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EARTHQUAKES AND ECONOMIC GROWTH

by:

Peter Simonsen Fisker



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Earthquakes and Economic Growth

Peter Simonsen Fisker*

March 13, 2012

Abstract

This study explores the economic consequences of earthquakes. In particular, it is investigated how exposure to earthquakes affects economic growth both *across* and *within* countries. The key result of the empirical analysis is that while there are no observable effects at the country level, earthquake exposure significantly decreases 5-year economic growth at the local level. Areas at lower stages of economic development suffer harder in terms of economic growth than richer areas. In addition, the analysis proposes an explanation to the paradox that there is a pronounced negative effect at the regional level while no effect appears at the country level. To this end, the effects of earthquake exposure is investigated not only for the impact zones, but also for areas with an average distance to the epicenter of around 100 km. The results indicate that the decrease in production in one part of a country is (partially) off-set by an increase in production in the surrounding regions.

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Este trabajo examina las consecuencias económicas de los terremotos. En particular, se muestra cómo la exposición a los terremotos afecta el crecimiento económico en los países, y en las regiones dentro de los países. El resultado principal es que aunque no se observan efectos a nivel nacional, la exposición de terremotos sí disminuye el crecimiento económico a nivel local. Las zonas con menores niveles de desarrollo económico sufren más en términos de crecimiento económico que las zonas más ricas. El análisis propone una explicación para la paradoja de que hay un marcado efecto negativo sólo a nivel regional, y ningún efecto a nivel nacional. Para ello, se investiga los efectos de la exposición a los terremotos no sólo en las zonas de impacto, sino también en zonas con una distancia media del epicentro de 100 km en promedio. Controlando por diferencias en el nivel de ingreso medio y efectos fijos a nivel nacional, los resultados sugieren que la disminución de la producción en las regiones afectadas de un país se compensa por un aumento de la producción en las regiones circundantes.

Keywords: Economic growth, natural disasters, spatial distributionJEL Codes: O11 O49 R11 R12

1 Introduction

In the wake of the climate change debate, there has been a increased interest in the empirical relationship between natural disasters and economic growth. It has been claimed that the number of natural disasters will rise and that this provides an economic incentive to invest in climate change prevention.

Earthquakes are useful in examining how economies react to natural disasters for at least two reasons: firstly, since it has so far proved impossible to predict when and exactly where they occur, the variation in exposure to earthquakes can be assumed to be *exogenous*, i.e. unaffected by other determinants of growth. Secondly, the quality of the data on earthquakes is remarkably detailed and reliable. Even though earthquakes are not directly linked to climate change, the results may have implications for the natural disaster literature as a whole since the type of damage they invoke is similar in to that of other disaster types such as hurricanes. Better knowledge of how earthquakes affect the economy could therefore also help policy-makers gauge the consequences of a general increase in natural disasters.

In the context of development economics, a fundamental question is how large a share of donor money should be devoted to relief assistance. To provide an answer, it is important to know how natural disasters affect economic activity. According to most of the existing articles on the macroeconomic impact of natural disasters, earthquakes rarely influence economic growth. There is a consensus, however, that developing countries are generally more vulnerable to natural disasters; more people are killed and more buildings are destroyed in poor areas. But whether natural disasters actually *cause* lower levels of development is still an open question.

When a large earthquake strikes, news agencies often quickly state an estimated *cost* of the disaster based on the number of collapsed buildings and destroyed physical capital. As an example, reconstructing Haiti following the 2010 earthquake is estimated by the Inter-American Development bank to have cost around \$14 billion. These figures, however, only mirror the direct costs of replacing lost physical capital. It is the goal of this study to contribute to the understanding of how earthquakes (and thereby natural disasters in general) more fundamentally affect economic development. In order to do so, the following research question is set up:

What are the effects of earthquakes on economic growth?

From a theoretical point of view, the answers are ambiguous. On the one hand, the destruction of physical capital means that some production units are forced to halt; this affects growth negatively. On the other hand, the immediate need for reconstruction workers and building materials could push aggregate demand much in the same ways as expansionary fiscal policy, contributing positively to growth in GDP. Under different assumptions and circumstances, it will be analyzed which of the two is the dominant effect.

This study contributes to the existing literature in two important respects: firstly, an alternative to the standard source for data on natural disasters is advanced: the *Exposure Catalog* (EXPO-CAT) provided by the U.S. Geological Surveys (USGS).¹ Secondly, in an attempt to identify the *local* economic consequences of earthquakes, the analysis moves beyond the use of countries as units of observation and employs regional income data at the 1×1 latitude–longitude level.

The analysis is structured in the following way. The next section reviews the existing literature on growth and natural disasters. Section 3 shortly examines how earthquakes enter theoretical models of economic growth and section 4 presents four testable hypotheses. Section 5 accounts for the way in which earthquakes are measured in the EXPO-CAT, holding it up against the EM-DAT. Section 6 contains the main econometric analysis and section 7 concludes.

¹As opposed to commonly used *Emergency Disaster Database* (EM-DAT).

2 Literature review

The literature on the effects of natural disasters on growth took a great step forward around 20 years ago with a book called *The Political Economy of Large Natural Disasters* (Albala-Bertrand, 1993). In recent years – possibly due to enhanced availability of data – the interest in empirical research of the subject has experienced a remarkable increase. This section surveys some of the most valuable contributions to the field starting with a brief outline of the main conclusions regarding the effects of natural disasters (and earthquakes in particular) on economic growth. Subsequently, a decomposition of the overall effects is undertaken with special focus on differences based on disaster intensity and the environments in which disasters occur.

2.1 The economic consequences of natural disasters

The existing literature on the economic consequences of natural disasters is surprisingly inconclusive; surprising since all recent studies build their analyses on the same data source and since most studies focus their attention on 5-year GDP growth rates. Some analysts find a positive effect on economic growth, some a negative and many find no evidence of an effect at all.

Arguments for a *positive* effect on economic growth from some or all types of natural disasters can be found in Albala-Bertrand (1993), Loayza et al. (2009), Skidmore and Toya (2002) and Ahlerup (2011).

Albala-Bertrand (1993) is one of the first formal explorations of the eco-

nomic effects of natural disasters using regression methods. It includes a model of disaster occurrence and reaction on a sample of 28 large natural disasters happening from 1960 to 1979 in low- or middle income countries.² Earthquakes constituted around half the incidents with droughts, cyclones, floods and tsunamis counting for the rest. The analysis showed no effect on economic growth from the disasters in the long run, but a slightly positive one in the short-run. The reason for the latter result is supposedly an "endogenous response mechanism" taking place within the country although this is not tested empirically. The study is based on before-after estimation comparing the growth rates of GDP per capita in the country where the disaster hit for two years up until the event with growth rates in the two following years. In combination with the small sample size, the conclusions in Albala-Bertrand (1993) may not be very robust.

Both Skidmore and Toya (2002) and Loayza et al. (2009) find that climatic disasters have a positive impact on growth while geological events (such as earthquakes) do not. Ahlerup (2011) uses disaster frequency as explanatory variable and employs variation in energy released by earthquakes as an instrument, thereby noting the questionable selection process of the commonly used EM-DAT database on natural disasters.

Arguments for a negative effect on economic growth from natural disasters are found in Noy (2009), Cavallo et al. (2010), Raddatz (2007) and Loayza et al. (2009). None of the mentioned studies, however, find evidence that

²With Italy and Australia being the only exceptions.

disasters on average affect growth negatively: Noy (2009) finds adverse effects only for developing countries and only in the short term, Cavallo et al. (2010) limit their study to rare catastrophic events and Raddatz (2007) find that only climatic and humanitarian disasters affect growth negatively.

Loayza et al. (2009) apply a dynamic GMM estimator to a 1961–2005 cross country panel data set in order to estimate the effects of several types of natural disasters on economic growth in different sectors of the economy. Using the EM-DAT, they document a negative effect only for droughts whereas floods on the other hand have a positive impact.

2.1.1 Earthquakes and other geophysical events

Earthquakes belong to the group of disasters termed *geophysical* disasters by the EM-DAT, which, apart from earthquakes, encompasses volcanic eruptions, rockfalls, avalanches, landslides and subsidence.³ Some authors examine the category as a whole while others study the specific disaster types individually. The studies with specific notions about geophysical events include Loayza et al. (2009), Raddatz (2007), Ahlerup (2011) and Horwich (2000).

Earthquakes and other geological events, rarely cause any significant impact on economic growth according to the literature; in fact, among the studies reviewed here, Ahlerup (2011) is the only paper to find a significant effect on aggregate economic growth from earthquakes.⁴ Loayza et al. (2009)

³Subsidence is the downward motion of land surface relative to sea-level

 $^{{}^{4}}$ Resulting from regressing the annual *number* of earthquakes taking place in a country

find that earthquakes generally do not significantly change growth rates; the only exeption being the industrial sector as response to particularly severe earthquakes. Raddatz (2007) also concludes that geological events (such as earthquakes) have no significant impact on growth.

Horwich (2000) represents a completely different approach to the research problem by taking on an in-depth case-study of the economic aftermath of the 1995 Kobe earthquake — one of the most destructive urban natural disaster ever. The worst demolitions happened in a 2 by 20 km zone; all within the metropolitan area of Kobe. Around 200,000 buildings collapsed, 120 of the 150 quays in the port were destroyed and an estimated 5,500 people died. At the time of the disaster, many speculated that the process of recovery would last at least a decade and that the negative consequences for Japan's economy would be enormous. However, Horwich concludes, "less than 15 months later, in March 1996, manufacturing in greater Kobe was 98 percent of its pre-earthquake trend. Eighteen months after the quake, in July 1996, all department stores and 79 percent of shops had reopened ... and complete reconstruction of the port was celebrated after 26 months".

When studying the macroeconomic impacts of the catastrophe, Horwich concludes that, if any at all, the effect on the Japanese economy had been positive. 1995 saw a significantly higher growth rate than any of the preceding years in that decade. Also, the price level was stable, real balances rose and — contrary to what would normally be expected from a leftward shift on growth.

of the aggregate supply curve — interest rates fell.⁵

2.2 Differential effects

Whereas the average effect on economic growth from natural disasters is subject to dispute, researchers seem to agree that the effects are different for different disasters and in different circumstances. Fundamentally, there are two dimensions on which the effects of natural disasters differ:

- 1. *Disaster intensity:* Larger natural disasters entail harder consequences than smaller ones. Sometimes these consequences are found to be disproportionately larger.
- 2. Economic and institutional environment: The seriousness of natural disasters depends on the income level of the area they hit. Also, the economic consequences depend in large part on how the recovery process is administered at the societal level. Therefore both the effectiveness and the responsiveness of political system need to be taken account of.

2.2.1 Disaster intensity

It is common to assume that some sort of scaling is needed when analyzing natural disasters. In the oft-preferred database, EM-DAT, three indicators for disaster intensity are available: number of affected, number of killed or estimated economic damages. These figures are then scaled by the researchers

⁵Possibly due to the fact that the supply curve did not, move much to the left because the Japanese economy was in a recession with unexploited production capacity.

in relation to country population or GDP, in order to be able to argue for a linear relationship between e.g. the percentage of the population affected and the effect on economic growth.

A few research papers consider the possibility that the economic consequences of disasters do not increase linearly with the observed impact measure. They speculate that whereas most of the moderate to large natural disasters have no detectable effect, catastrophic events must decrease growth rates significantly. Some build their argument around counteracting forces that allow countries to grow faster when exposed to natural disasters up until a point where the effect turns negative.

Loayza et al. (2009) use as their intensity indicator the number of affected as percentage of a country's population. In order to test for potential non-linearities, they construct a dummy variable indicating that a certain occurrence is part of the top ten percent of a specific type of natural disasters according to intensity. This dummy-variable is then interacted with the intensity of the natural disaster and added to the growth regression. It turns out that moderate earthquakes exert a positive effect on the industrial sector, while severe earthquakes, on the other hand, decrease industrial growth. Severe events, it is claimed, are so devastating that the loss of capital cannot be compensated by increasing capacity, thus dissipating the potential gains.

Cavallo et al. (2010) focus exclusively on *catastrophic* natural disasters defined as incidents where at least one person is reported killed. They investigate the effects of disasters at the 99^{th} , 90^{th} and 75^{th} percentiles in terms of

number of persons killed and compare growth in countries hit by these disasters with growth in countries belonging to synthetic control groups. They conclude that only *extremely* large events (belonging to the 99th percentile) have a negative impact on growth — and only because they usually spur social unrest and political changes. It should be noted, though, that no more than 10 events belong to the 99th percentile.

In sum, there is some evidence suggesting that the effects of earthquakes and other natural disasters change when they become extreme. However, estimates of these effects could potentially suffer from small sample bias.

2.2.2 Economic and institutional environment

Just as it is generally assumed that the effects of natural disasters change with magnitude, all of the studies reviewed in this section seem to agree that developing countries are more vulnerable to disasters than developed countries. The devastation of Haiti due to the January 2010 earthquake represents a stark contrast to the February 2010 earthquake in Chile which was of a higher magnitude and also hit a densely populated area but caused much less destruction. Cavallo and Noy (2009) note that "these dissimilar outcomes originated from different policies, institutional arrangements and economic conditions". Or, as Horwich (2000) puts it:

A quake that kills 1,500 in San Salvador would only rattle the china in San Francisco. Papers that explicitly emphasize the aspect of *economic* conditions include Albala-Bertrand (1993), Loayza et al. (2009), Noy (2009), Strömberg (2007), Kahn (2005) and Skidmore and Toya (2007). The four last-mentioned likewise discuss the role of *institutions*, as do Cavallo et al. (2010) and Horwich (2000).

Noy (2009) concludes that developing countries and smaller economies face much larger output declines following a disaster of similar relative magnitude than do bigger, or more developed countries. A number of potential explanations for this result are mentioned, all circling around countries' ability to mobilize resources for reconstruction: literacy rate, institutions, per capita income, degree of openness to trade and levels of government spending.

Strömberg (2007) compares a sample of high-income and low-income countries of about the same size and exposure to natural disasters. The groups differ in both their respective average GDP per capita and their average score on the the *Polity IV* democracy index.⁶ The study finds that during the period 1980–2004, around twelve times as many died from natural disasters in the low-income group than in the high-income. Further, controlled for income level, more democratic countries apparently see more fatalities than less democratic countries — a result probably explained by more complete reporting by democracies.

Skidmore and Toya (2007) use time series data to investigate whether human and economic losses from natural disasters are reduced as economies

 $^{^6\}mathrm{Average}$ GDP per capita: 23,021 vs. 1,345. Average Polity IV score: 9.5 vs. 3.2

develop. They find evidence in the EM-DAT that there is a significant negative correlation between GDP per capita and both the number of killed and economic losses as percentage of GDP.

Despite not being an economic research paper, Allen et al. (2009) is interesting because it is the only published paper to have used the EXPO-CAT in a formal cross-country analysis, although not concerning economic growth. The authors derive country specific earthquake vulnerability rankings (a ratio between observed deaths and predicted deaths from a model based on earthquake intensities) and find that these are highest in Yemen and lowest in the United States, generally replication the pattern that vulnerability decreases with income.

Horwich (2000) agrees that disasters are a product of economic development; the 1995 Kobe earthquake was an extreme event, yet most of the larger (and newer) constructions survived. In a similar urban setting, but in a poor country, the same geophysical event would probably have had a way larger negative effect on both local and aggregate economic activity.

All in all, the conclusion reached by Albala-Bertrand (1993) does not seem to have changed much in recent years: "Disasters are primarily a problem of development, but essentially not a problem for development"; disasters cause more damage in developing countries but do not themselves cause lower levels of development.

I now turn to the articles that consider the role of political institutions in determining the vulnerability to natural disasters. Kahn (2005) finds that democracies and nations with higher quality of institutions generally suffer less death from natural disaster. In a regression analysis he uses $\ln (1 + deaths)$ as dependent variable and a large set of variables measuring political institutions as explanatory variables: average protection against expropriation risk, democracy, regulatory quality, voice and accountability, rule of law and control of corruption. All indicators show negative signs (i.e. better institutions causing fewer deaths) and fairly small standard errors controlled for real GDP per capita, disaster frequency and magnitude. Kahn also chooses to instrument his measures of institutions by settler mortality rate (as in Acemoglu et al. (2001)) and national legal origins (as in La Porta et al. (1999)) finding qualitatively similar results as with the OLS estimates.⁷

The stated reason why democracies experience fewer casualties from natural disasters is that democracy entails political accountability "so that the government takes proactive steps to adapt to such shocks and to mitigate their impact when they do occur". By taking such ex-ante and ex-post actions, the politicians increase their chance of getting re-elected; incentives that are less urgent in totalitarian regimes. The findings of Kahn (2005) somewhat contradicts those of Strömberg (2007) who maintains that democracies on average report more deaths from natural disasters than authoritarian regimes. Both papers use the EM-DAT to calculate fatality-rates and the POLITY-index

⁷Perhaps not surprisingly, since, if places with fewer natural disasters inherently develop societies with better institutions (i.e. due to fewer negative shocks to the development process), this factor might also affect settler mortality rates and thus where colonists chose to settle down permanently. In other words, these instruments might not altogether satisfy the exclusion restriction.

to compare levels of democracy across countries.

Skidmore and Toya (2007) reach the conclusion that smaller governments (i.e. countries where government consumption as a percentage of GDP is lower) experience fewer deaths and less economic damage from natural disasters. They concur that a larger government may translate into greater public assistance, but also note that it may be *"less responsive and less efficient at handling disaster response initiatives"*.

Whether natural disasters cause more human and economic damage in less democratic countries is a popular topic that is also brought up by Cavallo and Noy (2009). This study distinguishes explicitly between ex-ante insurance and ex-post disaster financing, finding that even consolidated democracies such as the United States under-invest in precautionary measures. Among the problems with ex-ante insurance coverage for natural disasters are huge uncertainty about potential losses, highly correlated risks (at least within regions) and moral hazard.⁸ Political reluctance to insure against natural disasters is caused by a disincentive to incur costs today and possible payoff in an undetermined future. On the other hand, "since governments are typically held accountable for their **response** to disasters, they have strong incentives to massively invest in **ex-post** assistance".

This tendency to resort to disaster response instead of prevention is likely to diminish, the more democratic a society is. As an example Japan (a

⁸Refers to the situation where people or local governments living in disaster prone areas will reduce their own willingness to invest in safety because they know the central government will assist them anyways.

country that scores the highest possible value on the *Polity IV* index) has passed several strict laws since the 1960's to ensure that all new constructions are earthquake-proof, whereas Indonesia (a relatively new democracy also plagued by many earthquakes) passed its first disaster prevention law in 2007 — three years after the devastating Indian Ocean tsunami.

Finally, the aspect of government responsiveness is discussed thoroughly in the case study by Horwich (2000). The immediate efforts to provide emergency infrastructure by the government were crucial to the reconstruction of Kobe; in two days, most of the 300,000 homeless were re-accommodated and later temporary housing was constructed for the families that couldn't return to their homes. But bureaucracy and a monopolistic approach to the provision of infrastructure such as heating, water, electricity etc. slowed the process down. Interestingly, the Kobe authorities at first rejected any foreign assistance, but following pressure from the media and the central government, they yielded and let the foreigners participate. This indicates that strong, yet democratic, authorities with both the capacity to act and will to be responsive, are to be preferred during the reconstruction phase following a major earthquake.

In sum, the literature agrees that institutional capacity has *some* intermediating effect on how earthquakes affect the economy. Most concur that more democratic institutions lead to both higher responsiveness and more ex-ante insurance. Some authors, however, withhold that democratic institutions sometimes entail rigid bureaucracy that could in principle be an obstacle to the provision of relief assistance and reconstruction.

2.3 The spatial distribution of economic consequences

If one area of a country is hit by a natural disaster, it might lead to very different consequences in other parts of the country; a decrease in production in one place due to a natural disaster could mean higher demand for goods and services elsewhere. Researchers have become more aware of this spatial element since the thorough account of the Kobe earthquake by Horwich (2000) — However, it has so far not been treated formally in a cross-country set-up.

Horwich explains the city of Kobe's "phenomenally rapid" recovery with three mechanisms of substitution that take place in a modern economy: First, he argues, labor and physical capital are to a certain degree substitutable and a large negative shock to the stock of physical capital could then open up for a higher demand for labor in order to maintain production output. Second, increased use of energy could substitute for disrupted capital (i.e. extra heating in buildings where the walls now have holes in them) and lastly, and most interesting in this context, spatial resource substitution could occur: "among these substitutions in Kobe were the transfer of its port business to other ports, the shift of output of large manufacturing companies to plants in other locations, and the replacement of both large and small manufacturers' output by that of firms outside the earthquake zone".

The fact that surrounding areas were at all able to increase production

dramatically in order to fill the imminent gap between supply and demand in the city of Kobe as well (as the fact that the workers of Kobe were able to supply more hours of labor) apparently helped reconstruction greatly. To this end, it may well have been a blessing in disguise that the Japanese economy had been facing a slowdown since around 1990 and that especially the industrial sector in the Kobe region had seen a decline.

2.4 Shortcomings of the existing literature

The following is an attempt to briefly identify some of the limits of the studies contained in this review. Firstly, the use of before-after-methods is questioned; secondly the focus is turned to the shortcomings of more recent, regression based analyses.

According to Noy (2009), virtually *all* empirical studies on the economics of natural disasters before the end of the nineties were based on before-after univariate analysis of a small sample of disasters chosen by the authors. To see the limits of this methodology, consider natural disasters as a special type of *treatment*, the effects of which must be evaluated in order to conclude what is the outcomes on the subjects to the treatment, in this case countries. Having access to panel data, one way to evaluate the effects of such a treatment is to make use of the before-after estimator that compares outcome variables for an observation before and after treatment. Using expectation operators, the assumption required in order to identify a causal effect is:

$$E(y_{0,it}|w_i = 1) = E(y_{0,it-1}|w_i = 1)$$
(2.1)

Where $y_{0,it-1}$ is the outcome value before treatment, $y_{0,it}$ is the counterfactual outcome for no treatment and w is a treatment-indicator. If the outcome we observe is per capita growth in GDP and the treatment is an earthquake, it is in other words assumed that per capita growth in GDP would have been the same before and after the earthquake, had it not occurred. Especially given a small sample size and a limited set of control variables, this assumption seems implausible.⁹

Most recent papers on the economic impacts of natural disasters use cross-country panel data regressions on relatively large samples. Methods incude OLS (Skidmore and Toya, 2007), GMM (Loayza et al., 2009) and 2SLS (Ahlerup, 2011). Cavallo and Noy (2009) encapsulate the recent literature by generalizing the estimated models of these studies. A widespread specification is:

$$Y_{it} = \beta_0 + \beta_1 D_{it} + \beta_2 X_{it} + u_{it}$$
(2.2)

⁹The problems with this methodology are illustrated in the study of Card (1990) who went on to investigate the effects of a sudden large-scale immigration of Cuban workers in 1980 on unemployment in Miami. By using the before-after estimator, it would be concluded that, since unemployment rose dramatically from 1979 to 1981, the influx of Cubans must have had a negative effect on employment. However, comparing the development in Miami with a control group consisting of other cities of Florida during the same period, he found no evidence of the immigration having a negative effect on the labor market (Angrist and Pischke, 2008).

Where the left hand side is a measure of economic performance (typically real GDP per capita in country i at time t), D is the explanatory variable of interest denoting a relevant natural disaster indicator (e.g. a binary indicator, count variable or a measure of disaster magnitude), and X is a vector of control variables expected to affect growth. On top of this, country dummies as well as interaction terms between the disaster measures and factors such as income and political institutions are often included. Continuous impact variables are typically transformed logarithmically in order not to assign too much weight on extreme events.

Though the quality of the econometric attempts to establish causality have improved, two major shortcomings prevail throughout the present literature:

- 1. It is almost entirely built on data from the EM-DAT, that may suffer heavily from skewed indicators and selection bias.
- 2. It focuses solely on effects at the country level.

The former issue will be illustrated in more detail in section 5. The latter constraint is probably a consequence of data availability. One way to mitigate this is to conduct case-studies like that of Horwich (2000). While this approach can be extremely informative, it has the obvious hitch that it only concentrates on a single event and the results therefore might not be generalized.

The finding of Loayza et al. (2009) that floods are estimated to have a

large positive effect on the growth of all sectors of the economy — even agriculture — serves to illustrate the shortcomings of studying natural disasters at the country level. As mentioned by the authors, "Too much water is clearly damaging. Yet, when floods are localized, and if they are also associated with plentiful supply of water nationwide which would positively affect agriculture including through the collection of irrigation water, the latter effect may well outweigh the former, resulting in a positive overall effect of floods on agricultural growth". No studies have so far attempted to conduct regression based research of the economic consequences of natural disasters at a larger scale using sub-national units of observation.

3 Theoretical framework

If and how earthquakes affect economic growth is essentially an empirical question. However, it might be helpful to consider what economic theory would predict if earthquakes enter the equations.

Central to most economic growth models is a production function that describes how different input factors contribute to final output. A formal representation could look something like:

$$Y = F(K, L, H, A) \tag{3.1}$$

where Y is output, K is physical capital, L is labor, H is human capital and A is a measure of technology (or total factor productivity).

By and large, earthquakes destroy physical capital but usually leave labor and human capital relatively unaffected. Technology must also be assumed unaffected, unless it is thought to be embedded in the capital goods destroyed by an earthquake. Figure 3.1 illustrates the effects of an exogenous negative shock to the capital-labor ratio in a simple Solow model.

Destruction of physical capital will lead to short run deviations from the steady state path, but insofar technological change is assumed to be exogenous, effects on long-run growth do not appear. When an earthquake hits, production will jump to a lower level, followed by a period of growth driven not only by the exogenous rate of technological change, but also transition towards the steady state. Based on the Solow model, it is therefore expected

Figure 3.1: Earthquakes in the Solow model



Notes: y = Y/L, k = K/L, s is the savings rate, n is the population growth rate and d is the rate of depreciation of capital. An earthquake decreases the capital-labor ratio exogenously from k^* to k_1 generating a drop in output followed by a period of positive transitional growth towards the steady state.

that exposure to earthquakes during a five year period on average affects growth over the same period negatively.

In principle, earthquakes could also affect total factor productivity, A; either negatively by the destruction of capital goods with embedded technology or positively by letting firms replace old hardware with newer technologies. The former argument could apply to AK-style endogenous growth models where technology exhibits increasing returns to capital (i.e. large amounts of capital needed for innovations); the latter is essentially the idea behind Schumpeterian creative destruction. In any case, these effects apply mostly to long-run growth and are therefore not expected to shine through here.

4 Hypotheses

Based on the existing empirical studies in combination with the mechanics of the simple economic growth model described above, in this section the expectations formed about the effects of earthquakes on economic growth are boiled down to four hypotheses:

- i On average, earthquakes cause little to no effect on economic growth at the country level.
- ii At the regional level, earthquakes induce a negative effect on growth locally and a positive effect in the surrounding regions.
- iii The effect of earthquakes depends on their intensity.
- iv The effect of earthquakes depends on levels of income and institutional quality.

The first hypothesis follows directly from the literature reviewed in section 2 and is backed by two considerations: firstly, many countries are simply too large to be significantly affected by earthquakes; secondly, even in smaller economies, the effects of earthquakes are ambiguous — the collapse of buildings might halt production whereas increased demand for materials and skilled labor during the reconstruction phase might lead to faster growth.

The second hypothesis originates from the ideas of spatial substitution advanced by Horwich (2000). Production units will, if the earthquake is strong enough, be forced to relocate to other parts of the country. Likewise, skilled and unskilled workers from within a certain radius are likely to contribute to the reconstruction, and finally, demand for goods produced in areas not directly affected could rise if locally produced goods become unavailable. All of this means that at a radius of around 100 kilometers from the epicenter of an earthquake, it is expected that economic activity will rise as a consequence of the event.

Hypothesis *iii* states that the effect of earthquakes depends on their intensity. As the size of the disaster increases, so does the number of collapsed buildings thereby reducing the production capacity of businesses in the affected zone. However, a decrease in production capacity is not the only effect earthquakes cause on the economy. At lower intensity-levels, the ground shaking is mostly non-destructive (cracks in walls, damaged windows etc.) and the sudden increased demand for reparations could actually influence growth positively. It might be the case that for smaller earthquakes this effect is the dominant while it is off-set by a decrease in production when a disaster reaches a certain level. In other words, how economic growth is affected by earthquakes changes with their intensity — and not necessarily in a linear fashion.

The last hypothesis claims that for given intensities, earthquakes affect the economy differently across different stages of economic and institutional development. Richer countries are expected to see more positive effects from earthquakes because they are better able to provide (private or public) relief aid and undertake rapid reconstruction than poorer countries. Wellfunctioning credit-markets and infrastructure are traits of development that are imperative when it comes to bringing a disaster zone back to normal.

Differences in the quality of institutions could also affect the economic consequences of natural disasters. Governments need to be both efficient and responsive towards the needs of the victims in order to facilitate reconstruction. Also, preventive legislation such as high construction standards in earthquake prone zones is expected to be more likely in countries with democratic institutions while ex-post relief can be a manner of winning sympathy in all kinds of regimes.

5 Measuring earthquakes

This section presents the data that will be used to examine the economic effects of earthquakes. It begins with a critique of the data chosen by most of the studies reviewed in section 2 and is followed by a presentation of the basis for this analysis: USGS' catalog of earthquake exposure, the EXPO-CAT.

5.1 Vices of the EM-DAT

The EM-DAT is a huge database created by the Centre for Research on the Epidemiology of Disasters (CRED) at the University of Louvain in Brussels.¹⁰ It comprises natural disasters classified into five groups: geophysical, meteorological, hydrological, climatological and biological disasters. Every group can then be divided into smaller groups; as an example, the geophysical group includes ground shaking, volcanic eruptions, rockfalls, avalanches, landslides and subsidence.

Ahlerup (2011) criticizes the database for counting too many, too weak natural disasters and calculates that the median reported economic damages is zero percent of GDP among countries where a natural disaster has occurred. Among countries that have reported *positive* economic damages the median is 0.05 percent of GDP. The median *human* loss among countries in which natural disasters occurred is 0.0002 percent of the country population

 $^{^{10}}$ www.emdat.be.

and at the 99th percentile the loss is only 0.022 percent (in the full sample). This should indicate that the larger part of the natural disasters contained in the database are too minuscule to affect a country's aggregate economic development.

The skewness of the indicators is not, however, the main headache for empiricists who want to conduct econometric analyses on the basis of the EM-DAT. Rather, the obtained estimates could be biased due to non-exogenous selection criteria. For a disaster to be included in the database, at least one of the following criteria must be fulfilled:

- Ten or more people reported killed
- Hundred or more people reported affected
- Declaration of state of emergency
- Call for international assistance

None of these are completely independent to other factors that plausibly also affect economic growth. Both Kahn (2005) and Strömberg (2007) demonstrate that more people are killed in developing countries than in developed countries by similar kinds of natural phenomena. Poorer countries might also have an incentive to inflate the reported number of people affected in order to attract international assistance; different political regimes might follow different procedures when declaring a state of emergency, and finally, more calls for international assistance would be expected from countries that are less capable to manage a disaster situation internally. Further, Strömberg (2007) shows that the number of natural disasters in the database not only differs substantially across levels of income and polities, but also that the number of disasters increases dramatically over time — while at the same time the total number of fatalities from natural disasters decreases over time.

Most existing studies using the EM-DAT condition on at least the level of income and institutional quality; more uncommon is the use of time dummies (to catch the effect of more complete reporting over time). Estimated effects are likely to suffer from selection bias since there is a great risk that selection is based on omitted variables. It becomes even more suspect if countries that are systematically over-reporting the number of natural disasters do so deliberately because they expect there to be some sort of benefit to it.¹¹ Finally, the measures for economic losses are specifically problematic since these rely almost entirely on self-reporting (Ahlerup, 2011).

5.2 Virtues of the EXPO-CAT

This section explores in detail the EXPO-CAT database constructed by the U.S. Geological Survey (USGS). It is a combination of the Prompt Assessment of Global Earthquakes for Response-Catalog (PAGER-CAT), the ShakeMap Atlas and the Oak Ridge Laboratory's Landscan 2006 global population database (Allen et al., 2009). The catalog lists all earthquakes that have hit inhabited areas of the planet (i.e. not open sea, Antarctica etc.)

¹¹This is sometimes referred to as *sorting gain* (Angrist and Pischke, 2008).

between 1973 and 2007 and have been recorded to have a magnitude of at least 5.5.

There are two overarching reasons why the EXPO-CAT is better suited for econometric analysis than the EM-DAT. First, the selection process by which events enter the catalog is based on objective criteria, and second, since population density is always associated with economic activity, the key figure (the number of people affected at different intensity levels) is a very precise indicator for how much earthquakes affect the economy.

In the following it will be discussed first what is meant by *instrumental intensity* and why this is the best indicator for the strength of earthquakes when attempting to measure their effects on the economy. Secondly, the different steps in creating the EXPO-CAT are presented thereby providing an overview of selection criteria and methods.

5.2.1 Magnitude or instrumental intensity?

When news agencies report from earthquakes, the first two pieces of information typically given are the moment magnitude (or just magnitude) and the location of the epicenter. The epicenter is the point on the surface of the Earth vertically above the hypocenter (or focus), which in turn is the point of initial rupturing within the Earth. The distance between the epicenter and the hypocenter is the depth of an earthquake. The moment magnitude is the reported decimal number that tells something about the size of the earthquake. Earlier, another measure called the Richter Scale was used and this name is still often used misleadingly when actually referring to the moment magnitude. Except for very large earthquakes the moment magnitude and the old Richter Scale are equivalent, though. The magnitude scale is logarithmic; the amount of energy released during a M6.0 earthquake is approximately ten times as great as during a M5.0 earthquake (Keller and Blodgett, 2006). Table 5.1. lists the average annual number of earthquakes at different magnitudes and shows that the average annual number of events decreases dramatically with magnitudes.

Magnitude	Average annual number of events
≥ 8	1
7 - 7.9	17
6 - 6.9	134
5 – 5.9	1319
4 - 4.9	13,000
3 - 3.9	130,000
2 – 2.9	1,300,000 (approx. 150 per hour)

Table 5.1: Magnitudes and frequencies of global earthquakes

Source: Keller and Blodgett (2006)

Whereas the magnitude of an earthquake is determined by the size of the underground rupture, the type of fault and the rigidity of the rocks near the hypocenter of the earthquake, its *intensity* is related to how an earthquake is *felt* on the surface. To see why the intensity is more relevant than magnitudes, imagine two different earthquakes with the same magnitude but different depths: the deeper earthquake will feel lighter at the surface than the shallower one.

There are basically two types of intensity measures: the *Modified Mercalli* Scale contains twelve categories each with a description of how people on the ground perceived the ground shaking and the extent of observed damage to structures. This, as opposed to the moment magnitude scale, is not an objective measure of the destructive capabilities of an earthquake. It is, however, a good measure for how much assistance is needed in the wake of the disaster.

The other measure of intensity, namely *Instrumental intensity* is used to describe the *potential* damage in different surface locations around the epicenter of the earthquake. As opposed to the more subjective Modified Mercalli scale, the instrumental intensities are derived entirely from exogenous factors. It is either estimated on basis of output from on-ground seismic equipment or estimated from the depth of the hypocenter, geological conditions and the direction and type of the fault line.

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	1	-	IV	V	VI	VII	VIII	IX	X+

Table 5.2: Peak ground acceleration and instrumental intensities

Source: http://earthquake.usgs.gov/earthquakes/shakemap/

Appendix B includes a so-called ShakeMap of a recent earthquake in Turkey provided by the USGS. The legends beneath the map (also depicted in table 5.2) contain information on the different levels of instrumental intensities depicted on the maps. Each ladder on the 9-point scale is associated with an interval of *peak ground acceleration*. For example, an area of the ground that is estimated to have been shaken with a velocity of 8.1-16 centimeter per second is normally (in seismological terms) perceived as *strong* shaking, causes *light* potential to damage structures and would usually correspond to VI on the Modified Mercalli Scale.

5.2.2 PAGER-CAT and ShakeMap Atlas

The foundation of the EXPO-CAT is the PAGER-CAT: a database containing detailed information on hypocenters, timing and magnitudes for over 22,000 earthquakes since January 1900 enlisted from eight recognized global earthquake catalogs. Since 1973 information has been gathered by the USGS's own *Preliminary Determination of Epicenters*, which has estimated around 540,000 events up until 2007.¹² The PAGER-CAT contains no information that could not be obtained elsewhere, but aggregates the best information from different sources into a comprehensive digital format (Allen et al., 2009).

The ShakeMap Atlas is a publicly available collection of maps (also provided by the USGS) showing the distributions of instrumental intensities for around 5,650 earthquakes taking place between 1973 and 2007. It combines point ground shaking observations (by seismic equipment) with ground

¹²This program was initiated mainly for political reasons since the seismologists at the USGS were able to pick up when and where the Soviet Union was conducting nuclear tests.
motion predictions to produce a *spatial shaking distribution for each event* (Allen et al., 2009). Since the vast majority of the incidents recorded in the PAGER-CAT have no potential of causing damage whatsoever, the creators of the ShakeMap Atlas (Allen et al., 2008) chose to reduce the number of observations by around two orders of magnitude. The criteria for selection of events into the atlas are as follows:

- 1. The earthquakes must have a minimum recorded magnitude of M5.5; for earthquakes taking place in stable continental regions, however, this requirement is relaxed to M4.5.
- At least 3,000 people must have been exposed to the earthquake at an intensity level of VI or greater.¹³
- 3. All earthquakes with a depth exceeding 100 km are removed, except those that resulted in casualties.
- 4. For earthquakes with magnitudes less than M6.5, events with hypocentral depths of more than 45 km are removed, except those that resulted in casualties.

In order to avoid sample selection bias in this study, all earthquakes with depths greater than 45 km for M < 6.5 and 100 km for the remainder are removed. This way the selection criteria are solely based on natural phenomena. This effectively reduces the sample to around 4,200 observations.

¹³The methods for estimating population exposure are similar to that of the EXPO-CAT described below except that population densities in this case are not discounted back in time.

5.2.3 The Exposure Catalog

As a further development of the ShakeMaps Atlas, the USGS created the Exposure catalog (or EXPO-CAT) in order to be able to asses the potential human and physical damages of earthquakes almost instantaneously. The database estimates the number of people exposed to discrete levels of instrumental intensities by combining the ShakeMaps Atlas with figures for population densities obtained from the *Oak Ridge Laboratory's Landscan 2006 global population database*.¹⁴ These present-day population densities are then discounted back to the year of the earthquake using UN estimates for population growth rates and the following equation:

$$E_h = \frac{E_p}{(1+r)^T} \tag{5.1}$$

where E_h is the calculated historical exposure, E_p is present (hypothetical) exposure, r is the population growth rate provided by the UN and T is the number of years between the event and mid 2006. Instead of the standard instrumental intensity scale with 10 levels, population exposure in the EXPO-CAT is divided into 20 categories each representing half a unit of instrumental intensity. This increases the precision of the estimates (Allen et al., 2009).

A minor concern with the EXPO-CAT is that the method for population hindcast might be too simple; it doesn't take into account intra-country population movements between the earthquake and 2006. In particular, urban

¹⁴http://www.ornl.gov/sci/landscan/

areas in growth economies are likely to have seen the largest increases in population densities since 1973.



Figure 5.1: Frequencies of global earthquakes and number of exposed

Source: Own calculations based on EXPO-CAT (Allen et al., 2009) and Penn World Tables (Heston et al., 2011) *Notes*: The data underlying the right-hand figure is the sum of people exposed to *any* level of intensity of at least one of the earthquakes included in the sample during a specific year.

As can be seen from figure 5.1, there is a small tendency that the number of observed earthquakes per year has increased since 1973. However, when looking at exposure relative to the world population, there is no trend to be observed. It should be stressed that the increase in the number of observed earthquakes is not related to improvements in the measurement of earthquakes; during the period, the USGS has been using the same method to record earthquakes and the criteria for inclusion in this sample are constant over time: a magnitude of at least 5.5 and at least 3,000 people exposed (measured by present-day population densities).

6 Econometric analysis

In this section, the EXPO-CAT data is combined with measures of per capita income in order to test hypotheses i - iv empirically. In the first part of the analysis, a 1973–2007 panel of countries is analyzed so as to test hypothesis i; later, relating to the second hypothesis, the focus will be turned to the subnational level over the period 1990–2005.¹⁵

In both cases, several specifications will be considered in order to investigate the differential effects foreseen by hypotheses iii - iv — and as a means to check the robustness of the results. Most notably, throughout the analysis, the theoretical relationship between income and earthquakes assume two different forms: In the basic model, income is perceived to be a function of a number of socio-economic variables, an unobserved country-specific effect and a common trend. The alternative model is based on the assumption that income is *autoregressive* (or *dynamic*), i.e. dependent on lagged realizations of itself. This is common in empirical growth models since it allows controlling for the effects of conditional convergence; however, identification becomes more complicated.

The analysis proceeds as follows: section 6.1 outlines the empirical strategy and how to identify the effect of earthquakes on economic growth at the country level. Section 6.2 reviews the data sources and section 6.3 presents the primary set of results. In section 6.4, the robustness of the results are

¹⁵The former will be referred to as the *country level* and the latter the *cell level* analysis.

put to the test, and in section 6.5 the analysis is repeated at the subnational level.

6.1 Empirical strategy

The following sets up the framework for an empirical investigation of the effects of earthquakes on country level economic growth. Firstly it is stated how earthquakes enter a structural equation of the determinants of per capita income. Secondly it is discussed how to obtain valid estimates of the effect of earthquakes on economic growth using *ordinary least squares* (OLS). In doing so, the risk of omitted variables bias as well as potential parameter heterogeneity will receive special attention.

The basic theoretical relationship between income and earthquakes can be expressed by the following equation using panel data:

$$y_{it} = \beta Q_{it} + \gamma' X_{it} + \mu_t + \eta_i + \epsilon_{it} \tag{6.1}$$

Where the subscripts *i* and *t* represent country and time period respectively. *y* is real PPP-adjusted GDP per capita, *X* is a vector of control variables, and \tilde{Q} is a measure of earthquakes.¹⁶ The unobserved country-specific effects, η_i , reflect differences in the initial productivity among countries whereas μ_t captures a trend common to all countries. η_i and μ_t may also represent the country-specific and period-specific components of measurement error. ϵ_{it} is

 $^{^{16}}$ The measure of earthquakes entering the structural equation could be seen as the *stock* of earthquake exposure (defined in section 6.2) accumulated in a country up until year t

an error term.

By taking logs (suppressed) and *first-differencing* equation 6.1, it is possible to obtain a specification for economic growth expressed by the change in the logarithm of per capita income between two periods:

$$\Delta y_{it} = \beta Q_{it} + \gamma' \Delta X_{it} + \mu_0 + e_{it} \tag{6.2}$$

The deltas indicate the subtraction of the value in period t - z from the value in period t.¹⁷ Compared with equation 6.1, μ_t turns into a constant term, and the time-invariant country-specific effect η_i disappears, since it is constant over time. e_{it} equals $\Delta \epsilon_{it}$ and is thus first-order serially correlated by construction. In this set-up, Q is the amount of *earthquake exposure* occurring in country i between period t - z and t. β is thus the parameter of interest: the effect of earthquake exposure on economic growth.

In the structural equation (6.1), β would not be identified by the OLS estimator since it would not be possible to separate the effects on GDP per capita caused by variation in Q from the unobserved country-specific effects. In equation 6.2, on the other hand, these country-specific effects have been differenced out, and the regression is expected to yield consistent estimates of β insofar e_{it} is orthogonal to Q_{it} conditional on ΔX_{it} . In order to substantiate this last condition, the next step is to consider the elements of X.

¹⁷In most of the regressions of this analysis, z = 5

6.1.1 Control variables

With the goal of reducing the potential for omitted variable bias in OLSestimates, it is common to include in regressions a number of variables that influence economic growth. Per capita income is determined by a large amount of economic variables: investment rates, capital-labor-ratio, openness to trade, etc. If these factors were to be included in a growth regression, they would explain a large part of the cross-sectional variation in growth rates. However, as is argued by Acemoglu (2009) among others, variation in factors that affect growth in the short run is often caused by more fundamental determinants that explain why some countries end up richer than others. Since it is not the aim of this study to explain as much as possible of the variation in growth rates, but merely the impact of earthquakes, these are the ones sought accounted for here. As a bonus, a limited set of control variables helps maintaining parsimony and a large sample size.

The three most important fundamental causes of differences in income and growth are geography, culture, and institutions. Geography undoubtedly affects income levels, but when considering the causes of 5-year growth rates over the 1973–2007 period, this group of explanations is ruled out since it varies very little over time. In other words, geographic indicators such as climate, elevation or average distance to the sea are assumed not to affect growth above and beyond its influence on the initial productivity, η_i . The same arguments hold for cultural differences such as religion, albeit these are more likely to differ over longer periods. Institutions, however, have changed considerably in many countries since 1973. Institutions are commonly defined in the economic literature as "the rules of the game in a society or, more formally, the humanly devised constraints that shape human interaction" (North, 1990). By this broad definition, anything from written-down constitutions to vague perceptions of corruption is referred to as institutions. According to the proponents of the institutions hypothesis, there are many channels through which changes in the quality of institutions affect economic growth: people's incentives to work, companies' incentives to invest, the provision of the right amount of public goods, etc.¹⁸

6.1.2 Differential effects

One of the lessons learned from the studies reviewed in section 2 is that the effects of natural disasters generally differ along two dimensions: the characteristics of the societies in which they occur and the scale of the disaster. The latter is partially dealt with by the construction of the earthquake exposure index (see next section); only if the economic consequences of earthquakes vary in a non-linear fashion, the specification needs to be altered.¹⁹ The former dimension, however, is equally important to keep in mind in order to identify β correctly and will be treated below.

 $^{^{18}}$ The debate on the effects of institutions on economic growth intensified a decade ago with *The Colonial Origins of Comparative Development* (Acemoglu et al., 2001), supported by e.g. Rodrik et al. (2002) and criticized among others by Glaeser et al. (2004) who emphasize the role of human capital.

¹⁹These considerations are taken up in section 6.4.2.

As discussed by Horwich (2000), the effect of an earthquake depends on government effectiveness and responsiveness since these factors play huge roles in the reconstruction process. Especially the provision of immediate relief aid and the ability to coordinate foreign aid by the central or local governments can significantly alter the final outcomes of an earthquake. In order to check whether earthquakes generally cause more harm to the economy in countries with poor institutions, thereby testing one part of hypothesis iv, an interaction term between earthquake exposure and quality of institutions is added to the equation.

The other part of hypothesis iv, namely that lower income levels would lead to more negative effects on the economy, is not directly testable by OLS on this specification since an interaction term between earthquake exposure and income-level would be *endogenous*. To identify the variation in effects over income levels, an additional regression will be performed on a sample of developing countries only.²⁰ The fully specified relationship reported in column 3 of table 6.2 is therefore:

$$\Delta y_{it} = \beta Q_{it} + \gamma_1' \Delta I_{it} + \gamma_2 (I \times Q)_{it} + \mu_0 + e_{it} \tag{6.3}$$

where ΔI_{it} refers to changes in institutional quality and $(I \times Q)_{it}$ captures the effect of earthquake exposure at different levels of institutional quality.

²⁰In the regional analysis of section 6.5, the role of income will be addressed with the use of an interaction term including average country income per capita. Since it examines the within-country variation in growth resulting from earthquake exposure, this interaction term will not be endogenous.

6.2 Data

This section presents the sources of the data that forms the backbone of the analysis as well as any calculations and considerations made prior to its application.

6.2.1 The earthquake exposure index

The data for earthquake exposure, labeled Q in the equations above, is derived from the EXPO-CAT database (Allen et al., 2009).²¹ In the catalog, the intensity of any given earthquake is divided into 20 levels²² and the number of people exposed to each intensity level is then reported. In order to turn this information into a single, continuous measure of earthquake exposure, an index is created that sums the observed number of people exposed, takes account of the fact that higher intensity levels cause more destruction and proportionate the figure to the population of the unit of observation. Hence the following index is calculated:

$$Earthquake \ Exposure = \frac{\sum_{int=1}^{int=20} \left((People)_{it,int} * intensity \right)}{Population_{it}}$$
(6.4)

Where People refers to the number of people exposed to an earthquake in unit *i* at time *t* and intensity level *int*. *Intensity* is an integer from 1 through

 $^{^{21}}$ Described in in detail in section 5

 $^{^{22}\}mathrm{Each}$ referring to half a step on the instrumental intensity scale analogous to the Modified Mercalli scale, c.f. section 5

20 and *population* is the population of unit i at time t. For now the units of observation are country-years and the population figure is derived from the Penn World Tables 7.0 (Heston et al., 2011). When used later in the regional analysis, the population data for each gridded cell (1 × 1 latitude longitude) is taken from the (Nordhaus et al., 2006) G-Econ project directly.

Table 6.1: Earthquakes and earthquake exposure statistics, 1973-2007

	Number of earthquakes in sample	Mean pct. of world pop. exposed	Mean magnitude	Mean index value	Mean index value if hit by an earthquake.
1973-2007	4,192	14.47	6.08	2.30 (13.7)	11.27 (28.6)

Source: Own calculations based on EXPO-CAT, (Allen et al., 2009). Notes: Mean pct. of world population exposed to any intensity level of an earthquake included in the sample.

6.2.2 Income per capita

The dependent variable is 5-year growth in per capita income. To be specific, what is referred to is real, *Purchasing Power Parity* (PPP)-adjusted GDP derived from version 7.0 of Penn World Tables (Heston et al., 2011) and the G-Econ project (Nordhaus et al., 2006) respectively. Since there are only minor discrepancies between per capita output (GDP) and per capita income, these definitions are used interchangeably.

GDP per capita is a measure for productivity; i.e. how much each person in an area produces each year. Especially when dealing with the economics of natural disasters, one should be aware that growth in per capita GDP does not necessarily imply growth in aggregate utility.²³ Moderate natural disasters may affect GDP positively since light destruction of physical capital implies higher demand for reparations without obstructing the production of goods and services. While at a large scale this may generate growth in GDP, the citizens and insurance companies who have to pay for reconstruction are clearly not better off.

The figures are PPP-adjusted in order to account for both systematic changes in the overall price level and arbitrary changes in relative price levels across countries or regions. Even though Horwich (2000) finds no evidence of changes in overall price levels caused by the 1995 Kobe earthquake, it seems plausible that earthquakes from time to time could have an effect on prices. If buildings collapse and industrial production is halted for a period, it leaves a gap between demand and supply for certain goods, presumably leading to (uneven) increases in prices.²⁴ With PPP-adjusted income measures these worries are hopefully avoided.

6.2.3 Institutions

The regression analysis includes a control for changes in the quality of institutions. Institutions in this study are measured by the widely used *Polity*

²³One of the classic examples of the limits of GDP is a road accident where the driver is injured (but can still go to work the next day) and the car is totally damaged. This has a positive effect on GDP since the driver may need to be seen by doctors and needs to buy a new car. However, it is hard to argue for any positive effect on aggregate utility.

²⁴As an example, Loayza et al. (2009) showed that earthquakes affect the industrial sector the most and have little to no effect on agriculture; the relative prices of industrial to agricultural goods must therefore be expected to change after an earthquake.

IV-index (Marshall et al., 2010).²⁵ It encompasses 162 countries including all countries with a population of more than half a million. It attributes a score from 0 to 10 to each country every year on two independent scales: *autocracy* and *democracy*. The final polity index value is then calculated as *Polity* = *democracy* - *autocracy*; an index stretching from *hereditary* monarchy (-10) to consolidated democracy (10).



Figure 6.1: Average Autocracy, Democracy and Polity-scores, 1973-2007

Source: Marshall et al. (2010).

Notes: As can be seen from the figure, there has been a general increase in institutional quality over the years with a clear shift towards more democratic institutions around 1990.

 $^{^{25}}$ In the natural disaster literature both Strömberg (2007) and Kahn (2005) use versions of the index as explanations for vulnerability to natural disasters.

6.3 Results

Table 6.2:

Table 6.2 contains the results of estimating equation 6.2 by OLS using a 1973-2007 panel of countries. Column 1 shows the basic correlation between values on the earthquake exposure index and 5-year growth in GDP; column 2 includes the Polity-IV-measure for institutional quality and column 3 additionally an interaction term between institutions and earthquake exposure.

	1	2	3
Earthquake Exposure	.094 (.465)	.218 (.561)	.328 (.706)
Institutions		004 (.002)	003 (.002)
Earthquakes*Institutions			.000 (.001)
Constant	.090*** (.009)	.088*** (.010)	.087*** (.010)
Observations:	1200	990	990
Countries:	187	159	159
R-squared:	.000	.003	.004

Effect of Earthquake Exposure on GDP growth, basic specification. OLS on equation 6.2.

Dependent variable: 5-year GDP growth rates, 1973-2007. Robust standard errors, clustered by country are reported in parentheses. *, ** and *** indicate significance at the 0.01, 0.05 and 0.1-level respectively.

None of the parameter estimates are significant; in other words the regression does not allow us to reject the null-hypothesis of zero influence from earthquake exposure on 5-year growth in GDP. There is a slight tendency that earthquake exposure has a positive effect on growth, but since this effect is highly insignificant, what stands out is that no effect is detectable. Likewise, changes in institutional quality over each 5-year period does not seem to influence per capita income growth nor alter the effects of earthquakes.

Table A.1 in the appendix shows the same set of regressions for the poorest half of the countries only. None of the parameter estimates change significantly compared with table 6.2. From this we therefore cannot conclude that earthquakes affect growth differently in developing countries.

6.4 Robustness

The following is an attempt to consolidate the results obtained above by applying different sets of assumptions and specifications. First and foremost, the structural income equation will be changed so that it becomes dynamic, i.e. including a lagged response variable as regressor. In order to obtain valid estimates, the *Generalized Method of Moments* (GMM) estimator is employed. Next, alternative non-linear specifications are considered in order to check whether an effect emerges for some values of the earthquake exposure index while not for others. Third and lastly, it is tested whether growth rates are affected by earthquakes in the shorter run by using year-on-year growth regressions.

6.4.1 Dynamic model

The assumption that economies may be outside their steady state growth rates and converging towards it is now added. In other words, instead of being described by equation 6.1, the structural relation between income and its determinants can be stated as an autoregressive process:

$$y_{it} = \alpha y_{i,t-z} + \beta \tilde{Q}_{it} + \gamma' X_{it} + \mu_t + \eta_i + \epsilon_{it}$$
(6.5)

Again, the structural equation is first-differenced in order to eliminate country-specific fixed effects. The equation to be estimated is therefore analogous to equation 6.2 except for the inclusion of a lagged dependent variable regressor:

$$\Delta y_{it} = \alpha \Delta y_{i,t-z} + \beta Q_{it} + \gamma' \Delta X_{it} + \mu_0 + e_{it} \tag{6.6}$$

The presence of $\Delta y_{i,t-z}$ on the right-hand side of the equation poses a challenge to the estimation procedure. By OLS, α is not consistently estimated since e_{it} is correlated with $\Delta y_{i,t-z}$ by construction.²⁶ Therefore, an estimation method that allows for endogeneity in one or more of the regressors is needed since even if variation in earthquake exposure over time is exogenous, its effect on growth may not be estimated correctly if some or all of the other explanatory variables are endogenous.

The following estimation is consequently based on the Arellano and Bond (1991) Generalized Method of Moments (GMM) estimator in first-differences originally developed by Holtz-Eakin et al. (1988). When estimating growth in per capita income by equation 6.6, the lagged dependent variable and the control variables are treated as endogenous and therefore *instrumented*

²⁶E.g. for z = 1, $e_{it} = \epsilon_{it} - \epsilon_{i,t-1}$ and $\Delta y_{i,t-1} = y_{i,t-1} - y_{i,t-2}$. Because $\epsilon_{i,t-1}$ is included in $y_{i,t-1}$, $\Delta y_{i,t-1}$ cannot be an exogenous regressor.

by vectors of previous observations. Q_{it} , on the other hand, is not instrumented since it is believed to be exogenous. Institutional quality is often instrumented in empirical growth studies since it can be hard to determine the direction of causation; by using all *previous* realizations of the Polity IV-index as instruments for the value of period t, the GMM estimates rule out concerns about reversed causality in this variable too.

	1	2	3
Earthquake Exposure	.244 (1.16)	1.02 (1.29)	.133 (1.34)
Lagged growth rate	.621*** (.154)	.574*** (.093)	.634*** (.083)
Institutions		010** (.005)	010** (.005)
Earthquakes*Institutions			.003* (.001)
Observations:	1013	837	837
Countries:	186	158	158
Number of instruments:	28	49	70
AR(1)-test:	.028	.001	.000
AR(2)-test:	.209	.611	.486
Hansen test:	.185	.059	.248
Difference-in-Hansen:	.176	.298	.232

Table 6.3: Effect of Earthquake Exposure on GDP growth, dynamic specification. GMM on equation 6.6.

Dependent variable: 5-year GDP growth rates, 1973-2007. Period dummies included in all columns (not reported). Arellano-Bond robust standard errors, reported in parentheses. *, ** and *** indicate significance at the 0.01, 0.05 and 0.1-level respectively. Test statistics in italics are all p-values against null-hypotheses of no autocorrelation or exogeneity.

Table 6.3 contains the results of applying the first-difference GMM estimator to equation 6.6. The columns are analogous to those of table 6.2 except for the added *lagged growth rate*. As in the model with no autocorrelation, we observe a minor tendency towards earthquake exposure having a positive impact on growth, but since none of the coefficients are significant, a conservative guess would be that earthquake generally do not influence growth. What is different from table 6.2 is that changes in the quality of institutions in this set-up influence growth negatively²⁷ and that better institutions does indeed seem to increase the benefits (or reduce the costs) of experiencing an earthquake.

The specifications in column 1 through 3 are all overidentified meaning that there are more instruments (and thus moment conditions) than regressors. This implies that it is possible to test for overidentifying restrictions, i.e. whether the set of non-endogenous regressors (including GMM-style instruments for endogenous regressors) are jointly exogenous. To this purpose, table 6.4 reports the Hansen J-test since the usual Sargan-test is not applicable when the standard errors are robust or clustered. In all three columns, we cannot reject the null-hypothesis of joint validity. As a further check to robustness, the table reports the result of the so-called Difference-in-Hansentest calculating first the χ^2 test statistic for the subset of GMM-style instruments and then subtracting it from the Hansen test statistic in order to test the exogeneity of the non-GMM-style instruments (Roodman, 2009). The results show that we cannot reject that even this subset of instruments

 $^{^{27}{\}rm This}$ seemingly contradictory finding could be driven by the large wave of democratization that took place around 1990 which was rather chaotic and led to several economic crises.

are exogenous, which further strengthens the assumptions made about the parameters.

The AR-tests in table 6.3 refer to the Arellano-Bond test for zero autocorrelation in the errors. The null hypothesis of no autocorrelation at order 1 is rejected due to the first-differencing of the model. At order 2, we cannot reject the null, meaning that we should not be concerned about serial correlation in the first-differenced error terms.

The results of estimating the effects of earthquake exposure on economic growth in a dynamic growth model seem to confirm the results from the basic set-up, namely that there is no effect. The analysis is therefore in line with other recent such as Loayza et al. (2009) and Raddatz (2009). The results further indicate that countries with better institutions seem to handle earthquakes better, but these effects are small comparative to the overall picture, so they do not confirm that earthquakes are directly beneficial to growth even in countries with high-quality institutions. The results are qualitatively similar for the full sample and a set of countries consisting of bottom half in terms of income per capita.

6.4.2 Non-linearity

Some of the studies of the effects of natural disasters on growth, including Loayza et al. (2009), have shown that the effects of extreme events might differ from moderate ones in a non-linear fashion. There are numerous ways to capture this potential non-linearity in a regression. Table 6.4 contains two of the most common approaches: including a squared version of the explanatory variable (columns 1 and 3) or creating a dummy indicator variable for, say, the 10 percent of the observations with highest values on the earthquake exposure index and then interacting it with the value (columns 2 and 4).

Table 6.4:

	1	2	3	4
	Basic model, quadratic	Basic model, dummy	Dynamic model, quadratic	Dynamic model, dummy
Earthquake Exposure	-1.39 (1.79)	254 .429	-1.51 (3.00)	.002 (1.18)
Lagged growth rate			.605*** (.156)	.607*** (.162)
Earthquake Exposure squared	36.8 (47.9)		42.8 (75.7)	
Extreme events (10 pct. highest exposure)		2.45 (2.02)		.936 (2.64)
Observations: Countries: R-squared:	1,200 187 .001	1,200 187 .004	1,013 186	1,013 186 -
No. instruments: AR(1)-test:	-	-	29 . <i>032</i> 228	29 .032 242
Hansen test: Difference-in-Hansen:	-	-	.220 .203 .234	.242 .198 .217

Effect of Earthquake Exposure on per capita income growth Checks for non-linearity, OLS and GMM

Notes: Dependent variable: 5-year growth rates in GDP per capita, 1973-2007. All variables are in logs. In column 1-2, robust standard errors, clustered by country, are reported in parentheses. Column 3-4 include period dummies and report Arrelano-Bond robust standard errors. *, ** and *** indicate significance at the 0.01, 0.05 and 0.1-level respectively. Test statistics in italics are all p-values against null-hypotheses of no autocorrelation or exogeneity.

Both methods yield similar parameter values on earthquake exposure to

those reported in table 6.2 and 6.3. In other words, allowing for a non-linear relationship does not change the fact that there is no detectable impact of earthquakes on economic growth at the country level. This result differs from what is found by Loayza et al. (2009), namely that an extreme events dummy interacted with their measure of disaster intensity resulted in a negative parameter estimate. This deviation in results could either be caused by the fact that extreme earthquakes are not as destructive as other types of disasters or simply that the data source is different.

6.4.3 Short-run growth

So far, the analysis has concentrated on 5-year growth rates with the amount of earthquake exposure during that period as explanatory variable. Table 6.5 contains the alternative results of estimating year-to-year growth rates on earthquake exposure taking place that year. Similar to the 5-year analysis, the results show that there is no effect from earthquakes on economic growth.

It is important to note, though, that the p-values of the Hansen tests in table 6.5 may be implausibly high due to the problem of *too many instruments* (see Roodman, 2009). It is therefore difficult to assess whether the instruments included in column 3-4 are exogenous.

	1	2	3	4
	Basic model	Basic model w/controls	Dynamic model	Dynamic model w/controls
Earthquake Exposure	.001 (.001)	.001 (.002)	.003 (.002)	001 (-002)
Lagged growth rate			.982 (.009)	.908 (.015)
Institutions		001* (.001)		002** (.001)
Earthquakes*Institutions		.000 (.002)		.001*** (.002)
Observations:	6,068	4,876	5,881	4,863
Countries:	187	159	187	159
R-squared:	.000	.003	-	-
No. instruments:	-	-	596	1,820
AR(1)-test:	-	-	.000	.000
AR(2)-test:	-	-	.009	.070
Hansen test:	-	-	1.00	1.00
Difference-in-Hansen:	-	-	.563	1.00

Table 6.5:Effect of Earthquake Exposure on yearly per capita income growthOLS and GMM

Notes: Dependent variable: year-to-year growth rates in GDP per capita, 1973-2007. All variables are in logs. Column 1-2 contain the results of OLS estimation. Robust standard errors, clustered by country, are reported in parentheses. Column 3-4 include the results of a GMM-estimation with period dummies and report Arrelano-Bond robust standard errors. *, ** and *** indicate significance at the 0.01, 0.05 and 0.1-level respectively. Test statistics in italics are all p-values against null-hypotheses of no autocorrelation or exogeneity.

6.5 Regional analysis

In sum, the answers provided by the country level analysis to the question of how earthquakes affect economic growth are few and uninformative. If anything is to be concluded, it is that earthquakes do not affect economic growth; yet, imagining the devastation caused by some of the large events, this conclusion seems unsatisfactory.

Therefore, the study now goes beyond the use of countries as unit of analysis and instead employs income data at the subnational level. This will serve two purposes: First and foremost, it provides a new way to search for an answer to the research question of identifying an effect of earthquakes on economic growth. But it will also potentially shed light on reasons why no effect is evident at the country level. In particular, it will become possible to test the mechanisms of spatial substitution observed by Horwich (2000) at a large scale. If hypothesis *ii* is true, that is, if it is concluded that a lower growth rate locally is accompanied by an increase in economic activity in the regions encircling the disaster zone, this might cancel out the total effects at the national level, thereby providing at least some explanation for the lack of results so far.

In this section, the Allen et al. (2009) EXPO-CAT data is combined with data from the the Nordhaus et al. (2006) *Geographically based economic data* (G-Econ) project in order to investigate if earthquakes influence economic growth at the regional level. Firstly, the identification strategy will be discussed; secondly, the G-Econ data is introduced and thirdly, the results are presented along with different robustness-checks. Finally, potential threats to identification will be assessed with a special focus on the presence of unobserved cell-specific effects.

6.5.1 Estimation strategy

At the cell-level, the structural relationship between per capita income and earthquake exposure can be described by the following equation:

$$y_{cit} = \beta \tilde{Q}_{cit} + \gamma' X_{cit} + \mu_{it} + \eta_{ci} + \epsilon_{cit}$$
(6.7)

where the added subscript relative to equation 6.1, c, refers to individual $(1 \times 1 \text{ latitude-longitude})$ cells. Two additional changes from the country level analysis need attention: firstly, \tilde{Q} is now effectually split in two variables: one for cells directly exposed to earthquakes (*impact cells*) and another for cells directly adjacent to these (*close call cells*). Secondly, the regression will allow for time-varying country-specific effects, μ_{it} . By first-differencing equation 6.7, we obtain a measure for economic growth:

$$\Delta y_{cit} = \beta Q_{cit} + \gamma' \Delta X_{cit} + \mu_i + e_{cit} \tag{6.8}$$

The time-invariant unobserved cell-specific effect, η_{ci} (affecting initial cross-sectional differences in income per capita) is differenced out. Yet compared with the country-level analysis, the additional level of detail allows for further control for country-specific factors that affect not only differences in

initial performance, but also growth. The regressions therefore include μ_i , measuring country specific trends. The variation in economic growth originating from exposure to earthquakes on this form thereby resembles that which occurs within countries and not across countries. What this means for identification is that the scope for omitted variables bias is reduced dramatically: cultural and geographical influences on per capita income are omitted by the first-difference transformation and since institutional changes are country-specific,²⁸ they do not affect within country variation in growth.

At the outset, equation 6.8 will be estimated by OLS including 183 country dummy variables for both the basic specification and a version with the lagged income-level as a regressor. The latter requires that the first-differenced error term, e_{cit} in equation 6.8 is assumed to be IID; an assumption made more plausible by the inclusion of country fixed effects. In section 6.5.4, the model will be estimated by GMM as a further check to robustness.

6.5.2 Data

The Nordhaus et al. (2006) G-Econ dataset contains information on gross cell product (GCP) at market exchange rate and purchasing power parity prices, population and a number of climatic variables for the years 1990, 1995, 2000 and 2005.²⁹ This yields three five-year periods in each of which the sum of earthquake exposures are related to growth.

The unit of observation in the G-econ data is essentially *country-cell-year*:

 $^{^{28}\}mathrm{At}$ least the ones measurable here.

²⁹Version 4.0 of May 2011 is being used here. Downloadable from http://gecon.yale.edu/



Figure 6.2: Gross Cell Product per capita in the G-Econ data (\$'000)

a terrestrial quadrant of the Earth measuring one degree latitude by one degree longitude, belonging to a specific country measured in three different years. When two (or more) countries share the same land cell, it is split into two (or more) observations. A degree of latitude measures around 110 km whereas the distance between two longitudes changes with latitude from 111.3 km at the equator narrowing gradually as it nears the poles.³⁰ The areas of the observational units are thus getting smaller the further away from equator they get. The mean area of a unit in the sample is 6832 square kilometers corresponding to a trapezoid of around 110 by 62 kilometers slightly narrower at the end pointing away from the equator. The standard deviation of the distribution of areas in the sample is 3805 square kilome-

Source: Andersen et al. (2011)

 $^{^{30}}$ In Copenhagen at 55.7°N, the length of a longitude is 62.87 km.

 $ters.^{31}$

Per capita income measures are derived from national accounts at the subnational level and rescaled spatially to fit gridded cells. The need to rescale stems from the fact that in national accounting, economic activity is defined inside political boundaries not identical to cells drawn by latitude and longitude. The reported figure for each cell thus becomes a function of the average income level in each political subdivision contained in the cell and their respective shares of its total area.³² In most cases, information is available at multiple administrative levels: the national level, state level and county level, i.e. two subdivisions.

The standard procedure described above is referred to by Nordhaus et al. (2006) as the *old country method*. When economic output data is not available at any sub-national level, other methods are being used ranging from estimating GCP from employment numbers to extrapolating from national GDP. Since the aim here is to study the *local* effects on the economy from earthquakes, all observations where estimates of GCP are not derived from national accounts at the sub-national level are excluded. The full sample holds 27,445 observations of terrestrial land units (6,145 of which are located in Antarctica) in 246 country method has been applied, the number of ob-

 $^{^{31}}$ The main reason for the great disparity in the areas of the cells are that many are limited by the ocean or political borders.

 $^{^{32}{\}rm The}$ process of estimating Gross Cell Product (GCP) for each cell is described in detail in Nordhaus et al. (2006).

servations drops to 18,817 and the number of countries represented in the sample to 183.

Estimates of population per grid cell are included in the G-Econ data from the *Gridded Population of the World* (GPW) project at Columbia University³³. Unlike the *Oak Ridge Landscan* used by the USGS to create the ShakeMaps Atlas, the GWP is available at different spatial resolutions, it relies on census data only, and includes more administrative units. However, the level of detail is lower than in the Landscan project³⁴.

Each observation in the G-Econ data is uniquely defined by its latitude, longitude and country ISO-code.³⁵ If more than one earthquake included in the sample hits a cell during any of the three five-year periods, the *sum* of people exposed to the earthquakes at different levels of instrumental intensities is used in the Earthquake Exposure index. In order to be able to compare effects from earthquakes between the impact cell and the surrounding zones, the values of the explanatory variables are also assigned to to the 4 nearest cells (the dotted cells in the left panel in figure 3.2) or to all surrounding cells (the 8 dotted cells in the right panel). It is the former that constitutes the main representation of *close call* cells in the analysis whereas the latter is used only as a robustness check.

There are three aspects of the (Nordhaus et al., 2006) G-Econ data one

³³http://sedac.ciesin.columbia.edu/gpw/

 $^{^{34}{\}rm A}$ comparison of the two population density datasets is available at http://sedac.ciesin.columbia.edu/gpw/

 $^{^{35}\}mathrm{The}$ latitudes and longitudes describe the south-western corner of a cell.

Figure 6.3: Impact- and close call cells



The illustration to the left shows what is meant by impact cells and close call cells in the regressions below. Values on the earthquake exposure index are assigned to both impact and close call cells, but with different variable names.

should keep in mind when reading the output of the regressions. Firstly, it relies heavily on the availability of high-quality national accounts at the subnational level (i.e. states or counties). While abundant in some countries, the quantity and quality of data naturally drops with governmental capacity and income level. Secondly, rescaling the income data from areas defined by political boundaries to 1×1 latitude-longitude cells is not an easy feat and holds numerous sources for measurement error. Finally, the unit of observation (squares of about 100×100 kilometers at the equator) will often be ill-situated with respect to the epicenters of earthquakes. It can easily be assumed, however, that these measurement errors are more or less randomly distributed, so the estimates are expected to be consistent.

6.5.3 Results

Table 6.6 shows the results of estimating equation 6.8 by OLS. The first two columns contain the reduced form results for impact cells alone and for impact- and close call cells; column 3 and 4 employ the dynamic specification with the lagged income-level entering the right-hand side of the equation and finally column 5 and 6 adds an interaction term between country-average initial income level and earthquake exposure. All columns include country fixed effects.

Table 6.6:

OLS on equation 6.8.

Effect of Earthquake Exposure on per capita income growth, basic and dynamic specifications.

	1	2	3	4	5	6
Earthquake Exposure (impact cell)	-1.51*** (.131)	-1.53*** (.130)	934*** (.124)	939*** (.124)	960*** (.141)	990*** (.141)
Earthquake Exposure (close call cell)		.152*** (.039)		.068** (.034)		.068** (.034)
Initial income per capita			381*** (.055)	380*** (.055)	381*** (.055)	380*** (.055)
Earthquakes*Income					9.60*** (1.44)	9.63*** (1.45)
Observations:	51,942	51,942	51,942	51,942	51,942	51,942
Countries:	166	166	166	166	166	166
R-squared:	.007	.007	.193	.193	.193	.193

Dependent variable: 5-year growth rates in Gross Cell Product, 1990-2005. All variables are in logs. All columns contain country fixed effects (not reported). Robust standard errors, clustered by country, reported in parentheses. *, ** and *** indicate significance at the 0.01, 0.05 and 0.1-level respectively.

The primary result contained in table 6.6 is that earthquake exposure

significantly affects economic growth in a negative direction. Since the earthquake exposure index is measured in logs, the coefficients can be interpreted such that a percentage increase in the index value leads to around a percentage point drop in 5-year per capita income growth (depending on specification). This means, interestingly, that earthquake disasters do have a profound adverse effect on local growth as opposed to country level growth.

The implications of this could be that there is a spatial distribution of costs and benefits when an area is hit by an earthquake as suggested by Horwich (2000). Areas surrounding the earthquake zones experience sudden increases in demand for e.g. construction workers and building materials generating a boost to the economy while the areas directly hit first and foremost is negatively affected due to decreased production capacity. The results pertained in the second row indicates that this hypothesis is valid because on average, the four nearest cells to the impact zone see minor increases in growth rates as their "neighbors" are exposed to earthquakes.

Below average initial income levels generally leads to higher growth rates, representing some sort of convergence mechanism or unevenly distributed business cycles within countries.³⁶ Finally, consistent with the expectations formed by reviewing the literature on natural disasters, the interaction term has a positive coefficient meaning that countries with higher initial income levels cope better with earthquakes.

³⁶Notice that the coefficients on initial income per capita should be read differently than in the country level analysis. If α is the parameter on lagged income level in the structural equation, this parameter equals $\alpha - 1$.

6.5.4 Robustness

This section includes a number of regressions based on different specifications in order to check the robustness of the results of the regional analysis. Table 6.7 contains four columns, each with an alternative specification or estimation method to the one represented in table 6.6. The first column reports the effects of a binary earthquake exposure indicator on growth; in other a comparison of economic growth rates between impact cells and non-impact observations. The second column considers the possibility of a non-linear relationship in both impact and close call cells. Column 3 tests how the results change when eight close call cells are included instead of the usual four. Columns 1-3 report the results of altering the basic specification without the initial income level entering the regressions. Column 4 uses GMM instead of OLS in order to estimate the effects in the dynamic model.

Starting with the latter (GMM on dynamic model), what distinguishes this estimation from the ones in table 6.6 is that it uses previous values of $y_{ci,t-1}$ as instruments in order to avoid bias from its correlation with the error term.³⁷ Q_{cit} is still treated as exogenous; as are the country dummies entering the first-differenced equation directly. The effect of earthquake exposure on impact cells turns out to be slightly greater (in absolute terms) when estimated by GMM. This discrepancy might be caused by some unobserved factor affecting both $y_{ci,t-1}$ and Q_{cit} ; however the estimation could also have resulted in a different estimate because the GMM estimator needs two periods

 $^{^{37}\}mathrm{Analogous}$ to the estimation of country level effects in table 6.3.

	1	2	3	4
	Binary indicator	Non-linear specification	w/ 8 close call cells	GMM on dynamic model
Earthquake Exposure (impact cell)	023 (.062)	-3.45*** (.498)	-1.52*** (.130)	-1.72*** (.181)
Earthquake Exposure (close call cell)	.134*** (.048)	.751*** (.243)	.082** (.033)	.186*** (.065)
Initial income per capita				.135*** (.013)
Earthquake Exposure squared (impact cell)		1.11** (.262)		
Earthquake Exposure squared (close call cell)		316*** (.131)		
Observations	51,942	51,942	51,942	34,452
R-squared	.004	.007	.007	-
No. instruments	-	-	-	169

Table 6.7:Effect of Earthquake Exposure on per capita income growthRobustness checks

Notes: Dependent variable: 5-year growth rates in Gross Cell Product, 1990-2005. All variables are in logs. All columns contain country fixed effects (not reported). In column 1-3, robust standard errors, clustered by country, are reported in parentheses. Column 4 reports Arrelano-Bond robust standard errors. *, ** and *** indicate significance at the 0.01, 0.05 and 0.1-level respectively.

of lags thereby in effect estimating only the impact on growth from 2000 to 2005.³⁸ The low number of periods also means that the Arellano-Bond tests for serial correlation and the Hansen test for overidentifying restrictions are not possible to conduct.

The first column uses a binary indicator for earthquake exposure that takes the value 1 if at least one earthquake in the sample has had its epicenter

 $^{^{38}\}mathrm{Hence}$ the smaller number of observations in column 4 of table 6.7.

in a gridded cell during a five-year period and 0 otherwise. The results show that the effect on impact cells turns insignificant, but that the effect on the surrounding cells remains positive. Bearing in mind the rather clear negative relation between earthquake exposure and growth in table 6.6 in the results section, the insignificant coefficient on the binary indicator could be interpreted as a sign that smaller earthquakes exert a positive influence on growth whereas larger earthquakes influence negatively.³⁹

Column 2 tests the idea that the effects on both impact and close call cells might be quadratic instead of linear. The results of column 2 in table





6.7 indicate that the relation between earthquake exposure and growth could be quadratic; e.g. as depicted in figure 6.4. However, looking at the partial correlations, controlled for country fixed effects,⁴⁰ quadratic relationships are not obvious — especially in the case of impact cells.

 $^{^{39}}$ c.f. figure B.2 in the appendix

⁴⁰figure B.3 and B.4 in the appendix

The third column in table 6.7. contains the results of estimating equation 6.8 by OLS with the one exception that all eight surrounding cells are in the close call group, cf. right panel of figure 6.2. The results show what was to be expected: the effect of an earthquake on the surrounding regions remains positive, albeit smaller in size. This is in accordance with the fact that the average distance from the epicenter to the center points of the close call cells is longer in this specification than in the previous: longer distances means less scope for spatial substitution in production.

6.5.5 Threats to identification

So far, the reported results rest on two crucial assumptions: that the data in the G-Econ database is valid and that there are no unobserved effects at the cell level when controlling for country fixed effects. The data validity is discussed in the data section above and a potential alternative will be suggested in the conclusion. The concern about a potential presence of unobserved, cell-specific effects is the theme of the following.

Are there any unobserved characteristics of impact cells potentially affecting the results? The short answer has to be yes; after all, localities experiencing earthquakes in one of the three five-year periods from 1990 to 2005 differ from other areas in one important aspect: they are often placed within regions with high levels of seismic activity and it is therefore more likely that they are *generally* hit by more earthquakes. Around 80 percent of all earthquakes take place along subterranean fault lines (Keller and Blodgett, 2006), and this might have an effect on economic growth rates not only when major earthquakes occur, but also when they do not.

A way to test for unobserved heterogeneity in panel data is to conduct a so-called Granger causality test. The idea is to attempt to predict values of the dependent variable with future values of the explanatory variable. Since an explanatory variable in a time series regression cannot logically speaking *cause* anything that has already happened, dependent on crosssectional and trend effects, future values of the explanatory variable should not be significantly correlated with past response variables.

In this study, conducting a test for Granger-causality means the following: earthquake exposure in the 2000–2005 period should not affect growth in the periods 1990–1995 and 1995–2000. Likewise, cells that experience a close call in 2000–2005 should not deviate from other cells in the periods 1990 to 1995 and 1995 to 2000 in terms of economic growth. Table 6.9 presents the results of estimating growth one period (column 1 and 2) and two periods (column 2 and 3) into the past on both the basic and dynamic specification.

The results of the Granger causality test indicate that areas where more people are exposed to are observed generally tend to grow *faster* than other cells in non-impact years. Close call cells, on the other hand, experience slightly slower-than-average growth rates when their neighbors are not hit, but this result is less significant. The conclusion that needs to be drawn is that unobserved effects biasing the results of table 6.7 towards zero are
present.41

Table 6.8:

3	2	1	
Growth in t-2	Growth in t-1	Growth in t-1	Dependent variable:
.369 (.245)	1.50*** (.097)	1.48*** (.119)	Earthquake Exposure (impact cell)
068 (.049)	119* (.060)	050 (.056)	Earthquake Exposure (impact cell)
	388*** (.050)		Initial income per capita
17,471 164 .011	34,945 165 .211	34,945 165 .008	Observations: Countries: R-squared:
	3 Growth in t-2 .369 (.245) 068 (.049) 17,471 164 .011	2 3 Growth in t-1 Growth in t-2 1.50*** .369 (.097) (.245) 119* 068 (.060) (.049) 388*** .050) 34,945 17,471 165 164 .211 .011	$\begin{array}{c c c c c c c c } \hline 1 & 2 & 3 \\ \hline Growth in t-1 & Growth in t-1 & Growth in t-2 \\ \hline 1.48^{***} & 1.50^{***} & .369 \\ (.119) & (.097) & (.245) \\ \hline050 &119^* &068 \\ (.056) & (.060) & (.049) \\ \hline & &388^{***} \\ \hline & & (.050) \\ \hline \hline & & 34,945 & 34,945 & 17,471 \\ \hline 1.65 & 1.65 & 1.64 \\ \hline & .008 & .211 & .011 \\ \hline \end{array}$

Effect of future earthquake exposure on per capita income growth Granger causality check

Notes: All variables are in logs. All columns contain country fixed effects (not reported). Robust standard errors, clustered by country, are reported in parentheses. *, ** and *** indicate significance at the 0.01, 0.05 and 0.1-level respectively. Including institutions as a control variable does not alter signs or significance levels.

Two explanations for this unobserved effect both relate to the fact that places with high amounts of exposure to earthquakes are often located at seismic fault lines: first of all, earthquakes that are too small to be included in the EXPO-CAT dataset could potentially cause higher growth rates. Second, some of these zones might still be recovering from a previous large earthquake thus converging towards a steady state capital-labor ratio from below.

The EXPO-CAT data filters out all earthquakes with magnitudes less than 5.5. If earthquakes with low magnitudes (and consequently lower val-

 $^{^{41}}$ If impact cells generally grow faster than other cells, the observed negative effect in table 6.5 ought to be even greater in comparison.

ues on the earthquake exposure index) have a positive effect on economic growth, the absence of these in the data would explain the results. Recall from table 5.1 that the number of earthquakes increase with an order of magnitude for every step down the moment magnitude scale, meaning that for every earthquake included in the EXPO-CAT sample, there will be hundreds of unobserved smaller earthquakes, 80 percent of which occur along the same tectonic fault lines as the ones included. One way to check if smaller earthquakes affect the economy positively is to reduce the sample of earthquakes so that it only contains the lower end of exposure scale. Figure B.5 in the appendix shows the relationship between earthquake exposure and growth for the bottom 20 percent of observations. With this restriction on the data, earthquake exposure has a significant positive effect on growth and the same is the case when looking at the bottom decile.

The reasons why smaller earthquakes seem to affect growth positively follow directly from the counteracting mechanisms described earlier: the destruction of physical capital leads to higher demand for repair and replacements (affecting growth positively) as well as a potential drop in production capacity if production plants have collapsed and machinery stopped running (affecting growth negatively). Since the damage done by smaller earthquakes is mostly non-destructive, the former effect is likely to dominate the latter. Additionally, the smaller the earthquake, the more localized the effects will be. It is therefore more likely that all of the potential output gains in the areas surrounding the impact zone are contained within a single latitude × longitude cell.

The second explanation for the unobserved effects relates to the expectations formed about earthquakes in the Solow model discussed in section 3. When the capital-labor ratio is suddenly decreased due to an earthquake, there will be a one-time drop in production followed by transitional growth towards a steady state. If large earthquakes hit the same areas with a frequency of, say, a decade or two, some of the higher-than-average growth indicated by the Granger test could be a manifestation of such a transition phase. According to *Reid's elastic rebound theory*, this scenario could well be true. In what have later become standard knowledge for seismologists, Reid (1910) concluded that earthquakes are typically the result of the release of tension built up along fault lines as tectonic plates move comparatively. Since tension takes time to build up, large earthquakes are often followed by a relatively long period of tranquility (where only light earthquakes occur).⁴²

Altogether, the potential presence of unobserved effects does not compromise the identification of an overall negative effect at the regional level, but rather adds a layer of complexity to the analysis. Since impact cells on average grow faster than other observations in non-impact years, the experienced downturn in economic activity due to a major earthquake will be even more noticeable.

 $^{^{42} \}rm See~http://earthquake.usgs.gov/regional/nca/1906/18 april/what$ effect.php for a graphical representation of the theory.

7 Conclusion

The goal of this study was to analyze the effects of earthquakes on economic growth. Drawing on a hitherto unexploited data source on earthquake exposure, it has been possible to confirm the main results of other recent investigations; that earthquakes do not affect growth significantly at the country level.

The main contribution to the existing knowledge, however, lies in the identification of a pronounced negative effect at the local level. By combining the EXPO-CAT data on earthquake exposure with income data from the G-Econ project, it has been proved that for subnational units of observation, growth in per capita income declines when the number of people exposed to earthquakes (or the intensities of the quakes) increases.

In addition, it was tested what effect earthquakes centered in one location would cause on the surrounding regions. The idea of a spatial distribution of consequences originates from a case-study conducted by Horwich (2000) describing that production units were likely to move to other cities and that the reconstruction process took in labor from a large area surrounding the actual disaster zone. The results therefore matched expectations: areas next to the so-called impact cells showed a tendency to grow faster on average than other regions of the same countries.

A concern was raised that it would not be unproblematic to compare impact cells with non-impact cells due to the fact that on the surface above tectonic fault lines, seismic activity is more or less permanent. It is suggested (and backed by the data) that impact cells for this reason generally experience faster-than-average growth rates; the difference between periods with major earthquakes and periods with relative calm is therefore probably even more sizable.

The key results of the country level and regional analyses correspond to the confirmation of hypothesis i and ii. The results of testing the third and fourth hypothesis are less clear-cut. First off, at the country level there are no indications of non-linearity nor parameter heterogeneity with respect to income. In the dynamic model, though, estimates do hint that the quality of institutions could have a positive influence on the economic consequences of earthquakes.

At the local level, again there is not enough evidence to suggest that extreme events differ from moderate ones in a non-linear way. The characteristics of the societies in which they occur, however, do play a significant role: higher initial income per capita generally means that the costs (in terms of foregone growth) of being struck by an earthquake is relatively lower.

It is often difficult to suggest any policy implications from cross-country analyses since there will always be individual considerations. However, one implication of this study could be that the international relief aid community should not be blinded by the apparent lack of impact on national economies; local economies might suffer greatly, depending on the number of people exposed to high earthquake intensities and the income levels of the affected. From a development economics perspective, the indication that spatial substitution does occur would be another argument for increased investments in infrastructure so as to expand the radius of potential benefits.

In order to further investigate the complex effects of earthquakes on economic growth, one approach would be to employ income data at a much more detailed level. Henderson et al. (2009) introduce a new way of identifying changes in economic activity for observations of areas less 1 square kilometer: they aggregate nighttime satellite images of Earth taken by US Air Force weather satellites from 1992 to 2008 to construct global datasets for each year with grids of information on light-intensity. While this is not an direct measure of income, it has been showed that there is a strong correlation between growth in GDP and changes in the nighttime light intensities. This data could potentially be combined with the EXPO-CAT or the ShakeMaps Atlas to gain additional knowledge of the spatial distribution of losses and gains. In particular, one might even be able to construct a model that could in principle estimate the radius of adverse consequences the minute an earthquake strikes.

References

- Daron Acemoglu. Introduction to modern economic growth. Princeton University Press, 2009.
- Daron Acemoglu, Simon Johnson, and James A. Robinson. The colonial origins of comparative development: An empirical investigation. American Economic Review, 91(5):1369–1401, December 2001.
- Pelle Ahlerup. Are natural disasters good for economic growth? Working paper, 2011.
- J.M Albala-Bertrand. Political Economy of Large Natural Disasters With Special Reference to Developing Countries. Oxford: Clarendon Press. Princeton University Press, 1993.
- Trevor Allen, David Wald, Paul Earle, Kristin Marano, Alicia Hotovec, Kuowan Lin, and Michael Hearne. An atlas of shakemaps for selected global earthquakes: U.s. geological survey open-file report. 94, 2008.
- Trevor Allen, David Wald, Paul Earle, Kristin Marano, Alicia Hotovec, Kuowan Lin, and Michael Hearne. An atlas of shakemaps and population exposure catalog for earthquake loss modeling. *Bulletin of Earthquake Engineering*, 7:701–718, 2009.

Thomas Barnebeck Andersen, Carl-Johan Dalgaard, and Pablo Selaya. Eye

disease and development. Discussion papers, University of Copenhagen. Department of Economics, August 2011.

- J.D. Angrist and J.S. Pischke. *Mostly harmless econometrics: an empiricist's companion*. Princeton University Press. Princeton University Press, 2008.
- Manuel Arellano and Stephen Bond. Some tests of specification for panel data: Monte carlo evidence and an application to employment equations. *Review of Economic Studies*, 58(2):277–97, April 1991.
- Eduardo Cavallo and Ilan Noy. The economics of natural disasters a survey. Working papers, University of Hawaii at Manoa, Department of Economics, November 2009.
- Eduardo Cavallo, Ilan Noy, S. Galiani, and J. Pantano. Catastrophic natural disasters and economic growth. Working paper, IBD Working Papers, 2010.
- Edward L. Glaeser, Rafael La Porta, Florencio Lopez de Silanes, and Andrei Shleifer. Do institutions cause growth? Journal of Economic Growth, 9 (3):271–303, 09 2004.
- J. Vernon Henderson, Adam Storeygard, and David N. Weil. Measuring economic growth from outer space. Nber working papers, National Bureau of Economic Research, Inc, July 2009.
- Alan Heston, Robert Summers, and Bettina Aten. Penn World Table Version

7.0. Center for International Comparisons of Production, Income and Prices at the University of Pennsylvania, May 2011.

- Douglas Holtz-Eakin, Whitney Newey, and Harvey S Rosen. Estimating vector autoregressions with panel data. *Econometrica*, 56(6):1371–95, November 1988.
- George Horwich. Economic lessons of the kobe earthquake. *Economic De*velopment and Cultural Change, 48(3), 2000.
- Matthew E. Kahn. The death toll from natural disasters: The role of income, geography, and institutions. The Review of Economics and Statistics, 87 (2):271-284, 02 2005.
- Edward A. Keller and Robert H. Blodgett. Natural Hazards: Earth's Processes as Hazards. Disasters, and Catastrophes. Prentice Hall, 2006.
- Rafael La Porta, Florencio Lopez-de Silanes, Andrei Shleifer, and Robert Vishny. The quality of government. Journal of Law, Economics and Organization, 15(1):222-79, April 1999.
- Norman Loayza, Eduardo Olaberria, Jamele Rigolini, and Luc Christiaensen. Natural disasters and growth - going beyond the averages. Policy research working paper series, The World Bank, June 2009.
- M.G. Marshall, T.R. Gurr, and K. Jaggers. Polity IV, 1800-2009. Codebook, 2010.

- William Nordhaus, Qazi Azam, David Corderi, Kyle Hood, Nadejda Makarova Victor, Mukhtar Mohammed, Alexandra Miltner, and Jyldyz Weiss. The g-econ database on gridded output: Methods and data. Technical report, Yale University, 2006.
- D.C. North. Institutions, institutional change, and economic performance. Political economy of institutions and decisions. Cambridge University Press, 1990.
- Ilan Noy. The macroeconomic consequences of disasters. Journal of Development Economics, 88:221–231, 2009.
- Claudio Raddatz. Are external shocks responsible for the instability of output in low-income countries? Journal of Development Economics, 84:155–187, 2007.
- Claudio Raddatz. The wrath of god : macroeconomic costs of natural disasters. Policy research working paper series, The World Bank, September 2009.
- H. F. Reid. The mechanics of the earthquake, the california earthquake of april 18, 1906. Report of the state investigation commission, Carnegie Institution of Washington, Washington, D.C, 1910.
- Dani Rodrik, Arvind Subramanian, and Francesco Trebbi. Institutions rule: The primacy of institutions over geography and integration in economic de-

velopment. Nber working papers, National Bureau of Economic Research, Inc, 2002.

- David Roodman. How to do xtabond2: An introduction to difference and system gmm in stata. *Stata Journal*, 9(1):86–136, March 2009.
- Mark Skidmore and Hideki Toya. Do natural disasters promote long-run growth? *Economic Inquiry*, 40:664–687, 2002.
- Mark Skidmore and Hideki Toya. Economic development and the impacts of natural disasters. Technical report, Economic letters, 2007.
- David Strömberg. Natural disasters, economic development, and humanitarian aid. Journal of Economic Perspectives, 21(3):199–222, 2007.

Appendix

A Tables

Table A.1:

Effect of Earthquake Exposure on GDP growth, basic specification. Developing countries. OLS on equation 6.2.

	1	2	3
Earthquake Exposure	.748 (.671)	.860 (.779)	1.07 (.855)
Institutions		002 (.003)	001 (.003)
Earthquakes*Institutions			001 (.001)
Constant	.055*** (.012)	.050*** (.013)	.048*** (.013)
Observations:	575	519	519
Countries:	104	93	93
R-squared:	.003	.004	.008

Dependent variable: 5-year GDP growth rates, 1973-2007. Robust standard errors, clustered by country are reported in parentheses. *, ** and *** indicate significance at the 0.01, 0.05 and 0.1-level respectively. Only the poorest half of the countries in terms of income per capita are included in the regressions.

B Figures



Figure B.1: $lny_{it} - lny_{i,t-5}$ for different values of earthquake exposure. Country level.



Figure B.2: $lny_{it} - lny_{i,t-5}$ for different values of earthquake exposure. Regional level.



Figure B.3: Partial correlation between growth and earthquake exposure, impact cells.



Figure B.4: Partial correlation between growth and earthquake exposure, close call cells.



Figure B.5: Partial correlation between growth and earthquake exposure, impact cells - bottom decile of observations.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	1	11-111	IV	V	VI	VII	VIII	IX	Х+

 $\label{eq:source:http://earthquake.usgs.gov/earthquakes/shakemap/$