The Effects of Earthquakes on Infant Mortality Rates in Indonesia

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Abstract

In recent years, natural disasters have become more prevalent in the global community, making the understanding of their economic effects increasingly important. While some economists argue that natural disasters spur economic growth, others argue that the destruction of both human and physical capital hinders growth in the long run. This research tests the opposing perspectives through the specific study of the effects of earthquakes on infant mortality rates in Indonesian provinces from 1990-2015, using infant mortality as an economic indicator. Using United States Geological Survey data on earthquake shocks in Indonesia combined with Indonesian Family Life Surveys (IFLS) data on infant mortality and maternal characteristics from 1990-2014, we find a curvilinear relationship between the magnitude of earthquakes in the year prior to conception and infant mortality risk.

Introduction

In recent years, natural disasters have become more prevalent in the global community, making the understanding of their economic and health effects increasingly important. A vast literature examines how disaster-related destruction of human and physical capital hinders economic growth and health in the long-run. From a macroeconomic growth perspective, this destruction has been found to decrease GDP (Strobl 2012), particularly for developing countries that do not have the institutions to counteract negative effects of major disasters (Noy 2009; Toya and Skidmore 2007). At a micro-level, major natural disasters are found to negatively affect household consumption (Arouri et al. 2015), though resiliency depends on a number of factors including initial development level, access to credit, and social protection (Skoufias 2003). Natural disasters also impact individuals' health through exposure to stressors, which can contribute to health deterioration in utero (Torche 2018; Kudamatsu, Persson and Stromberg 2010).

While such evidence suggests that significant disasters are detrimental to economic and health outcomes, other literature suggests that natural disasters can spur economic growth. For growing economies, disasters can act as a form of creative destruction, such that reconstruction efforts stimulate the economy and bring new resources to the area (Skidmore and Toya 2002). Creative destruction suggests that the destruction of physical capital during a disaster can promote the creation and acquisition in new capital and more modern technology, particularly in developing countries (Noy 2009). Further, economic sectors involved in reconstruction can grow during recovery periods.

While many studies examine the effects of disasters of economic development and health, few studies directly measure how the severity of disasters in a given country account for the seemingly conflict evidence supporting both disasters and long-term economic hinderances and long-term economic stimuluses. This study uses 25 years of earthquake data in Indonesia to better understand how differences in the severity of a disaster may simultaneously provide evidence for the two hypotheses: that disasters are detrimental to long-term economic growth and health and that disasters spur economic growth and development. While relatively moderate disasters may act as a form of creative destruction for developing

communities, long-term economic and health problems likely arise from more catastrophic disasters. Infant mortality is an indicator of both economic develop and population health (Reidpath and Allotey 2003; Hauck et al. 2011, Zakir and Wunnava 1999); examining changes in infant mortality after disasters with varying levels of severity will allow us to better understand how different disasters influence potential economic growth and population health.

Using United States Geological Survey data on earthquakes in Indonesia combined with Indonesian Family Life Surveys (IFLS) data on infant mortality and maternal characteristics from 1990-2014, we examine how differences in the maximum magnitude of earthquakes in the year prior to conception form a curvilinear relationship with risk of infant mortality. In order to test this, we run models examining the effect of maximum magnitude on mortality with fixed effects for the province and year levels. Our results are consistent with the hypothesis that moderate level earthquakes decrease infant mortality in subsequent years, but that high magnitude earthquakes are associated with elevated infant mortality.

Background

Disasters and long-term outcomes

The impact of natural disasters on economic growth and overall development levels remains unclear, despite ample research in this field. Studies with contradictory findings often look at different natural disaster types in different settings (Loayza et al. 2012). In a meta-analysis employing over 750 estimations, Klomp and Valckx find a negative relationship between natural disasters and economic growth, which appears to be more pronounced in developing countries (2014). Widespread destruction can be more difficult to recover from in developing countries. Reconstruction efforts require high state capacity, and massive areas may be affected (Loayza et al. 2012). Furthermore, poor households are less able to replace productive assets, which can decrease their output (Loayza et al. 2012; Klomp 2016). Work by Felbermayr and Groschl examines natural disasters in 108 countries and echoes these results (2014). They find an overall negative impact on GDP, even after several years; finding is particularly strong when examining earthquakes.

Natural disasters may also be detrimental to birth outcomes, which are often used as indicators of population health and economic development (Reidpath and Allotey 2003; Zakir and Wunnava 1999). Further, adverse birth outcomes can have long-term impacts on both individuals' health and socioeconomic outcomes, making them important measures to consider when examining the impacts of natural disasters on a community (Barker 1995; Avison 2010). One study finds evidence suggesting that a significant earthquake acts as an environmental stressor and is associated with negative development outcomes among socially disadvantaged groups when the earthquake took place during the first trimester of the pregnancy (Torche 2018). Another study finds that infants born in arid areas experiencing droughts during their pregnancy face a higher risk of infant mortality (Kudamatsu, Persson and Stromberg 2010).

However, some studies find that natural disasters promote economic growth and development. In the long-run, higher numbers of natural disasters are associated with higher rates human capital accumulation, even though they are associated with decreases rates of physical capital investment, and increased total factor productivity, stemming from replacing and updating capital stock and technologies (Skidmore and Toya 2002). These findings are particularly relevant when studying disasters in developing communities. One study finds that earthquakes have a positive impact on industrial growth in 108 developing countries (Loayza et al. 2012). Physical capital destruction prompts the more intensified use of the remaining capital, as well as the creation of new capital, in these developing countries. This process employs other sectors involved in the reconstruction and can spur growth. One study finds that labor shifted from the agricultural sector to the construction sector as the demand for construction increased following an earthquake in Indonesia (Kirchberger 2017). These findings are consistent with the idea of creative destruction (Noy 2009).

Noy (2009) suggests that natural disasters become a form of creative destruction by forcing affected communities and countries to replace their older technologies and capital with improved technology and capital that exists. Thus, not only is the economy temporarily spurred by short-term boosts from rebuilding efforts that attract resources to the area, but the economy is also affected permanently in the long-run by

increased efficiency in production that results from more efficient infrastructure and the utilization of newer technology (Bennett 2008; Skidmore and Toya 2002).

Some studies find improved economic outcomes in the short-run, but that the economic indicators measured after disasters return to pre-disaster levels in the long-run. When examining the effect of hurricanes on labor market outcomes in Florida, one study finds an increase in real wages in counties directly affected by hurricanes in the short-run, as laborers move to neighboring, unaffected counties, decreasing the labor supply in the affect county (Belasen and Polachek 2009). However, as the laborers return to pre-disaster levels in each county hit by the hurricanes, the real wages return to pre-Hurricane levels. Thus, economic growth in some areas and markets may only hold in the short-run.

Variation in the type and intensity of a disaster, as well as the unique characteristics of a community and country, contributes to the variation in study findings. One study finds that natural disasters affect different economies in unique ways (Cuaresma, Hlouskova, and Obersteinern 2008). Among developing countries, only those that are relatively developed benefit from higher rates of new capital accumulation following disasters. Further, increased risk of disaster reduces knowledge spillovers, which are exchanges of ideas from developed countries to developing countries regarding techniques in production efficiency, economic set up, etc. Another study finds that different disasters have varying economic effects. Geophysical events—such as earthquakes—create more physical and capital damage compared hydro-meterological events or epidemics (Stromberg's 2007); this damage promotes a rebuilding effort in the affected area, increasing the labor supply demanded in that area and raising market equilibrium employed labor and wage. However, Loayza et al. note that creative destruction happens when the earthquake intensity is not too severe (2012). Few studies directly examine how severity of particular disasters account for variation in evidence. This leads to conflicting stories in the literature suggesting that disasters are both detrimental in the long-run and stimulate long-term growth.

Indonesia, earthquakes and infant mortality

In the 1970's, Indonesia began a period of vast demographic and economic change and is now considered an economic powerhouse in Asia (Belford 2010). The state of the developing economy in Indonesia suggests that moderate earthquakes could support more expediated development in the areas affected by the natural disasters: better healthcare, sanitation and building codes, as well as support increases in capital stock and technologies after the earthquakes' possible destruction. The Pacific island nation of Indonesia holds a considerable number of individuals susceptible to earthquakes. Located along the Ring of Fire, Indonesia is geologically placed among the most violent seismic activity in the Pacific Basin (Fackler and McDonald 2011). This provides variation in the number and severity of earthquakes that occur within a given province or year.

Natural disasters such as earthquakes are exogenous shocks that unexpectedly affect communities and economic markets (Belasen and Polachek 2009). In particular, earthquakes that result from global tectonic processes occur beyond the influence or control of humans;[1] scientists can statistically calculate the probability of future earthquakes in a given area, but they cannot predict a single earthquake or the effect of such an earthquake.[2] Further, earthquakes are often easy to measure, as their exact epicenter and severity can be calculated, and they typically occur quickly and without notice so that individuals cannot leave an area before and earthquake occurs. The exogeneity of earthquakes in Indonesian provinces and the precision of measuring the longitude and latitude of each earthquake epicenter both reduces possible endogeneity when examining disaster and development outcomes and allows us to easily associate every earthquake with a given geographic area (here: province) and date.

To examine the effect of an exogenous shocks, such as earthquakes, on economic development, infant mortality provides a comprehensive indicator of growth. Infant mortality rate is a common indicator used to examine economic development and describe population health. Infant mortality is measured as the

[1] "FAQs – Earthquakes, Faults, Plate Tectonics, Earth Structure," 27 October 2009, USGS Earthquake Hazard Programs, 5 November 2010. <http://earthquake.usgs.gov/learn/faq/?categoryID=1>.
[2] "FAQs – Earthquake Myths," 27 October 2009, USGS Earthquake Hazard Programs, 5 November 2010. <http://earthquake.usgs.gov/learn/faq/?categoryID=6>.

death of an infant within the first year of life. Infant mortality demonstrates the socioeconomic outcomes of a given region and is associated with the well-being of a population (Zakir and Wunnava 1999). Such rates demonstrate the current economic prosperity of a given region and indicate future economic prosperity. Areas with increased economic stability and success will have better healthcare and sanitation, lowering infant mortality rates and adverse birth outcomes. Improved infant mortality and birth outcomes are then associated with increased efficiency and productivity among workers in later life (Zakir and Wunnava 1999).. Further, infant mortality is an important indicator for population health and is a symbolic benchmark of how a nation cares for its future generations (Reidpath and Allotey 2003; Hauck et al. 2011). Infant mortality rates are also associated with negative health outcomes in later life, such as disability-adjusted life expectancies of populations (Reidpath and Allotey 2003).

This study explores the effect of earthquakes on infant mortality rates in Indonesian provinces to better determine the extent to which natural disasters strengthen a given economy's infrastructure and benefit population health. A linear regression model is tested to demonstrate the relationship between the dependent variable—infant mortality—on the independent variables-the maximum magnitude of earthquakes and the maximum magnitude squared within a given province year. The given province year corresponds to the province of birth, as well as the year prior to infant conception. This lag allows for the possible creative destruction process to occur during pregnancy and birth and disentangles the creative destruction process from the potential stress of an earthquake that may negatively impact birth outcomes if occurring during pregnancy.

We hypothesize that: (1) an overall increase in the maximum magnitude of earthquakes in a given province-year will decrease the odds of infant mortality, as such regions will have better healthcare services and building and health codes to account for the increased risk of disaster; and, (2) the exponentiated maximum of magnitude of earthquakes in a given province-year will increase the odds of infant mortality, such that earthquakes will the highest magnitudes are more likely to be more seriously destructive, making it more difficult to economies and communities to recover.

Data and Methods

Data

For this study, we merge data from the US Geological Survey (USGS) and Indonesia Family Life Survey (IFLS) to examine the effect of earthquakes on infant mortality rates in Indonesia. IFLS is a longitudinal survey conducted by RAND that collects data on family and community characteristics within 13 original provinces in Indonesia, which accounts for 83 percent of the nation's population. Surveys were conducted in 1993, 1997, 2000, 2007, and 2014. Our study includes pregnancy and birth data collected in waves 2 (1997), 3 (2000), 4 (2007), and 5 (2014). Pregnancy data is not included from wave 1 to preserve consistency in data collection processes and geographic IDs for our analysis. For our analysis, we use household data on married women's pregnancy experiences to calculate mortality; the unit of analysis is pregnancy, including only those pregnancies ending in live births. Each observation includes information on maternal characteristics, pre-pregnancy health and healthcare, and post-pregnancy infant health factors. This data was then merged to each household's data to included information regarding the urban/rural location of each household and province. Infant mortality measures whether an infant died within the first year of life.

The 1990-2014 USGS earthquake data include all earthquakes that occur in Indonesia that are considered 'significant' by the USGS. The classification of significance is based on magnitude of the earthquake, as well as the number of individuals who reported feeling the earthquake and the USGS PAGER (Prompt Assessment of Global Earthquakes for Response) alert level. While most earthquakes included in our study occurred on land, many significant earthquakes also occurred off the coast of Indonesia.[3] The earthquake data includes the date, longitude and latitude of the epicenter, magnitude, and depth of each earthquake. Earthquake data was collected by province-year, and province years without a significant

[3] The Indonesia terrain is composed mostly of coastal lowlands, making the populations more susceptible to the effects of earthquakes whose epicenters are located off the coast.

earthquake occurrence are given a magnitude of 0. Though some province-years have more than one earthquake recorded, over 95% of all province-years have 0 or 1 significant earthquake recorded.

Once compiled, the earthquake data was transferred into ArcMAP and plotted on an Indonesian shapefile to merge each earthquake with its appropriate Indonesian province (Map 1).

In the 13 original provinces in the IFLS study, 75 significant earthquakes were recorded between 1990 and 2014; 87 percent of the province-years had 9 earthquakes and about 9 percent of province years had 1 earthquake. The maximum magnitude earthquake recorded during this time measured 9.1 on the Richter scale, with a mean of 6.7 and a minimum magnitude of 2.9.

This earthquake data was then merged to Indonesian household and community data, collected from The Indonesian Family Life Survey (IFLS).

Methods

In order to test the impact of an earthquake on infant mortality, this paper employs fixed-effects logistic regression models. The fixed effects analysis examines how variation in earthquake levels within provinces and years corresponds to differences in infant mortality outcomes. This model alleviates concerns that infant mortality is merely a function of characteristics that vary at the province level (governance or geographic characteristics), or that we are merely identifying yearly variations in health outcomes.

The literature section above shows that there is potentially a non-linear relationship between magnitude and infant mortality. Creative destruction is only likely in cases where there is a moderate natural disaster, from which recovery is possible. Therefore, we assume that infant mortality will be reduced in cases where there was a moderate earthquake – but that infant mortality could increase for very large magnitude earthquakes. For this reason, we include a squared term on our main independent variable, maximum magnitude of earthquake. Birth years where no earthquake is observed receive a maximum magnitude of 0.

In order to allow for the process of creative destruction to take hold, we lag all of the shock variables such that earthquakes that occurred in the period 365 days preceding conception are recorded.

The main model estimated is:

$$Inf\ mortality_{pt} = \alpha + \beta_1 magmax_{p(c-1)} + \beta_2 magmax^2{}_{p(c-1)} + \beta_3 \chi_{pt} + \beta_4 \theta_{pt} + \delta_p + \gamma_t + \varepsilon_{pt}$$

Here, *p* is an indicator for province, *t* is an indicator for birth year and *c-1* an indicator for the year prior to conception. *Inf mortality* is a dummy variable for whether a child passed away before the age of 1, *magmax* is the maximum magnitude on the Richter scale recorded if there was at least one earthquake in the 365 days preceding conception in that province year, and takes on a 0 if there were none. *X* is a vector of mother's characteristics, θ_{pt} is a vector of the child's characteristics, δ_p is an indicator for province and γ_t is an indicator variable for year. ε_{pt} is the error term.

A number of models are presented in the appendix of the paper. The first two models estimates the impact of maximum magnitude on infant mortality controlling for mother and pre-birth characteristics, as well as whether the child was a male or born premature. Models 1 and 2 include province and year and province fixed effects, respectively.

Models 3 and 4 are similar to models 1 and 2, but include post-birth covariates indicating whether the child was ever breastfed and whether the mother had post-natal checkups within the first 40 days of birth. Models 3 and 4 include province and year and province fixed effects, respectively.

Therefore, the most complete model presented is model 6, which includes a full set of controls as well as fixed effects for province and year, and is robust to different standard error specifications including clustered and robust.

In a future version of this paper, we plan to perform a number of additional analyses and robustness checks. Firstly, we plan to estimate the same equation with province-level infant mortality rates and additional economic indicators at the province level in Indonesia. This can serve as additional evidence of our findings.

We also plan to use geographic coordinate data of the longitude and latitude of earthquakes, as well as the coordinates of respondent communities in our analysis. This overcomes the limitation of using province-level shocks which may not perfectly identify those births most affected by the earthquake(s). Furthermore, more precise geographic data will allow us to capture heterogenous effects of distance from the epicenter.

In order to understand the mechanism explaining the relationship between infant mortality and earthquakes, we also plan to stratify provinces by income or other state and local capacity variables. If moderate earthquakes are less likely to prompt creative destruction in situations where reconstruction is difficult and resources are too scarce, then we hypothesise that we will see a stronger negative impact on infant mortality in higher capacity provinces than in lower ones.

Results

Table 1 in the Appendix below shows descriptive statistics. The average maximum magnitude for earthquakes by province year is 6.8 for province years that experienced at least one earthquake. For all province years this number decreases to 0.674. The average number of earthquakes is 1.744 for province years that experienced at least one earthquake. For all province years this decreases to 0.173. There is a total of 75 earthquakes in the dataset.

Of the 17,325 births in the data, there are 466 infant deaths. The infant mortality rate is 26.9. The average age of mother at birth is 27 and a plurality of births have mothers with a high school education (31.6 %) followed by elementary education (31.1%). Around 80% of births were to mother's who received the tetanus toxoid injection (tt inject) which reduces a child's chance of seizing at or near birth. Over half of the births occur in urban areas, and 51.7% of births are male.

We run several checks to ensure that the earthquakes are not responsible for significant variation in our control variables. Most importantly, we find that births are not more likely to be male following an

earthquake shock. This indicates no imbalance in the sex ratio which could be linked to traced back to the earthquake.

Table 2 in the Appendix shows 6 models that we have run, with the 6th being the specification with all of the controls including province and year fixed effects. Results are reported as log-odds.

There is a significant relationship between maximum magnitude and infant mortality. More specifically, the significant and positive coefficient on the square maximum magnitude term and the negative coefficient on maximum magnitude, indicate that, as predicted, there is a curvilinear relationship between infant mortality and maximum magnitude. This is predicted by our theory above. Severe earthquakes are more likely to damage a responders house or local healthcare center, as well as injure the responder or the infant. Thus, an increase in the severity of an earthquake that the area experiences will be associated with higher infant mortality. At low levels of magnitude, earthquakes are unlikely to cause any substantial shift in infant mortality levels. For this reason, the observed coefficients indicate that moderate earthquakes decrease the likelihood of infant mortality, consistent with our predictions.

Discussion

The significant and curvilinear relationship between earthquake maximum magnitudes and infant mortality provide new evidence of how natural disasters affect health outcomes. Despite ample literature on the mixed effects of natural disasters on both health and economic development, it was not clear in this context how earthquakes would affect infant mortality. On one hand, a number of papers have found disasters to have positive effects on welfare (see Skoufias, 2003). However, these and other positive effects were found to be attenuated in developing countries, which include Indonesia (Loayza et al. 2012; Klomp and Valckx 2014).

The findings stated here are consistent with the creative destruction theory put forth in Skidmore and Toya (2002). In the case of Indonesia, earthquakes may be causing the affected areas to increase their standard of livings in order to better prepare for the next earthquake, or resources may be coming to affected

areas through aid, relief, or reconstruction efforts. This, in turn, creates an environment where new mothers have access to increased resources both in the clinic and at home. A micro version of this explanation would be that local clinics needed to replace machinery following a moderate earthquake, giving women in affected areas access to higher quality medical technology than previously.

Future iterations of this paper will seek to better understand the mechanism of creative destruction operating in Indonesia. For example, we hope to look at the effect in both high capacity and low capacity areas separately. Furthermore, we hope to include aid, expenditure or public funding data that may help us understand the process through which creative destruction happens more precisely.

We also hope to explore other stories that may be consistent with our results. For example, moderate earthquakes may cause women who are more frail or have reason to be concerned about their child's health to delay their fertility. This could artificially put downward pressure on infant mortality in the periods following these earthquakes. Future versions of this paper will check fertility rates to ensure this is not the case.

Understanding the impact of earthquakes on health more broadly, and infant health more specifically is particularly important as extreme weather may prompt increased disasters over time. Developing countries are likely to bear the brunt of these disasters, and citizens in the developing world are often more vulnerable. The data and methods presented here offer a unique perspective on this puzzle and provides new evidence of the relationship between earthquakes and infant mortality, which could be important in designing resilience or public health policy.

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Maps and Tables

Map 1 - Indonesia Provinces and Earthquakes

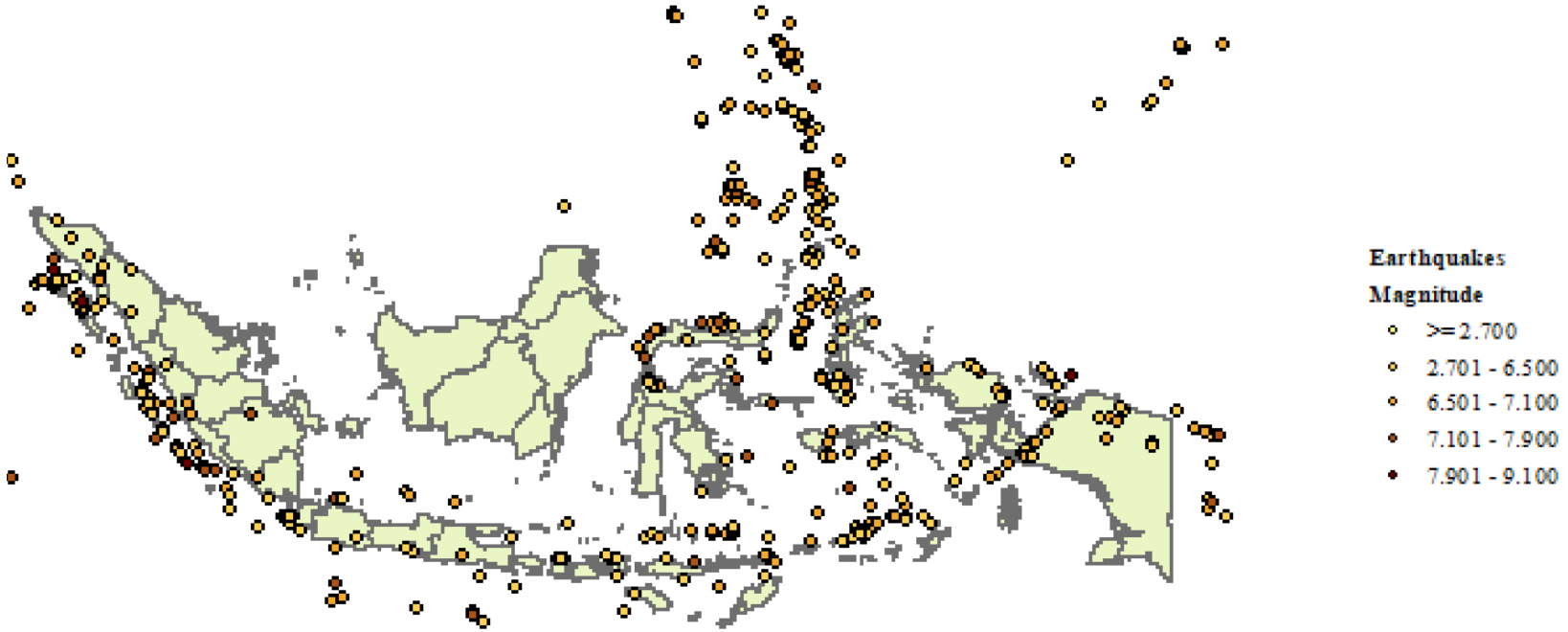

Table 1. Descriptive Statistics of Sample

Variable	Mean or Proportion	Standard Deviation
Earthquake Variables		
Maximum Magnitude (by Province year if >0)	6.805	0.553
Number of Quakes (by Province year if >0)	1.744	0.640
Maximum Magnitude (by Province year)	0.674	2.043
Number of Quakes (in Province year)	0.173	0.680
Dependent Variable		
Infant Mortality	0.027	0.162
Mother's Characteristics		
Mother's Education		
None	0.022	0.146
Elementary	0.311	0.463
Junior High	0.228	0.420
High School	0.316	0.465
Tertiary	0.118	0.323
Other	0.005	0.069
Age of Mother at Birth	27.114	5.987
Married	0.975	0.157
Received TT injection	0.804	0.397
Premature birth	0.086	0.281
Ever breastfed	0.964	0.186
Multiple births	0.038	0.192
Male infant	0.517	0.500
Check-up within 40 days	0.367	0.482
Urban Area	0.537	0.499
Count of Births	17, 325	
Count of Earthquakes	75	
Infant Mortality (Number)	466	

Table 2. Log Odds Ratio of Infant Mortality

	Model 1		Model 2		Model 3		Model 4	
Earthquakes' characteristics								
Maximum magnitude	-0.481*	[0.234]	-0.459	[0.240]	-0.616*	[0.248]	-0.562*	[0.254]
Sq. of max. magnitude	0.0688*	[0.0335]	0.0667	[0.0344]	0.0873*	[0.0354]	0.0808*	[0.0363]
Maternal characteristics								
Lives in urban area	-0.332**	[0.109]	-0.343**	[0.109]	-0.368**	[0.117]	-0.375**	[0.117]
Educational Attainment								
Elementary	-0.878**	[0.212]	-0.912**	[0.214]	-0.879**	[0.229]	-0.930**	[0.231]
Junior High	-1.034**	[0.231]	-1.068**	[0.233]	-1.056**	[0.249]	-1.097**	[0.250]
High School	-1.389**	[0.235]	-1.426**	[0.237]	-1.357**	[0.251]	-1.410**	[0.253]
Tertiary	-1.495**	[0.277]	-1.516**	[0.278]	-1.501**	[0.296]	-1.552**	[0.298]
Other	-1.220	[0.761]	-1.222	[0.762]	-0.976	[0.775]	-1.007	[0.782]
Mother's age at birth	0.00021	[0.0081]	0.00054	[0.0081]	-0.0102	[0.0085]	-0.0102	[0.0086]
Pregnancy characteristics								
Received TT injection	-0.0650	[0.120]	-0.0625	[0.121]	-0.00846	[0.128]	0.00211	[0.129]
Multiple births	0.704**	[0.186]	0.683**	[0.188]	0.692**	[0.205]	0.669**	[0.208]
Male infant	0.476**	[0.0992]	0.482**	[0.0995]	0.429**	[0.106]	0.432**	[0.106]
Premature birth	1.882**	[0.109]	1.893**	[0.110]	1.517**	[0.122]	1.517**	[0.123]
After birth characteristics								
Ever breastfed					-3.087**	[0.121]	-3.081**	[0.122]
Check-up within 40 days					-0.252*	[0.115]	-0.253*	[0.119]
Constant	81.57**	[16.22]	-4.813**	[1.089]	97.76**	[17.63]	-1.637	[1.119]
Province fixed effects	YES		YES		YES		YES	
Year fixed effects			YES				YES	
Observations	17244		17230		17244		17230	

Standard errors in brackets. * $p < 0.05$, ** $p < 0.01$, ** $p < 0.001$