | -0.28** |
| | (0.060) | (0.060) | (0.062) |
| ***INEQUALTY*** | 0.56 | 0.88** | 0.63 |
| | (0.405) | (0.416) | (0.422) |
| ***ESTIMATOR*** | *RANDOM* | *FIXED* | *FIXED* |
| ***Wald Chi-Square*** | 32.15** | 25.65** | 31.84** |
| ***Number of Observations*** | 269 | 264 | 259 |

Notes: Standard errors in parentheses:** and * denote significance at the 5% and 10%, respectively.

## *Table 5. Descriptive Statistics and Correlations for Preparedness Indices*

***Panel 5a. Descriptive Statistics of Preparedness Indices***

| *Variable* | *Mean* | *St. Deviation* | *Minimum* | *Maximum* |
|---|---|---|---|---|
| ***RSD*** | 0.61 | 0.49 | 0.00 | 1.00 |
| ***IHEE*** | 0.54 | 0.51 | 0.00 | 1.00 |
| ***EPDI*** | 3.70 | 1.76 | 0.00 | 8.00 |

***Panel 5b. Correlations of Preparedness Indices with GDPPC and INEQUALITY***

| *Variable* | *GDPPC* | *INEQUALITY* |
|---|---|---|
| ***RSD*** | 0.39 | -0.39 |
| ***IHEE*** | 0.48 | -0.43 |
| ***EDPI*** | 0.81 | -0.32 |

## *Table 6. Relations between GDPPC, INEQUALITY and Preparedness*

***Panel 2a. GDPPC, INEQUALITY and RSD***

| *Variable* | *RSD=0 Mean* | *RSD=0 Std. Dev.* | *RSD=1 Mean* | *RSD=1 Std. Dev.* | *Difference t-test* |
|---|---|---|---|---|---|
| ***GDPPC*** | 1,112.29 | 1,096.48 | 9,387.64 | 12,179.18 | -8,275.34** (2.13) |
| ***INEQUALITY*** | 45.34 | 10.55 | 38.39 | 6.44 | 6.94** (2.09) |

***Panel 2b. GDPPC, INEQUALITY and IHEE***

| *Variable* | *IHEE=0 Mean* | *IHEE=0 Std. Dev.* | *IHEE=1 Mean* | *IHEE=1 Std. Dev.* | *Difference t-test* |
|---|---|---|---|---|---|
| ***GDPPC*** | 962.36 | 962.56 | 10,698.35 | 12,510.16 | -9,735.99** (2.68) |
| ***INEQUALITY*** | 45.02 | 9.43 | 37.68 | 6.75 | 7.34** (2.31) |

***Panel 2c. GDPPC, INEQUALITY and EDPIX***

| *Variable* | *EDPIX=0 Mean* | *EDPIX=0 Std. Dev.* | *EDPIX=1 Mean* | *EDPIX=1 Std. Dev.* | *Difference t-test* |
|---|---|---|---|---|---|
| ***GDPPC*** | 1,130.25 | 974.20 | 18,248.00 | 17,921.46 | -17,117.75* (2.13) |
| ***INEQUALITY*** | 40.25 | 5.89 | 32.86 | 3.86 | 7.39** (2.34) |

Notes: t-statistics for differences in means are in parentheses; ** and * denote significance at the 5% and 10% levels, respectively.

## *Appendix 1. Description of Primary Data and Sources*

| *Variable* | *Description* | *Source* |
|---|---|---|
| ***Distance*** | Distance between the epicenter and the affected geographic region measured by the square root of the sum of the squares of the depth and surface-distance. | Latitude, longitude and depth of epicenter: NGDC Significant Earthquake Database.<br>Latitude and longitude of affected region: Getty Theasurus of Geographic Names on Line (www.getty.edu). |
| ***Fatalities*** | Number of casualties due to an earthquake. | NGDC Significant Earthquake Database |
| ***Frequency*** | Ratio of the number of 6+ Ritcher scale earthquakes occurring within a country during the period 1900-1959 to 60. | NGDC Significant Earthquake Database |
| ***GDP per capita*** | Real GDP per capita, expressed in constant (1995) U.S. dollars. | World Bank World Development Indicators 2002 |
| ***Inequality*** | Country's initial distribution of the operational holdings of agricultural land, ranging from 0-100, in percentage terms. | Decennial FAO World Census of Agriculture |
| ***Magnitude*** | Magnitude of an earthquake determined from the logarithm of the amplitude of waves recorded by seismographs; measured in Ritcher Scale. | NGDC Significant Earthquake Database |
| ***Population*** | Population of the province(s) affected, expressed in "thousands". | The World Gazetteer (www.world-gazetteer.com), GeoHive (www.xist.org), and Population Statistics (www.library.unn.nl). |
| ***Square Kilometers*** | Land area of the province(s) affected, expressed in "square kilometers". | The World Gazetteer (www.world-gazetteer.com), GeoHive (www.xist.org). |