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Abstract

An increasing number of studies analyze the relationship between natural disaster damage and income levels, but they do not consider the distinction between public and private disaster mitigation. This paper empirically distinguishes these two types of mitigation using Japanese prefectural panel data from 1975 to 2007. Our results show that public mitigation rather than private mitigation has contributed to mitigating the total damage resulting from natural disasters. Our estimation of cost-benefit ratios for each prefecture confirms that the mitigation efforts of urban prefectures are less effective than those of rural prefectures in focusing on frequent and small disasters. Hence, the national budget for their mitigation investments and support must shift from urban prefectural governments to rural governments. Furthermore, to lessen the damage resulting from extreme catastrophes, policy makers should invest in improved mitigation infrastructures when faced with a high probability of disasters.

Keywords: public mitigation; natural disaster; cost-benefit ratio; urbanization;
JEL Classification: H54, Q54, R53

1. Introduction

Natural disasters have caused tremendous damage throughout the world. In March 2011, a 9.0-magnitude earthquake struck Japan and resulted in more than 20,000 people considered either dead or missing. The 2004 Indian Ocean tsunami that was caused by an earthquake killed approximately 230,000 people in Southeast Asia. More than 60,000 people were victims of the 2008 Sichuan earthquake in China. These examples show that natural disasters cause massive losses in many countries. [1] In addition, climate change is expected to lead to an increase in extreme weather events and thus result in further damage (IPCC, 2007).

Unlike for other externalities, such as crime and pollution, we cannot control the number of natural disasters because they occur exogenously. Therefore, disaster damage reduction activities (i.e., mitigation) are important. The anticipation of and response to natural disasters require advances in the use of effective mitigation activities. Two countermeasures are addressed in this study: public mitigation and private mitigation.

The first countermeasure is public mitigation. To prevent or mitigate the damage incurred as a result of natural disasters, governments have an important role in providing disaster prevention infrastructures, such as dams, levees and flood control basins. The second countermeasure is private mitigation. Households can choose between several self-protection strategies, such as moving to less risk-prone areas, investing in building reinforcement or purchasing insurance based on their income (Smith et al., 2006).[2]

There is accumulating evidence regarding the relationship between fatalities/damage from disasters and mitigation measures. For example, using data from 73 countries from 1980 to 2002, Kahn (2005) finds that countries with high gross domestic product (GDP) per capita suffer fewer deaths from natural disasters compared with countries with low GDP per capita. Similarly, using data from 151 countries from 1960 to 2003, Toya and Skidmore (2007) reveals that the economic damage resulting from disasters in wealthy countries is less than the damage incurred in poor countries. Kellenberg and Mobarak (2008) show that the relationship between GDP per capita and death tolls is an inverted U-shape, which is similar to the environmental

[1] The economic loss and death toll resulting from 335 natural disasters in 2009 were approximately $41.3 billion and 10,655 people, respectively (Vos et al., 2010).
[2] See Kousky et al. (2006) for a discussion of the theoretical relationship between private investment and governmental protection.

Kuznets curve hypothesis (Grossman and Krueger, 1995).[3] These previous studies indicate that an increase in GDP per capita in developed countries leads to a decrease in natural disaster damage.

These studies apply GDP per capita do not explicitly distinguish public and private mitigation. Anbarci et al. (2005) suggest separating public and private mitigation measures for future studies. We distinguish these two measures using Japanese prefecture-level data. These data enable us to examine the reduction effects of public and private mitigation on disaster damage.

There is an additional advantage to using Japanese prefectural data. Unlike cross-country analysis, these data allow differences in detailed socio-economic and physical conditions to be incorporated into the examination of relationships. For example, geographical conditions, such as the absolute value of latitude and elevation, are key determinants of the damage that results from disasters (Kahn, 2005). Therefore, the geographical characteristics of Florida and Illinois in the United States clearly differ despite the location of these two states in the same country.

Furthermore, most previous studies have restricted their attention to medium- and large-scale natural disasters using the Emergency Events Database (ED-MAT)[4] (Kahn, 2005; Toya and Skidmore, 2007; Kellenberg and Mobarak, 2008) or to earthquakes based on the National Geophysical Data Center (NGDC)'s Significant Earthquake Database[5] (Anbarci et al., 2005; Escaleras et al., 2007)[6], but no previous studies have considered all types and scales of natural disasters due to the lack of data. The Fire and Disaster Management Agency in Japan provides all types of natural disaster damage data for each prefecture in its official statistics. Thus, we collect data pertaining to catastrophes (or large-scale specific disasters) and small-scale and infrequent disasters.

An increase in the number and intensity of natural disasters is likely in Japan (Guha-Sapir et al., 2004). However, there is considerable variation in the levels of disaster damage at the prefectural level. For instance, the total economic damage from 1975 to 2007 in

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3 In addition, Anbarci et al. (2005) show that GDP per capita and inequity have negative and positive influences on fatalities resulting from disasters based on their analysis of 269 earthquakes from 1960 to 2002. Escaleras et al. (2007) obtain the same results in line with the literature.

4 The ED-MAT is provided on the website of the Centre for Research on the Epidemiology of Disasters: http://www.emdat.be/.

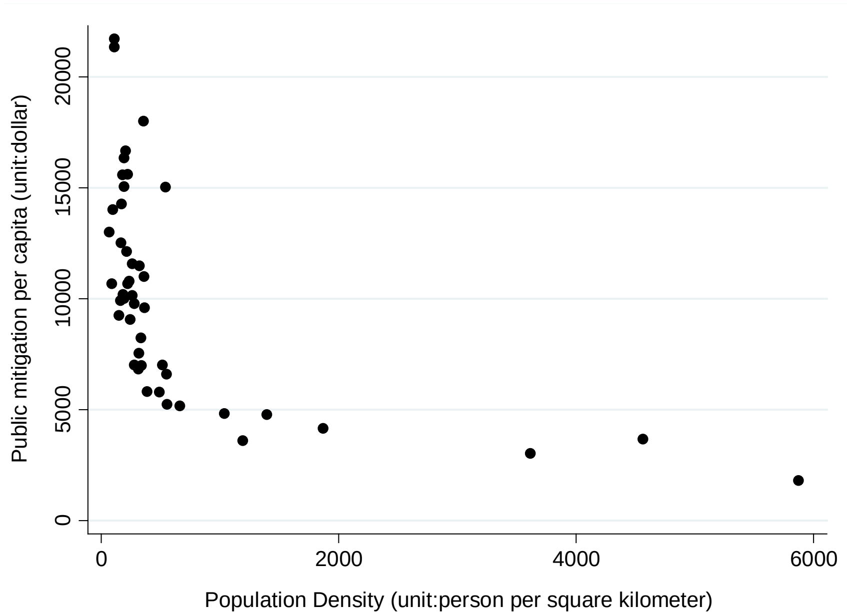
5 This database is published on the NGDC's website: http://www.ngdc.noaa.gov/ngdc.html.

6 Many studies have focused on measuring the effects of specific catastrophes, such as the Great Hanshin-Awaji Earthquake in Japan in 1995 (Hyogo Prefecture, 2008), Hurricane Andrew in 1992 (West and Lenze, 1994; Hallstrom and Smith, 2005), and Hurricane Katrina in the United States in 2005 (Baade et al., 2007).

the Hyogo prefecture was about US$ 81.4 billion as evaluated in 2007. This damage was primarily caused by the Great Hanshin-Awaji Earthquake (GHAE).[7] However, the damage during the same period in the Kanagawa prefecture was only $500 million.

Mitigation requires cost-effective implementation from economic perspective. There is wide variation in public mitigation measures among prefectures during our study periods. The public mitigation measures in this study represent disaster prevention infrastructure in mountains, rivers, and seashores (the detailed explanation will be provided in section 2)..For example, public mitigation per capita ranges from $1,807 to $21,696 per person in 2007 (see Figure 1). Public mitigation per income also varies; these measures range from 4.7 to 124.1% in 2007 (see Figure 2). Consequently, if there are large differences in the efficiency of public mitigation measures among prefectures, these differences could result from varying levels of economic damage because the economic damage is highly related to population density. Therefore, we also estimate the cost-benefit ratios of public mitigation and compare these ratios among prefectures. A more detailed discussion of our reasons for considering prefectural population density for the cost-benefit ratio is provided in Appendix 1.

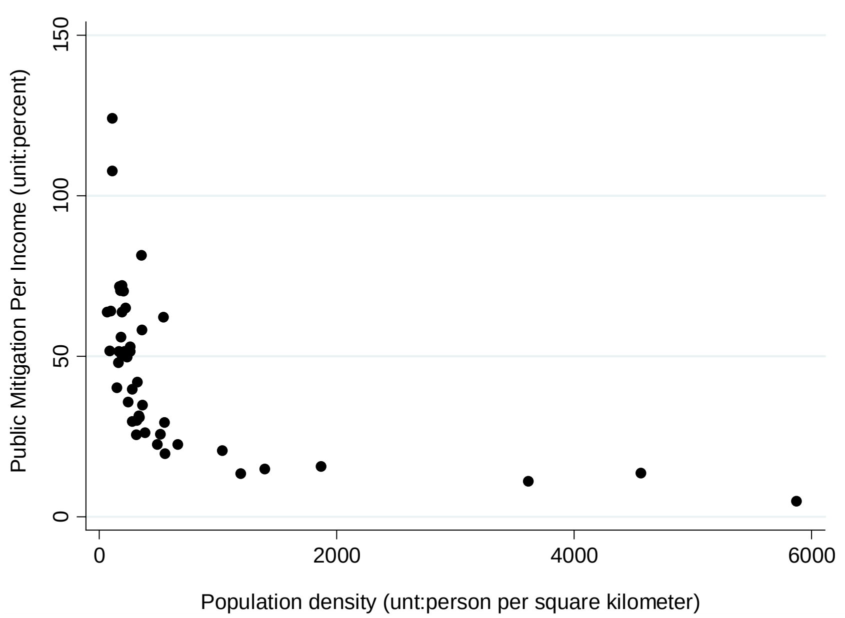
Figure 1. Public Mitigation Per Capita by Prefecture in 2007



Note: Obs.=46.

[7] The GHAE caused 6,437 deaths and 43,792 injuries in 1995.

Figure 2. Public Mitigation Per Income by Prefecture in 2007



Note: Obs.=46.

Ideally, if governments are aware of the true risks of prefectural disasters, such as the annual probability of a large earthquake occurrence, they can construct proper mitigation measures according to those risks. Then, when sufficient long-term data reflecting the exact risks are available, no difference among the efficiency of prefectural mitigation should be observed (however, we cannot obtain such data). If the measured cost-benefit ratios show significant variation between prefectures, it is considered that some prefectures provide their mitigation measures inefficiently as an ex-post judgment. Though there is indeed a limitation in our estimation due to the unknown true disaster risks, our ex-post evaluation of disaster countermeasures is valuable for policymakers.

Typically, analysts report the collection of more taxes in wealthy urban areas, but some of the collected tax is used for less wealthy rural regions as part of the national tax policy. Thus, the total social infrastructure is less sufficient in urban areas than in rural areas. Therefore, these expenditures must be allocated more toward urban regions (Yamano and Ohkawara, 2000). However, public mitigation which is a part of social infrastructure has not been evaluated from the ex-post viewpoint. Therefore, we estimate the efficiency levels and provide a discussion regarding the allocation of public mitigation measures between rural and urban prefectures.

This paper is organized as follows: Section 2 describes the empirical framework. Sections 3 and 4 present our data set and estimation results. Section 5 provides the estimated cost-benefit ratios for each prefecture and a discussion regarding the efficiency of disaster prevention measures. Section 6 provides the conclusion.

2. Empirical Model

2.1. Natural Disaster Damage

The benefits generated by public mitigation (prevention measures) are divided into three components (Ministry of Land, Infrastructure, Transportation and Tourism (MLITT), 2004): reductions in human capital loss, physical capital loss, and psychological loss. Human capital loss refers to the number of deaths, as well as missing and injured people, caused by natural disasters.

Physical capital loss consists of primary and secondary economic damage based on the duration of a natural disaster. Primary economic damage is the direct destruction of public or private infrastructure, such as roads, buildings or houses, and products that may include crops or goods. Secondary economic damage represents the indirect economic loss arising from primary economic damage, such as stagnation in logistics. Due to the lack of data sources, we obtain only primary economic damage data.

Psychological loss is the human anxiety that results from natural disaster occurrences. There are several approaches to measuring reductions in psychological loss, including the contingent variation method. However, it is difficult to obtain data pertaining to the number of people who experience anxiety as a result of natural disasters. Therefore, our data do not include psychological loss. This paper focuses on the human capital loss and physical capital loss associated with primary economic damage. Therefore, the levels of natural disaster damage defined in this paper are lower than the actual levels of damage.

Suppose that human capital damage (*HDM*) is composed of deaths (including missing people) and minor/major injuries. The total damage, TDM_{it}, in year t in prefecture i is defined as the summation of the economic damage (*EDM*) and *HDM*, as shown in equation (1). Let *ND* be the number of deaths, and *NMI* and *NMA* be the number of minor and major injuries caused by natural disasters. In addition, let *VSL* be the value of a statistical life, and *OCMI* and *OCMA* be the opportunity costs for minor and major injured people, respectively.

$$TDM_{it} = HDM_{it} + EDM_{it}$$
$$HDM_{it} = ND_{it} \cdot VSL_{it} + NMI_{it} \cdot OCMI_{it} + NMA_{it} \cdot OCMA_{it} \quad (1)$$

In this paper, it is necessary to determine the value of a statistical life and the opportunity costs. We use data from previous studies to generate these parameters using the following procedure.

There is abundant literature pertaining to the value of a statistical life in the United States (Viscusi and Aldy, 2003). However, there is minimal literature regarding this topic for Japan. One representative study includes the estimates provided by Tsuge et al. (2005), in which the value is approximately \$2.5 million, as evaluated in 2007. We established this value as the value of a statistical life in Japan.

In addition, considering the differences in the substantial price levels between years and between income levels among prefectures, we set DEF_t as the GDP deflator and INC_t as the average income per capita in year t. Then, we calculate the value of a statistical life, as evaluated in 2007, by year and by prefecture using the following formula.

$$VSL_{it} = 2.5\,(million\ dollar) \times \frac{DEF_{2007}}{DEF_t} \times \frac{INC_{it}}{INC_t} \quad (2)$$

We consider the loss of time required to completely recover from the damage as the opportunity cost for the injured. People suffering minor and major injuries due to an earthquake have an average recovery time of 8.8 and 55.6 days, respectively (Non-Life Insurance Rating Organization of Japan, 2001). Therefore, the opportunity costs, *OCMI* and *OCMA*, can be calculated based on the loss of income during hospitalization as follows.

$$OCMI_{it} = 8.8 \times INC_{it} / 365$$
$$OCMA_{it} = 55.6 \times INC_{it} / 365 \quad (3)$$

2.2. Damage Function

The public mitigation measures in this study include the social infrastructure associated with the protection of mountains, rivers, and seashores. The information pertaining to this social infrastructure is provided by the Cabinet Office (2007). The social infrastructure of mountains and rivers represent infrastructures for flood control and sand prevention, such as dams, levees, and groins. Alongshore, bulwarks and wave-dissipating blocks are types of social infrastructure.[8]

Public mitigation is intuitively expected to reduce natural disaster damage. Private mitigation may also reduce damage because wealthier people can afford to invest in self-protection activities, such as reinforcing their homes and moving to areas in which the natural disaster risks are low (Smith et al., 2006).

Furthermore, we are certain that the extent of damage also depends on the following three factors. The first factor is the social factor. If two massive earthquakes with the same scale occur in highly and sparsely populated prefectures at the same time, ceteris paribus, most of us intuitively expect that the number of injured people is larger in the highly populated prefecture than in the sparsely populated prefecture. Therefore, factors relating to social structure, such as population, affect the extent of damage that may be incurred.

According to Kahn (2005), the second issue is the geological factor. For instance, high tide does not occur in inland prefectures. People who live in prefectures without volcanoes do not suffer damage from volcanic explosions. Thus, the geographical characteristics of prefectures also influence the extent of damage that may be incurred.

Finally, the climate factor includes temperatures and rainfall amounts. Prefectures that experience heavy snow and rain are likely to face snow disasters, torrential rain, and subsequent landslides. Because these disasters cannot be completely captured by the geological factors, we incorporate the climate factors as determinants of the damage function.

Previous studies, such as Kahn (2005), Anbarci et al. (2005), Toya and Skidmore (2007), Escaleras et al. (2007), and Kellenberg and Mobarak (2008), have used GDP per capita as a proxy because high-income people are able to prevent damage (i.e., private mitigation) and/or wealthier governments can provide more effective disaster prevention projects (i.e., public mitigation). However, income level, which is actually a form of private mitigation, is not a sufficient variable with which to capture public mitigation efforts because *public* authorities invest in and construct disaster mitigation stocks in consideration of the society,

[8] The Cabinet office (2007) provides the social capital information regarding mountains, rivers, and seashores by prefecture only for 5 years. Therefore, we regress the capital in terms of year and squared year for each prefecture, and then we predict the missing values of social capital. The quadratic form is applied because the adjusted R-squares are approximately 0.99 in all estimations.

whereas *private* households do not have significant incentives to help unknown people in their society. In fact, the correlation between the income per capita (i.e., private mitigation) and the public mitigation stock per capita is only 0.32 in our dataset. Therefore, this study separates private and public mitigation measures using two different variables.

We estimate the damage function using equation (4). The dependent variable is the total damage per GDP, and the independent variables are the public mitigation stock (*PPS*) per capita, the income per capita (private mitigation) and the other control vector (**X**), as previously discussed. We convert all variables into logged values to consider the potential non-linear relationships between damage and mitigation.

$$\ln(\frac{TDM_{it}}{GDP_{it}}) = \alpha_1 \ln(\frac{PPS_{it}}{POP_{it}}) + \alpha_2 \ln(\frac{INC_{it}}{POP_{it}}) + \mathbf{X}_{it}\boldsymbol{\beta}' + \mu_i + \varepsilon_{it} \quad (4)$$

where α_1, α_2 and $\boldsymbol{\beta}$ are the parameters to be estimated, and μ and ε are the unobserved prefectural specific effect and error terms, respectively. To avoid endogeneity of residential choice problem on the population density, we use lagged population density in the estimation, similar to Wagner(2010).

The control vector **X** refers to the social, geological, and climate factors. We set the population density as a social factor. To account for geological factors, we apply the average degree of slant, the coastal length and the number of active volcanoes. The annual rainfall amount, maximum temperature, annual snow accumulation, number of approaching typhoons, and dummy for earthquakes with an intensity greater than 5 are applied for the climate factors. The threshold intensity of 5 is chosen because earthquakes that exceed this threshold not only affect human activity but also damage houses, the ground and lifelines, which are defined by the Meteorological Agency in Japan.

For the other determinants, we incorporate two dummy variables to control for the extreme effects of the GHAE and catastrophes. The dummy for GHAE is one in the 1995 Hyogo prefecture. Another dummy variable of one is used for catastrophes if there has been a catastrophe claiming more than 100 lives.

3. Data Sources

Our dataset includes Japanese prefectural panel data from 1975 to 2007, except for the Okinawa prefecture.[9] The data sources for each variable are as follows. Information regarding human and economic damage was obtained from the annual *White Book on Fire Service in Japan* published by the Fire and Disaster Management Agency. The white book reports the number of fatalities and injured people and the primary economic damage by year and by prefecture.

The amount of disaster prevention infrastructure stock in the form of public mitigation is obtained from the Cabinet Office (2007). We obtained population and income information from the annual *Basic Resident Register Population Survey* and the *Annual Report on Prefectural Accounts* published by the Japan Geographic Data Center and by the Cabinet Office, respectively. Data pertaining to the geographical characteristics for each prefecture were obtained from the *Survey of the Land Area for Shi, Ku, Machi, and Mura of Japan* and *Digital National Land Information* published by the Japan Map Center and by MLITT for the information regarding prefectural areas and regarding the coast length and average degree of the slant, respectively. The climate data were obtained from the Japan Meteorological Agency's website database.

The descriptive statistics for each variable are shown in Table 1, including decompositions of the natural disaster damage. The sample size of the dataset in our estimation is 1,457 (that is, 32 years multiplied by 46 prefectures minus 15 missing values because we employ first-year lagged population density).

The mean of the total damage per GDP is approximately 0.590%. Dividing this value into economic damage and human damage, we find that the mean of economic damage per GDP is 0.582%, which is up to 95% of the total damage. However, human capital damage accounts for only 5% of the total damage. Hence, most natural disaster damage results from direct physical destruction. The contribution ratio of human capital damage to total damage increases as the applied value of a statistical life increases. However, even if the value of a statistical life doubles, the economic damage still constitutes a significant portion of the natural disaster damage. Therefore, it is important for governments to place greater emphasis on preventing economic losses that result from natural disasters.

[9] There are 47 prefectures in Japan. A prefecture is roughly equal to a county in the United States.

Table 1. Descriptive statistics and data sources

	variables	unit	mean	s.d.	minimum	maximu	Source
Damage	Total damage per GDP	percent	0.590	1.954	1.18E-06	59.20	White Book on Fire Service in Japan
	Human capital damage per GDP	percent	0.028	0.302	0	11.08	White Book on Fire Service in Japan
	Economic damage per GDP	percent	0.562	1.694	7.88E-07	48.12	White Book on Fire Service in Japan
Preparation	Public Preparation per capita	$1,000/person	5.373	3.593	0.612	21.70	Cabinet Office (2007)
	Self Preparation per capita	$1,000/person	19.41	4.487	10.224	38.28	Annual Report on Prefectural Accounts
Social	Population density	person/square km	593.54	1035.45	64.37	5878.35	Basic Resident Register Population
Geological	Average degree of slant	degree	18.73	4.947	6.900	27.80	Digital National Land Information
	Length of shore	km	663.39	800.55	0	4139.30	Digital National Land Information
	number of active volcano		2.017	3.112	0	16.00	Japan Meteorological Agency
Climate	Annual rainfall	mm	1602.36	529.73	555.50	4383.00	Japan Meteorological Agency
	Maximum temperature	Celsius degree	35.69	1.640	29.10	40.90	Japan Meteorological Agency
	Snow accumulation	cm	88.92	165.33	0	1263.00	Japan Meteorological Agency
	number of approaching typhoon		2.951	1.762	0	10.00	Japan Meteorological Agency
	Dummy for earthquake with more than intensity 5		0.085	0.279	0	1.00	Japan Meteorological Agency
Other	Dummy for catastrophes		0.004	0.064	0	1.00	White Book on Fire Service in Japan
	Dummy for GHAE		0.001	0.026	0	1.00	White Book on Fire Service in Japan

Note: Obs.=1457. Monetary values are converted into U.S. dollars as evaluated in 2007.

4. Estimation Results

Table 2 presents the results of estimating the damage function, i.e., equation (4). The dependent variable is the logged total damage per GDP (*TDM/GDP*). We provide several specification results for the robustness check and a comparison with the results from previous studies.

Model 1 and models 2 through 4 represent the estimation results with and without prefectural fixed effects, respectively. To capture the unobserved prefectural specific effects, we use fixed effects estimator in model 2 to 4. In addition to fixed effects, an endogenous problem is considered in models 3 and 4. In the structure of equation (4), the income per capita is endogenous rather than exogenous because both sides of equation (4) contain the income variable. To avoid the endogenous problem, we employ an instrumental variable estimator, in which the current income per capita depends on the previous value and the previous disaster damage levels. We apply the number of dead and missing people as the damage level. In addition, we conduct the serial test for autocorrelation introduced by Wooldridge (2010), and we find evidence of an autocorrelation. Therefore, the heteroscedastic and autocorrelation consistent standard errors are used in models 3 and 4. In model 4, one independent variable, logged public mitigation per capita, is excluded to enable a comparison of the estimation results of previous studies.

Let us discuss the results from models 1 through 4, in which the independent variable is the total damage per GDP. The overidentification tests indicate that model 3, in which the prefectural fixed effects and endogeneity of income are included, is the most feasible result. Although both public and private mitigation are statistically significant and negative in model 1, public mitigation is not significant when we consider the prefectural fixed effects in models 2 and 3. Even when we consider the endogeneity problem in model 3, the coefficient of public mitigation is significantly negative, but that of private mitigation is not. Therefore, private mitigation has no robust influence on the reduction of the total natural disaster damage.

However, private mitigation may not be observed accurately on the basis of income level. There is one survey in Japan reported by Kobe Shinbun (2011). Two prefectures are compared: Hyogo prefecture, where the GHAE occurred in 1995, and Shizuoka prefecture, where there is a high probability that a large earthquake will occur within 30 years. The results show that the residents of the Hyogo prefecture undertook greater measures to prepare for a large earthquake than those in the Shizuoka prefecture. This evidence demonstrates that the extent to which people protect themselves depends on their past experience, and income levels may not accurately reflect the extent of individual mitigations for private mitigation. As a result, the expectation that wealthier people can reduce disaster risks in various ways (see Smith et al. (2006) regarding the United States) may not be relevant in Japan.

Furthermore, when we eliminate public mitigation from the determinants as in model 4, private mitigation is significantly useful for reducing disaster damage. This result is consistent with the results from previous studies. Therefore, we can conclude that the income per capita used in the literature cannot capture both types of mitigation and that public mitigation has an important role in decreasing disaster damage. Therefore, in examining the relationship between disaster mitigation and damage, we must place strong emphasis on the differences between public and private mitigation.

The coefficients of population density and length of shore for the other determinants are significantly negative. Therefore, sparsely populated (rural) and inland prefectures are likely to face more natural disaster damages[10]. Pluvial areas are also likely to suffer greater damage because the coefficient for these areas is positive at a 1% significance level. Although the dummies for large earthquakes and the number of approaching typhoons have significant positive effects on the levels of damage, the number of active volcanoes does not have a significant robust effect.

[10] The natural disaster damages in this paper include not only human damages but also economic damages. In addition, the damages are divided by prefectural GDP. Therefore, the results are not surprising though we intuitively suppose that coastwise prefectures are likely to suffer more human damages caused by tsunami.

Table 2. Estimation results for the damage function: the independent variable is *logged total damage per GDP (DMG/GDP)*

Dependent Variables	***ln(TDM/GDP)***											
	Model 1			**Model 2**			**Model 3**			**Model 4**		
Independent Variables	*Coef.*	*S.E.*		*Coef.*	*S.E.*		*Coef.*	*S.E.*		*Coef.*	*S.E.*	
logged Public Mitigation per capita	-0.306	0.117	***	-1.096	0.200	***	-1.069	0.194	***			
logged Private Mitigation per capita	-2.820	0.309	***	-0.517	0.506		-0.595	0.527		-3.236	0.211	***
logged Population Density$_{-1}$	-1.107	0.132	***	-2.311	0.525	***	-2.284	0.547	***	-2.001	0.551	***
logged Average Degree of Slant	-0.071	0.158		-0.451	0.591		-0.463	0.621		-1.674	0.590	***
logged Length of Shore	-0.006	0.003	*	-0.097	0.018	***	-0.097	0.019	***	-0.121	0.019	***
logged Annual Rainfall	1.090	0.122	***	2.188	0.160	***	2.188	0.152	***	2.182	0.154	***
logged Maximum Temperature	-0.825	0.816		-0.711	0.807		-0.709	0.823		-1.093	0.831	
logged Snow Accumulation	-0.003	0.003		-0.004	0.004		-0.004	0.004		-0.004	0.004	
Number of Active Volcanoes	0.006	0.015		-0.075	0.035	**	-0.073	0.037	*	-0.034	0.037	
Dummy for Large Earthquake	0.247	0.141	*	0.328	0.125	***	0.327	0.106	***	0.258	0.107	**
Number of Approaching Typhoons	0.176	0.021	***	0.117	0.019	***	0.117	0.017	***	0.123	0.018	***
Dummy for Catastrophes	2.126	0.344	***	2.219	0.386	***	2.216	0.484	***	2.156	0.490	***
Dummy for GHAE	5.421	0.373	***	4.977	0.432	***	4.986	1.182	***	5.303	1.196	***
Constant	1.204	3.333		-10.107	6.019	*	-9.864	5.802	*	6.512	5.078	
Adjusted/Centered R-squared	0.567			0.697			0.708			0.701		
F value (P-value)	147.71	(0.00)		61.83	(0.00)		61.83	(0.00)		60.83	(0.00)	
Overidentification Test (P-value)							0.01	(0.91)		0.16	(0.69)	
Municipal Fixed Effects	No			Yes			Yes			Yes		
Endogeneity	No			No			Yes			Yes		

Note: Obs.=1457. When the length of shore and snow accumulation are converted into logged values, we add them to 10^{-10} to avoid a zero problem. In models 1 and 2, robust standard errors are used. Heteroscedastic and autocorrelation consistent standard errors are used in models 3 to 4.

5. Cost-Benefit Ratio From the Results

5.1. Derivation of Cost-Benefit Ratio

In this section, we estimate the cost-benefit ratios of public mitigation for each prefecture using the predictions of the estimated damage functions. The estimation results of model 3 are used for our computations. If prefectures did not invest in mitigation against disasters, the natural disaster damage would be greater than the actual damage because the coefficient of public mitigation in model 3 is significant and negative. Therefore, the benefits derived from public prevention measures are defined as the difference between the damage levels with and without the investments for mitigation.

Using the estimated coefficients in model 3, we predict the total benefits evaluated in 2007, *TB*, derived from the public mitigation measures for each prefecture as follows:

$$TB_i = \sum_{t=1975}^{2007} \left[\frac{PTDM_{it|without} - PTDM_{it|with}}{(1+ir)^{t-2007}} \right] \tag{5}$$

where $PTDM_{it|without}$ and $PTDM_{it|with}$ denote the predicted total damage with and without the public mitigation investments, respectively. The social interest rate is *ir*.

Without public mitigation investments, the disaster prevention stocks of prefecture *i*, PPS_i, do not increase any more than the baseline, $PPS_{i,1975}$. Instead, the baseline stocks annually depreciate at the rate of *dr*. Hence, we calculate the public mitigation stocks without any investments and then predict $PTDM_{it|without}$ by applying the estimated coefficients.

In contrast, the total cost of prefecture *i*, TC_i, is a summation of the annual disaster prevention investments. Thus, we calculate the total costs for each prefecture, as evaluated in 2007 (see equation (6)). The 2007 investment is eliminated from the equation because it does not become the 2007 stock by the beginning-of-period method.

$$TC_i = \sum_{t=1975}^{2006} \left[\frac{PPS_{it+1} - PPS_{it} \times (1-dr)}{(1+ir)^{t-2007}} \right] \tag{6}$$

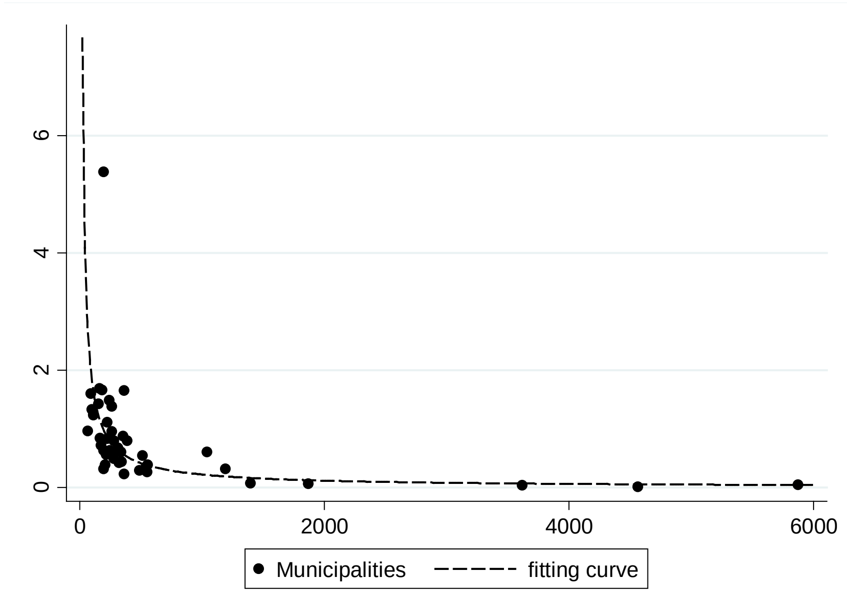
For calculation, we assume that both the social interest rate and the depreciation rate are 4% (MLIT, 2004). Based on equations (5) and (6), we calculate the cost-benefit ratios, *CBR*, for each prefecture as follows in equation (7).

$$CBR_i = TB_i / TC_i \tag{7}$$

5.2. Estimated Cost-Benefit Ratio

Figure 3 describes the estimated cost-benefit ratios, *CBR*, for each prefecture. The horizontal and vertical axes represent population density and cost-benefit ratio, respectively. The cost-benefit ratios in prefectures with a high population density (urban) are clearly lower than in prefectures with a low population density (rural) (see Appendix 1, which explains why we consider population density and its relation to the ratio). When the logged ratios are regressed on the logged population densities as the simple log-log linear regression, the coefficients of the density are significant and negative. Hence, public mitigation in rural prefectures, in which the population density is low, is more efficient than in urban prefectures.

Figure 3. Estimated Cost-Benefit Ratios by Prefecture



Note: Obs.=46. The X and Y axis denote population density and cost-benefit ratio, respectively. The ratio for the Hyogo prefecture is 14.94. The fitting curve is $CBR=(Population\ Density)^{-0.91} * \exp^{4.75}$.

Demonstrating the differences between rural and urban prefectures more clearly, Table 3 shows the average cost-benefit ratios by prefectural population density. The average ratio of all 46 prefectures is 1.15. The number of prefectures in which the estimated ratios are more than one is 13, which is approximately 28% of the 46 prefectures in Japan.

By sorting the 46 prefectures by population density, we label the top 5 and bottom 5 prefectures as “high population density” and “low population density,” respectively. The average ratio of sparsely populated prefectures reaches 1.27; thus, the ratios are more than one. Hence, most rural prefectures with a low population density construct cost-effective public mitigation measures for natural disasters. In contrast, the average ratio of urban prefectures with a high population density is only 0.05; thus, the ratio is much less than one. Therefore, public mitigation measures are not cost-effective in urban prefectures. The null hypothesis in which the average ratios of the two groups, the highly and sparsely populated prefectures, are not different from each other is rejected at a 1% significance level.

Table 3. Estimated Cost-Benefit Ratios by Population Density

	Cost-Benefit Ratio
average of prefectures with high population density	0.05
average of 46 prefectures	1.15
average of prefectures with low population density	1.27

Note: “high population density” refers to the top 5 prefectures: Tokyo, Osaka, Kanagawa, Saitama and Aichi, which are located in Japanese metropolitan areas. “low population density” refers to the bottom 5 prefectures: Hokkaido, Iwate, Akita, Shimane and Kochi.

This result has two implications. First, we confirm that only 28% of the prefectures have provided cost-effective disaster prevention works. However, there is a wide gap between the cost-benefit ratios of urban and rural prefectures. The ratios of urban prefectures are small, and the ratios of rural prefectures are large. Therefore, the results imply that urban prefectures likely need to reduce or reassess their investments to improve their social surplus.

Second, it is often argued that public infrastructures are too small in urban areas in comparison with rural areas in Japan (Yamano and Ohkawara, 2000). However, our results suggest that some specific public infrastructures in urban prefectures, such as disaster prevention works, may be an excessive investment even though public infrastructures may be excessively small as a whole.

5.3. The Case for Extreme Catastrophes

Although we consider that the frequent occurrences of both catastrophes and small-scale disasters, unlike in previous studies, here the damage resulting from catastrophes is incomparably larger than others. Japan has experienced two catastrophes since 1975: the GHAE in 1995 and the Higashi-Nihon Earthquake in 2011 (which is outside of our study period). In this section, we discuss these catastrophes using cost-benefit ratios.

The Hyogo prefecture suffered the GHAE in 1995. Table 4 presents the costs, benefits, deaths and economic damage in the Hyogo prefecture from 1975 to 2007. Although the total cost-benefit ratio is 14.94, the ratio decreases to only 0.33 when we exclude the 1995 data. Thus, it is clear that a terrible catastrophe dramatically increases the ratio. If the Hyogo prefecture had known of the GHAE prior to its occurrence, the prefecture could have reduced death tolls and economic damage by constructing more public mitigation measures.

Table 4. Estimated Cost-Benefit Ratios of the Hyogo Prefecture

	Cost-Benefit Ratio	Benefit	Cost	Death	Injuries	HDM	EDM	TDM
unit		**million dollar**		**persons**		**million dollar**		
Hyogo	14.94	1146806	76776	6497	40731	17756	81413	#####
Hyogo (only 1995)	14.61	1121658	76776	6281	39488	17264	74974	#####
Hyogo (exclude 1995)	0.33	25149	76776	216	1243	492	6439	6932

Note: HDM, EDM and TDM denote human capital loss, primary economic destruction and total damage as a result of natural disasters. The units of benefit, cost, EDM, HDM and TDM are represent in millions of U.S. dollars as evaluated in 2007. Deaths include missing persons.

The greatest earthquake and tsunami recorded, the Higashi-Nihon Earthquake, occurred in Japan's Tohoku area on March 11, 2011. Three prefectures in the area continue to suffer from tremendous damage.[11] In January 2011, the governmental Headquarters of Earthquake Research Promotion under the Ministry of Education, Culture, Sports, Science and Technology released a forecast stating that the probability of a huge earthquake occurring within 30 years in the Tohoku area with a magnitude of approximately 8.0 would be 99%. The public forecast underestimated the magnitude of the earthquake (the actual earthquake was 9.0 in magnitude), and extensive damage was generated.

The total cost-benefit ratios of the three prefectures in the area from 1975 to 2007 are presented in Table 6. Viewing the ratios of the three prefectures, we observe that the ratio for the Miyagi prefecture is less than one, whereas the ratios are more than one for the other prefectures. Although the population density of the Miyagi prefecture was 341 people per square kilometer in 2007, the density of the Iwate and Fukushima prefectures were 90 and 152 people per square kilometer, respectively. Again, we observe the trend in which the ratio of prefectures with a high population density is lower than those with a low population density.

A brief estimation of the damage incurred from the Higashi-Nihon Earthquake is also shown in Table 6. The death toll as of June 1, 2011, including missing and injured people, is provided by the governmental National Police Agency. In the Miyagi prefecture, the earthquake

[11] These three prefectures are the Iwate, Miyagi and Fukushima prefectures on the Pacific Coast.

generated 14,000 deaths and 3,000 injuries. The human damage resulting from the earthquake is calculated using income per capita and the value of a statistical life for the prefectures in 2007. To determine the levels of economic damage, we referred to Goldman Sachs reports, which estimate that the amount of damage was approximately $164.8 billion, as evaluated in 2007. Based on the assumption that only these three prefectures suffered economic damage, we assign the value of $164.8 billion to the three prefectures based on the scale of human damage.

How effective were the public mitigation measures in the prefectures in terms of alleviating the damage caused by the catastrophe? We must estimate the damage that would have occurred as a result of the Higashi-Nihon Earthquake if there had been no investment in public mitigation. We estimate the benefit derived from the mitigation in the catastrophe using the following procedure. It is assumed that the 2011 values of determinants (e.g., public and private mitigation, population, and snow accumulation) are identical to those of 2007. In contrast to the previous estimation, we add the three samples for the Miyagi, Iwate and Fukushima prefectures in 2011 to the observations in Tables 1 to 4 (that is, 1,457). We then incorporate three dummies of the Higashi-Nihon Earthquake for the Miyagi, Iwate and Fukushima prefectures as the determinants. Using 1,460 observations, we again estimate the damage function and then predict the damage with and without public mitigation.

The updated cost-benefit ratios that reflect the earthquake are presented at the bottom of Table 5. The ratios dramatically increase in the three prefectures; this result is consistent with the effect of the GHAE in the Hyogo prefecture. Even in the Miyagi prefecture, in which the ratio is below one before the earthquake, the ratio increases to 61.66 after the 2011 data are considered. Therefore, we conclude that a catastrophe is associated with significantly improved benefits.

As previously mentioned, the Higashi-Nihon Earthquake was forecasted by the Japanese government. Considering this fact and our results, we recommend that the three prefectures in the Tohoku area should increase their investments in mitigation because they are aware of the high probability of earthquake occurrences. In particular, the extent of public mitigation in the Miyagi prefecture should be approximately more than 60 times the current level; however, the calculation of optimal investments must reveal the marginal benefits and costs of public mitigation measures. Therefore, the governments in areas in which catastrophes are forecasted with a high probability should invest in and construct their mitigation measures more aggressively.

Regarding the countermeasures designed to mitigate extreme catastrophes that occur once every several hundred years, is the cost-benefit approach applicable to an extreme event? Tol (2003) discusses whether the cost-benefit analysis is an applicable tool with which to manage the global warming problem and concludes that cost-benefit analysis is beneficial if the uncertainties (that is, variances in both cost and benefit) are finite. For natural disasters, it is probable that the variances in both cost and benefit are finite even in an extreme event, such as the GHGE. Hence, it is appropriate to apply the cost-benefit approach for public mitigation against disasters.

Table 5. Effects of the Higashi-Nihon Earthquake in the Three Prefectures

	Cost-Benefit	Benefit	Cost	Deaths	Injuries	HDM	EDM	TDM
		million dollar		persons		million dollar		
	from 1975 to 2005							
Iwate	1.60	62087	38915	73	484	139	9648	9787
Fukushima	1.42	73030	51309	110	546	234	9674	9908
Miyagi	0.44	18940	43474	80	12051	190	6833	7023
	Higashi-Nihon Earthquake							
Iwate				7390	166	12451	48365	60816
Fukushima				1983	236	3736	14512	18248
Miyagi				14273	3459	26234	######	######
	from 1975 to 2005 + Hibashi-Nihon Earthquake							
Iwate	39.57	#######	38915	7463	650	12590	58013	70603
Fukushima	10.16	521307	51309	2093	782	3970	24186	28155
Miyagi	61.66	#######	43474	14353	15510	26424	######	######

Note: The quick estimation deaths (including missing people) and injuries were the values announced by the National Police Agency in June 1, 2011. In calculating *HDM* of Tohoku Earthquake, recovery time for opportunity cost is assumed to be 33.2 days, which is average time of 8.8 and 55.6 days for minor and major injuries, respectively.

Notably, our analysis might underestimate benefits for the following two reasons. The first concerns the analytic period considered in this paper. After new disaster prevention infrastructures are constructed, approximately 20% of them function for more than 40 years because our depreciation rate is assumed to be 4%. Therefore, the public mitigation measures constructed in 2006 will be maintained after 2007. It is desirable to predict and expand the data set to obtain an accurate value of the benefits observed after 2007. Thus, the estimated benefits in this paper are under-evaluated.

Second, the natural disaster damage defined in this paper excludes secondary economic damage and psychological damage due to the lack of a suitable reference. Secondary economic damage is likely to be greater in urban prefectures than in rural prefectures. In addition, if the extent of human anxiety for people in urban areas does not differ from that in rural areas, then the amount of psychological damage in urban areas would be greater than in rural areas. These omitted types of damage may close the cost-benefit ratio gap between the rural and urban prefectures, but there are still large gaps between rural and urban areas. Future research should consider these two concerns.

6. Conclusion

Natural disasters are among the most important externalities that we must confront because extreme events, such as massive earthquakes and hurricanes, generate a tremendous number of deaths and severe economic destruction. We cannot control the probabilities of disaster occurrences; in contrast, we can control the other externalities derived from our economic activities. Furthermore, disasters may have significant effects on governmental electricity and environmental policies throughout the world. For example, the 2011 Higashi-Nihon Earthquake in Japan recently resulted in more than 20,000 dead and missing people. This earthquake halted the generation of electricity from nuclear power plants and caused radioactive leaks. The earthquake will likely cause significant changes in future Japanese environmental policies.

Because we must discuss mitigation policies against natural disasters, studies examining natural disasters from the economics viewpoint have been conducted. Although most previous studies have examined the relationship between development and disaster damage, they have not explicitly treated governmental roles as disaster protection works providers. This paper is the first study to examine the relationship between public/private mitigation and disaster damage and consider public and private mitigation separately.

Focusing only on Japan, in which many natural disasters (e.g., earthquakes, typhoons, gales, high tides) occur every year, we are able to incorporate detailed information into our econometric model. Therefore, a variety types and scales of natural disasters and climate and socio-economic conditions are considered in the analysis.

The previous studies in the literature show that wealthier countries tend to suffer less damage and that economic growth is a good countermeasure with which to decrease disaster damage. However, using Japanese prefectural data from 1975 to 2007, we find that public mitigation has a key role in mitigating the total disaster damage from the viewpoint of efficiency. We also found that the private mitigation (economic growth) effect is limited.

Additionally, we revealed a wide gap between the efficiency levels of public mitigation measures among prefectures despite evidence that these measures are capable of mitigating the damage incurred. In particular, the effects of public mitigation in urban prefectures are smaller than those in rural prefectures.

This result highlights four important implications. First, people may not richly recognize the natural disaster risks of the areas in which they live. If people were aware of the true risks, private mitigation measures should effectively reduce disaster damage because many people could afford to invest in self-protection measures, such as house reinforcement, based on their income levels, as shown in the literature.

Second, governments must effectively and efficiently construct disaster prevention infrastructures based on natural disaster risks because public mitigation can reduce the damage incurred from disasters. In addition, informing residents regarding these risks is also crucial to bridging the asymmetric information gap between governments and residents.

Third, urban prefectures should reassess their public mitigation measures. Despite the low number of disaster occurrences, the cost-benefit ratios of public mitigation measures in urban prefectures are small due to excessive investments (the cost is excessively large) or ineffective mitigation measures (the benefit is excessively small). In either case, urban prefectures must reconsider their public mitigation measures to improve their social welfare.

Finally, prefectures that have a high probability of suffering massive earthquakes in the near future should construct more aggressive prevention infrastructures. In Japan, except for the Tohoku area, there are several areas in which large earthquakes are expected to occur with a high probability. To protect our society in a more cost-effective manner, we must accumulate economic studies pertaining to disaster prevention.

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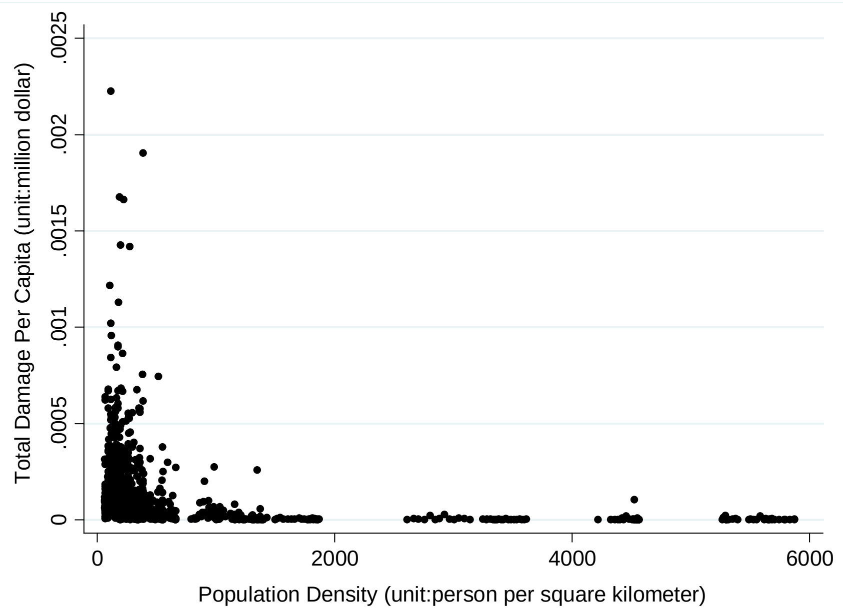
Appendix 1. Performance Analysis of Prefectures

In general, there is smaller per capita damage in urban areas because large cities historically tend to be constructed in areas with lower disaster risks. Figures A1 and A2 support this claim by showing higher levels of damage per capita and damage per income in rural areas in terms of population density. Therefore, we expect that there could be a clear difference in the cost-benefit ratios over population density. We determine whether we can expect more damage in areas with lower population density by applying a nonparametric data envelopment analysis (DEA).

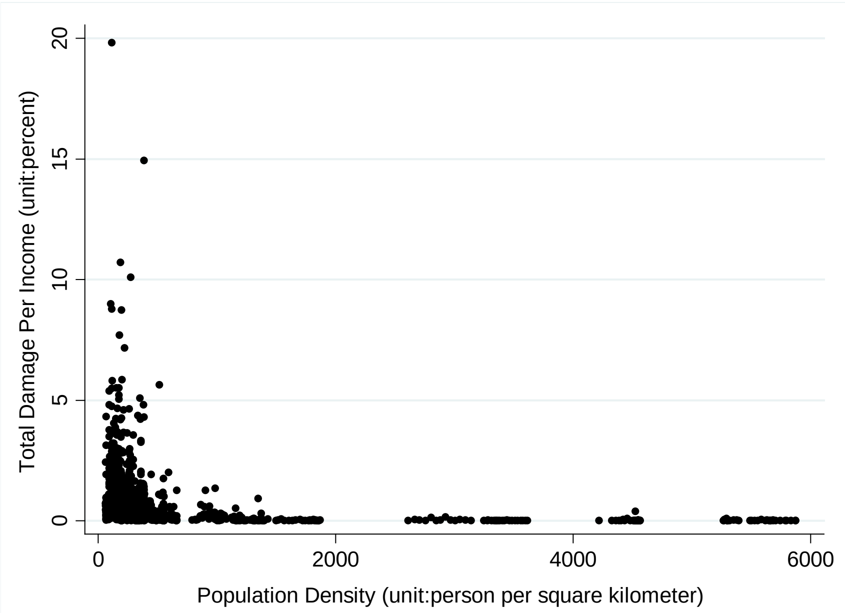
DEA is an effective data analysis tool because it does not require a specific function form and allows us to easily view the DEA scores. In this paper, we consider simple input-output combinations in which more labor, public mitigation stocks and other social infrastructure stocks are the inputs for producing income as a positive output and reducing disaster as an undesirable output. Chen et al. (2011) and Barros et al. (2011) developed and provided an application that measures overall and undesirable output (disaster) scores. The technical inefficiency score is an indicator between 0 and 1 that indicates the extent to which prefectures suffer damage as a result of natural disasters. Therefore, smaller scores indicate

Figure A1. Total Disaster Damage Per Capita by Prefecture from 1975 to 2007



Obs.=1503. The values of total disaster damage per capita in 1995 in the Hyogo prefecture and in 1983 in the Shimane prefecture are 0.0170 and 0.0047, respectively.

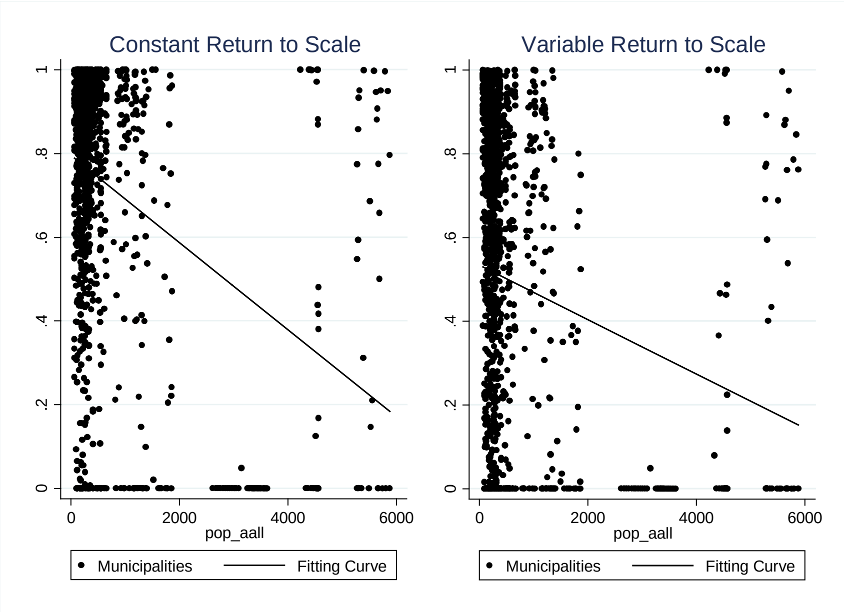
Figure A2. Total Disaster Damage Per Income by Prefecture from 1975 to 2007



Obs.=1503. The values of total disaster damage per income in 1995 in the Hyogo prefecture and in 1983 in the Shimane prefecture are 73.4 and 38.3, respectively.

with linear fitting curves. These results show that lower population density areas are associated lower levels of natural disaster damage. Figure A3 provides the technical inefficiency results with high technical inefficiency scores; thus, rural prefectures suffer more disaster damage per input. Therefore, we intend to consider the differences of cost-benefit ratios by various population density ranges.

Figure A3. Nonparametric Results (left: constant return to scale, right: variable return to scale)



Note: Obs.=1503. The vertical axis is the technical inefficiency score for disasters based on the DEA.

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