**IS THERE AN ENVIRONMENTAL KUZNETS CURVE FOR NATURAL HAZARDS IN THE THAI AGRICULTURAL SECTOR? ***

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**and**

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**ARE Working Paper No. 2558/4**

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**ภาควิชาเศรษฐศาสตร์เกษตรและทรัพยากร**

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**ARE Working Paper**

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# ABSTRACT

Over the past 20 years, flood and drought in Thailand have impacted up to 2.58 million farming households and caused damages about 6,000 million Baht each year. Various studies have examined natural hazard impacts on the Thai economy and particularly on agricultural sector. Moving towards sustainable development, economic vulnerability to natural hazards should be improved which could be linked to disaster mitigation policies and development. This study aims to explore the Kuznets relationship between economic growth and damages from flood and drought in the Thai agricultural sector using annual data at the provincial levels during 1989-2012. It is hypothesized that as the country becomes wealthier, appropriate development and investment in disaster mitigation could lead to disaster reduction in agricultural sector. Results from the random effect regression support the Kuznets hypothesis in the models for both flood and drought. Precipitation variation increases agricultural damages due to flood and drought significantly. Agricultural damages reduce with rising provincial incomes, increased flood retention area and increased areas for perennial crops.



***Keywords:*** Flood, Drought, Thai agricultural sector, Environmental Kuznets curve

**JELClassification : Q54, O44**

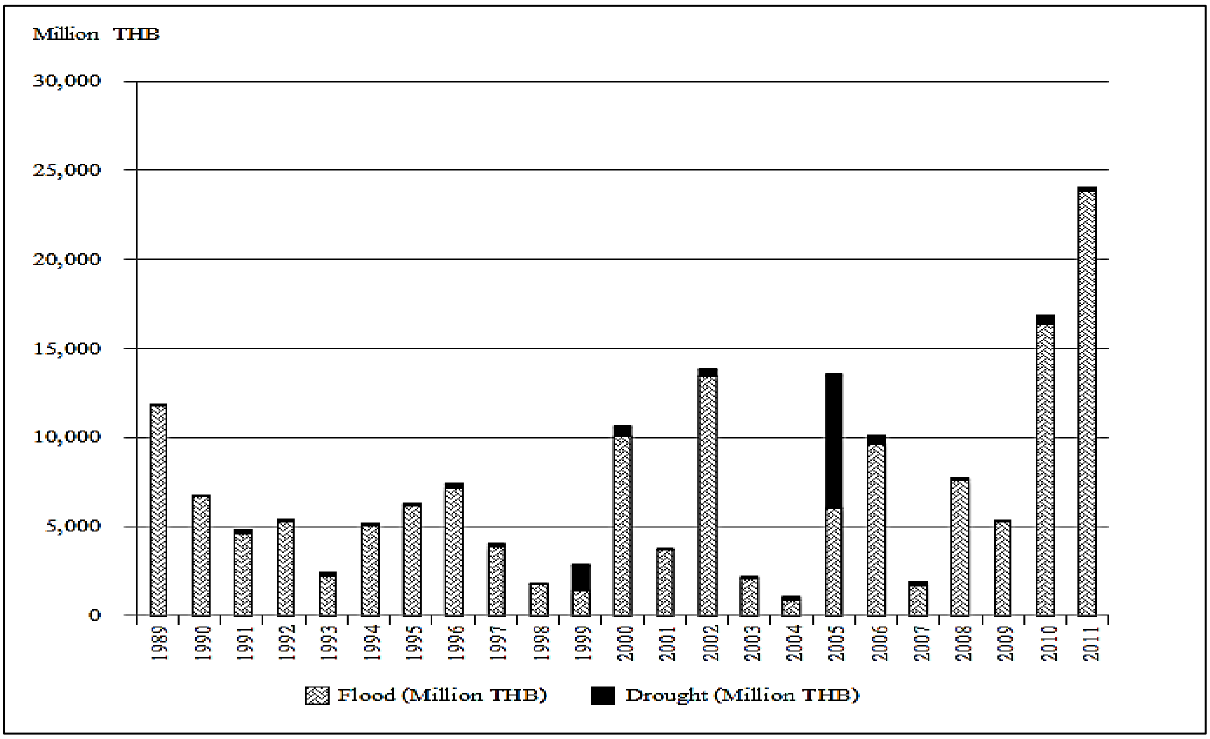
## Introduction

Various studies confirm that increasing mean temperature, changing precipitation patterns, rising sea level, and increasing frequency and growing intensity of extreme climate events caused by climate change are evident in Southeast Asia (IPCC, 2012; ADB, 2009; IPCC, 2007). The Inter-governmental Panel of Climate Change (IPCC) also confirms that economic losses from natural hazards are world-wide and tend to increase in the near future (IPCC, 2012). The Climate Change Vulnerability Map of Southeast Asia prepared by IPCC published in 2009 shows that the countries in this region are highly susceptible to climate disasters. In Southeast Asia, the average temperature has been reported the increased 0.1–0.3°C per decade over the last 50 years, and 1.04–1.80°C per century for Thailand (Jesdapipat, 2008). If no action is taken, this region particularly Thailand, Indonesia, Philippines, and Viet Nam could suffer a loss equivalent to more than 6% of GDP annually by 2100, more than double the global average loss (ADB, 2009). Increases in floods and droughts exacerbate rural poverty in parts of these countries due to negative impacts on rice crops and resulting increases in food prices and the cost of living.

Natural hazards particularly floods and droughts have increased vulnerability of Thailand's agricultural sector (The Thai Department of Disaster Prevention and Mitigation, 2012). From statistics, floods and droughts in Thailand have impacted up to 2.58 million farming households and caused damages about 6,000 million Baht each year during 1989-2011 (Figure 1). On average, agricultural areas have been damaged about 8.9 million rai1 (or 1.4 million ha) from flood and 2.8 million rai (or .45 million ha) from drought annually (The Thai Office of Agricultural Economics). The most severely flood disaster of Thailand occurred in 2011 with 11.8 million rai (or 1.9 million ha) of farmland submerged in flood water causing THB 23,839 million (or USD722.4 million) of agricultural losses. This caused the loss of 6.3% of GDP in agricultural sector. The most severe drought occurred during the end of 2004 to mid-2005. This extremely dry event caused the losses in agricultural sector amounted to THB 7,565 million (or USD 229.3 million) which contributed to 2.1% of GDP in agricultural sector. The event caused Thailand the most severely hit region of drought among Southeast Asia, with 70 out of 76 provinces reported with almost a million hectares of agricultural land being water deprived. The rice crop was reduced by about a million ton and the sugar crop dropped by 30%. The recent report by IPCC (2014) revealed that during 2009-2010, a severe drought condition prevailed over the Mekong region including Thailand. This event caused Thailand to declare 40 provinces as drought effected zone, with a decrease in the crop yields by about 1.4 million tons. Figure 1 illustrated how natural hazard such as flood and drought has caused the losses in the Thai agricultural sector.

To cope with increased disasters from natural hazards, the 11th National Economic and Social Development Plan of Thailand (2012-2016) has provided a framework and guidelines that recognize the importance of preparedness in coping with climate change and natural disaster. The newly established government agency, Department of Disaster Prevention and Mitigation found in 2002 under Ministry of Interior has its direct role to handle disaster management responsibilities of Thailand. In agricultural sectors, various government departments play roles in prevention, mitigation, and relief. Among them, Royal Irrigation Department and the Office of Agricultural Economics are the key government agencies for water resource management and agricultural policies and planning, respectively. As long as agriculture continues to depend on the weather in the production process, these government agencies are the key to assist Thai farmers to cope with greater climate variability and natural hazards.

Figure 1 Agricultural losses (million THB) in Thailand over the period of 1989-2011




Although impacts of natural hazards on economic growth are informative and evident, many studies have reported how significant of economic development in reducing natural disasters. Following the environmental Kuznets curve (EKC) hypothesis, this study aims to explore the Kuznets relationship between economic growth and damages from flood and drought in the Thai agricultural sector. To investigate for the inverted-U shape of EKC, it is hypothesized that at low level of economic development, the economy may be more engaged with economic activities that could increase risk of exposure to natural hazards. At higher level of development, effect of increasing wealth may lead to higher education of people, more awareness environmental protection, strengthening protection and mitigation measures that reduce the risk from natural disaster.

The structure of the paper is as follows. The next section describes the conceptual and empirical models. Section 3 provides details data and sources. Section 4 presents the results. The conclusion and discussion are presented in the final section.

**Conceptual framework**

Stern (2004) reviews the history of the environmental Kuznets curve (EKC) that it is named for Kuznets (1955) who hypothesized that income inequality first rises and then falls as economic development proceeds. The original EKC hypothesis is an invert U-shape relationship between income inequality and economic development. In environmental economics, the popularity of EKC is realized, which is a hypothesized relationship between various environmental indicators and per capita income. Dinda (2004) also provides a brief history of EKC and reviews the EKC studies. He stresses that the EKC hypothesis is intended to represent a long term relationship between environmental impact and economic growth. Empirical evidence for the existence of an EKC has been found in several studies. However, most of them employ the reduced form model to test the various possible relationship between pollution level or environmental pressure and income (Dinda, 2004).

The conceptual link between economic development and natural disasters has been adapted from the EKC. Many studies that determine the effects of development on disaster risks are found in the literature but few studies attempt to identify the Kuznets relationship. Most of them are found using international database provided by international organizations. At the present time, current research identifying the relationship between economic growth and natural disaster and testing the EKC hypothesis in Southeast Asia have not been found. Among the few studies, Kahn (2005), Toya and Skidmore (2007), Kellenberg and Mobarak (2007), Raschky (2008), and Schumacher and Strobl (2011) all derived the non-linear relationship between economic development and disaster risks, using pooled time-series and cross-sectional data at cross country level. Natural disasters are measured in terms of deaths and economic losses. All studies conclude that there exists a negative relationship between per capita GDP and deaths from natural disasters, as the richer nations suffer fewer deaths from natural disasters. Kahn (2005); Kellenber and Mobarak (2008); and Shumacher and Strobl (2011) find that deaths from disasters increase with higher population density. With regard to policy variables, Toya and Skidmore (2007) find that fewer losses from natural disasters are associated with increased government expenditure, higher education attainment of people, and greater openness. Interestingly, Raschky (2008) find that countries with better institution experience less victims and lower economic losses from natural disaster. Although the literatures on EKC for natural disasters are quite rare, all the above studies provide insights on how the models are constructed and suggest the key factors in determining the natural disaster losses. These studies also address the gaps for researches to explore further on the economics of natural disasters.

## Empirical specification

The study begins with a basic model for Kuznets hypothesis using aggregate data during 1989-2012. Damages from natural disaster at the national level (loss) is as a function of per capita income (Y) shown in a quadratic form, equation (1)

$$loss = a_0 + a_1 Y + a_2 Y^2 + \varepsilon \quad (1)$$

Based on EKC hypothesis, the sigh of $a_0$ is expected to be positive whereas the negative sign is expected for $a_1$.

Annual data on losses from floods and droughts were regressed with per capita income using quadratic specification. Using two types of the dependent variables "economic loss in Thai Baht (THB)" and "damaged area in rai", the models are estimated using OLS (Table 1). The linear, log-linear, and log-log functions, without and with lagged variables were checked. The models were also checked for auto-correlation by using Durbin's alternative test and Breusch-Godfrey LM test. With the quadratic specification, both models do not provide favorable results, but the presence of inverted-U shape was found in Model 2 when disaster losses are measured as "damaged area".

Table 1 Estimation results of disaster-economic development relationship at national level

| Variable | Model I: Financial loss (THB) as dependent variable | | Model II: Damaged area (rai) as dependent variable | |
|---|---|---|---|---|
| | Coefficient | t-statistic | Coefficient | t-statistic |
| Constant | $5.39 \times 10^{10}$ ** | 2.52 | $-1.30 \times 10^{7}$ | -0.35 |
| | $(2.14 \times 10^{10})$ | | $(3.76 \times 10^{7})$ | |
| $Y_{t-1}$ | -1,097,967 ** | -2.45 | 621.29 | 0.79 |
| | (448288.40) | | ( 786.81) | |
| $Y^2_{t-1}$ | 6.072851 ** | 2.69 | -0.004 | -0.91 |
| | (2.26) | | ( 0.004) | |
| Adjusted R-squared | 0.3248 | | 0.00100 | |
| No. of observation | 23 | | 23 | |
| Turning point (THB/person/year) | 90,399 | | 86,069 | |
| Inverted-U shape | No | | Yes | |

Note: Data in parentheses are standard errors.

The results of the above models are illustrated in Figures 1a and 1b as follows:

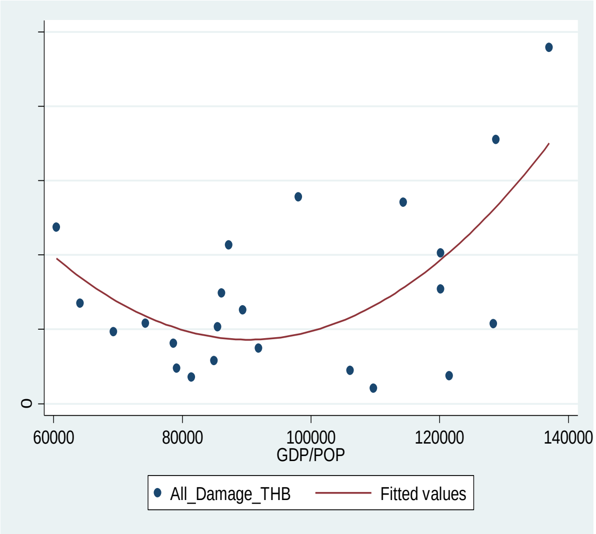



Figure 1a Results from model I presenting the relationship between agricultural loss in THB and per capita GDP

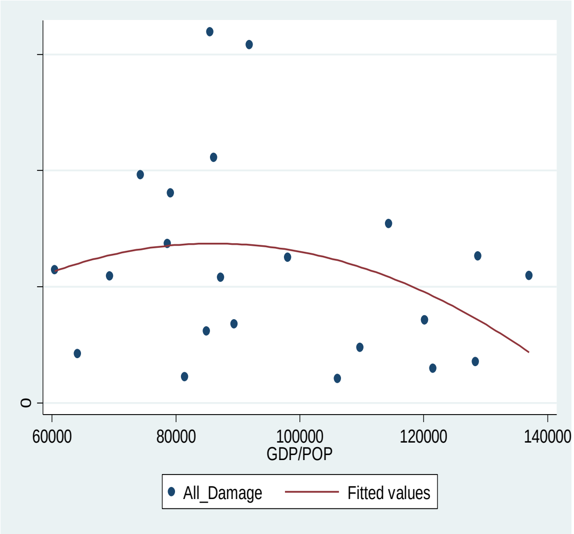



Figure 1b Results from model II presenting the relationship between damage area in rai and per capita GDP

For further investigation, the relationship between economic development (*Y*) and disaster impact (*Damage*) is determined at the provincial level. Several variables representing the accompanying economic growth and mitigation in agricultural sectors are also included as explanatory variables. These variables represent conditions on human capital, natural capital, physical capital, climate, and policy. Many studies suggest that the variables on disaster losses should be interpreted with care (Kahn, 2005; Skidmore and Toya, 2007; Raschky, 2008). How relevant of these data and their accessibility are often a problem, especially at the provincial level. The data that represent "agricultural loss" at provincial level in financial terms were not available, only agricultural damages in physical terms were found, such as "damaged area", "number of livestock loss", and "number of affected farmer". The basic model used with provincial data is the following.

$$loss \; = b_0 + b_1\, Y + b_2 Y^2 + b_3 human\ condit + b_4 natural\ condition$$
$$+b_5 physical\ condition\; + b_6 climate\ condition + b_7 policy\ dummy + \varepsilon \qquad (2)$$

The linear and log forms of model were explored but the double log function provides better results statistically. As suggested by Raschky (2008), taking the natural log of the variables makes the different coefficients more compatible and allows researchers to interpret the coefficient as elasticity.

In this study, we decided to use the "damaged area" and "affected farmer" at provincial level to represent "loss". In the final analysis, the result obtained from "damaged area" is more favorable statistically. Thus, the empirical models presented only the estimated results using "damaged area in province i and year t ($Damage_{i,t}$)" as dependent variable based on equation (3)

Different estimation methods for panel data have been explored. After performing the Hausman test for both flood damages ( $\chi^2$ = 14.93, Prob. > $\chi^2$=0.1347) and drought damages ( $\chi^2$ = 4.66, Prob. > $\chi^2$= 0.5879), the study uses GLS random effect model for the analysis. Two separated models for flood and drought in the reduced form are presented in section 4.

$$\ln\left(damage_{i,t}\right) = b_0 + b_1 \ln\left(Y_{i,t}\right) + b_2 \ln\left(Y_{i,t}^2\right) + b_3 \ln\begin{pmatrix} human \\ condition_{i,t} \end{pmatrix}$$
$$+ b_4 \ln\begin{pmatrix} natural \\ condition_{i,t} \end{pmatrix} + b_5 \ln\begin{pmatrix} physical \\ condition_{i,t} \end{pmatrix}$$
$$+ b_6 \ln\begin{pmatrix} climate \\ condition_{i,t} \end{pmatrix} + b_7\, policy\ dummy + \varepsilon \tag{3}$$

**Data**

The analysis is based on national level and provincial level panel data of 76 during the period 1989-2012. It is noted that Bueng Kan, the 77th province was not included as it was established in 2011. The data used in this study have been collected from various official sources (table 2).

The data of flood and drought damages in monetary terms were found at the national but not the provincial level from Department of Disaster Prevention and Mitigation. These data, although official reported, were recalculated based on financial losses in agricultural products estimated from the damaged agricultural area collected at the village level by Department of Agricultural Extension. In this study damages were used in the physical terms, the agricultural damaged areas and the affected number of farmers at provincial level. The two separate set of data were analyzed, one is damages from flood another is from drought. The damaged areas are reported in local unit, "rai" (0.16 ha) per year.

The data on economic development and population came from the Office of National Economic and Social Development of Thailand. Per capita Gross Provincial Product (*GPP*) was used as a proxy of economic development. The variable "*Y*" is obtained by taking GPP over gross population in different provinces over the years then adjusted in real terms.

Some data such as the variability of rainfall $\left(VARRAIN_{i,t}\right)$ is calculated from the amount of monthly rainfall (*R*) collected from the Thai Department of Meteorology. The term $\bar{R}$ is the average rainfall, and *N* is the number of months, in year *t*. The calculation for rainfall variability is the following.

$$VARRAIN_{i,t} = \frac{\sum\left(R - \bar{R}\right)^2}{N}$$

As other developing countries, official statistics in Thailand at early periods could not be available at the same year and could be fabricated. For example, data on precipitation at provincial level were reported over the period of 1977-2012 compared with the GPP data that were reported over the period of 1995-2012. The details of variables and their descriptions as well as expected signs are illustrated in Appendix Table.

Table 2 Official source and data collected for this study

| Official source | Data |
|---|---|
| Ministry of Interior<br>- Department of Disaster Prevention and Mitigation | Economic loss from floods, national level (THB/year)<br>Economic loss from droughts, national level (THB/year) |
| Ministry of Agriculture and Cooperatives (MOAC)<br>- Department of Agriculture Extension<br><br><br><br><br><br>- Office of the Permanent Secretary for MOAC<br><br><br>- Royal Irrigation Department<br><br>- Royal Forest Department | Damaged area from floods (rai/year)<br>Damaged area from droughts (rai/year)<br>Production area of rice, field crops, fruits, trees, pasture,and idle land (rai/year) Land holding, owned, and rented (rai/household)<br>Number of public and private shallow well used during dry season<br>Education of farmer household head<br>Areas of community forests (rai)<br>Areas of natural water bodies (rai)<br>Number of natural water bodies<br>Number of educated farmer household head (person)<br>Irrigated and irrigation area (rai)<br>Irrigated water availability (million $m^3$)<br>Number size of wetland, swamp, lake<br>Public forest area (rai)<br>Community forest area (rai)<br>Forest farm area (rai) |
| Prime Minister's Office<br>- Office of the National Economics and Social Development Board | Gross provincial products (THB)<br>Total provincial population (person)<br>Total provincial land area (rai) |
| Ministry of Information and Communication Technology<br>- Meteorological Department of Thailand | Rainfall at provincial level (mm.)<br>Number of rain day at provincial level (days/year) |

**Results**

***Flood damages***

To determine the relationship between economic development (*Y*) and flood disaster impact (*DamageF*), the following log-log regression function is presented in Table 3. Explanatory variables that represent factors determining the flood damages are added in the classic EKC specification. The two models follow Kuznets hypothesis. According to the model performance listed at the bottom of the table, model III is more favorable than model IV statistically. In Model III, damaged areas in province i and year t ($DamageF_{i,t}$) is determined by per capita income ($Y$ and $Y^2$), rain variation (*VARRAIN*), provincial population (*POP*), number of agricultural households (*Ag_HH*), number of farmers who attain secondary schools or above (*HIGH_EDU_H*), paddy land (*PADDY*), and perennial land (*PEREN*).

Results show that flood disaster would be reduced with an increased land for perennial crops. Increasing number of natural water storages such as wetland, swamp, or lake in the province would reduce flood damages. Increase in rain variation, population, land for paddy and field crops would increase flood damages. The turning point for flood damages is THB109,837 /person/year (USD 3,328/person/year)

Table 3 Estimation results of flood damage-economic development relationship at provincial level

| | Model III: ln DamageF $_{i, t}$ | Model IV: ln (DamageF/Ag_Land) $_{i, t}$ |
|---|---|---|
| ln $Y_{i, t-1}$ | 8.589 *** | 7.158 ** |
| | (2.6783) | (3.456) |
| $[\ln Y_{i, t-1}]^2$ | - 0.370 *** | - 0.293 ** |
| | (0.1126) | (0.1446) |
| ln $(VARRAIN)_{i, t}$ | 1.489 *** | 1.422 *** |
| | (0.2287) | (0.259) |
| ln (POP) i, t | 1.203 *** | |
| | (0.4013) | |
| ln $(Ag\_HH)_{i, t}$ | | 0.787 ** |
| | | (0.380) |
| ln $(HIGH\_EDU\_H)_{i, t}$ | | - 0.470 * |
| | | (0.272) |
| ln $(PADDY)_{i, t}$ | 0.682 *** | |
| | (0.2519) | |
| ln$(PADDY/ALL_LAND)_{i, t}$ | | 0.952 *** |
| | | (0.205) |
| ln $(PEREN)_{i, t}$ | - 0.433 ** | |
| | (0.2105) | |
| ln $(PEREN/ALL\_LAND)_{i, t}$ | | - 0.374 * |
| | | (0.206) |
| ln (FIELD) i, t | 0.150 * | |
| | (0.0797) | |
| ln $(IRR\_AREA/ALL\_LAND)_{i, t}$ | | 0.079 |
| | | (0.207) |
| ln $(SWAMP)_{i, t}$ | - 0.188 * | - 0.226 ** |
| | (0.108) | (0.108) |
| Constant | - 74.390 *** | - 67.873 *** |
| | (15.9988) | (21.118) |
| No. of observations | 111 | 112 |
| No of groups | 52 | 53 |
| R-squared | 0.6853 | 0.6447 |
| Prob. (F-stat, $\chi^2$) | 0.0000 | 0.000 |
| Tuning point (THB/person/year) | 109,837 | 201,797 |

**Note:** *** significant at the 1%, ** Idem.5%, * Idem.1%

***Drought damages***

Table 4 presents the results of the double log models for drought damages. Based on the general equation (4), the two models are estimated. Both follow the Kuznets hypothesis. With better statistical results, model V is selected for further interpretation. The coefficients of rain variation and land for field crops are positive which imply the positive relationship with drought damages. Result of model V indicates a turning point of THB85,717/person/year (USD2597/person/year). Province with per capita income less than this amount would suffer from drought damages.

Table 4 Estimation results of flood damage-economic development relationship at provincial level

| | Model V: ln DamageD $_{i, t}$ | Model VI: ln $(\frac{DamageD}{ALL\_LAND})_{i, t}$ |
|---|---|---|
| ln $Y_{i, t-1}$ | 38.938 *** | 40.072 ** |
| | (14.4047) | (15.653) |
| $[\ln Y_{i, t-1}]^2$ | - 1.714 *** | - 1.760 ** |
| | (0.6271) | (0.683) |
| ln $(VarRain)_{i, t}$ | 1.032 ** | 0.882 ** |
| | (0.4247) | (0.444) |
| ln(FIELD) i, t | 0.397 *** | |
| | (0.1224) | |
| ln $(FIELD/ALL\_LAND)_{i, t}$ | | 0.309 ** |
| | | (0.125) |
| ln $(IRR\_AREA/ALL\_LAND)_{i, t}$ | | - 0.165 |
| | | (0.295) |
| ln $(SWAMP)_{i, t}$ | | |
| ln$(COM_FOREST/ALL_LAND)_{i, t}$ | | - 0.088 |
| | | (0.121) |
| Constant | - 221.910 *** | - 241.843 *** |
| | (82.7775) | (90.443) |
| No. of observations | 63 | 63 |
| No of groups | 40 | 40 |
| R-squared | 0.2327 | 0.1740 |
| Prob. (F-stat, $\chi^2$) | 0.0002 | 0.018 |
| Tuning point (THB/person/year) | 85,717 | 87,912 |

**Note:** *** significant at the 1%, ** Idem.5%, * Idem.1%

**Conclusion and Suggestions**

The purpose of this paper is to test the Kuznets hypothesis and show the key determinants of damages from floods and droughts in Thailand. The relationship between per capita income and measures of disaster losses were explored more closely using provincial panel data. The results indicate the existence of an inverted-U shape relationship between per capita GPP and disaster losses in agricultural sector of Thailand. This confirms that damaged areas from flood and drought increase at initial level of economic growth then reach the turning points and start to decline once the provinces continue to get wealthier beyond the turning points. The results show that losses associated with floods and droughts increase with income up to per capita GPP level of THB 109,837 and THB 85,717 per year, respectively and decrease thereafter. In the model for flood, it is found that 54 out of 76 provinces of Thailand were on the upward slope portion of the curve. Most of them are located in the northeast (35%) and the north (30%).  It is also found that 48 provinces still face increased damage from drought as their per capita incomes grow. Likewise, most of them are located in the northeast (40%) and the north (31%).

From a policy perspective, the study suggests that flood disaster would be reduced with an increased land for perennial crops and increased number of natural water storages such as wetland, swamp, or lake as flood retention areas in the provinces that are still at flood risk. To reduce risk of drought disaster, the study suggests that the provinces that are prone to drought should control the expansion of field crops, especially those that are more water-demanded. Rain variation increases agricultural damages in both flood and drought situations. The study suggests the need for accurate and on-time information of meteorological conditions, which should come in line with effective preparedness schemes. An improvement of database on disaster losses from agricultural sector will benefit not only for any mitigation efforts but also for further researches on economics of disaster risk reduction.

This study only uses the reduced form non-linear relationship between disaster losses and economic development. The relationship is more complicated than that of presented as remarked by Kellenberg and Mobarak (2008) and Schumacher and Stobl (2011). Thus, the implication of inverted-U shape EKC found in the study is not that simple as increasing income leading to reducing disaster losses. Further studies could examine more detailed causal relationship with advanced analysis. Many factors that increase or decrease the risk of flood and drought damages should also be further investigated. These include the policy variables in agricultural sector such as disaster insurance, flood and drought mitigation measures, and water management policies. The studies related to the issues of economic growth that increase disaster risk is also equally important to the issues of mitigation factors that reduce disaster risk. Finally, it is also suggested that further analysis at provincial level could be undertaken using spatial econometrics.

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Appendix Table: Description of variables used in the models, annual data at provincial level.

| Dependent variable | Description | Unit | |
|---|---|---|---|
| FL_DAMAGE | Damage area from flood | Rai | |
| DR_DAMAGE | Damage area from drought | Rai | |
| FL_VICTIM | No. of affected farmer from flood | Person | |
| DR_VICTIM | No. of affected farmer from drought | Person | |
| FL_DAMAGE/ALL_LAND | Damage area from flood/provincial area | % | |
| DR_DAMAGE/ALL_LAND | Damage area from drought/provincial area | % | |
| **Explanatory variables** | **Description** | **Unit** | **Relation** |
| **Economic condition** | | | |
| Y | Per capita GPP | Mill THB /person | ( + ) |
| $Y^2$ | Per capita GPP | Mill THB /person | ( - ) |
| **Physical condition** | | | |
| AG_POP | No. of farmer | Person | ( + ) |
| AG_HH | No. of farmer household | HH | ( + ) |
| VARRAIN | Variation of rainfall | $mm^2$ | ( + ) |
| AG_LAND/ALL_LAND | Farmland/provincial area | % | ( + ) |
| PADDY/ALL_LAND | Rice production land/provincial area | % | ( + ) |
| FIELD/ALL_LAND | Field crop land/provincial area | % | ( + ) |
| PEREN/ALL_LAND | Perennial crop land/ provincial area | % | (+,-) |
| HORT/ALL_LAND | Horticulture land/provincial area | % | ( + ) |
| PASTURE/ALL_LAND | Pasture land/provincial area | % | ( + ) |
| WASTE/ALL_LAND | Idle land/provincial area | % | ( + ) |
| FARM_SIZE | Average farm size | Rai/HH | ( + ) |
| OWN_LAND | Average owned farmland | Rai/HH | ( + ) |
| RENT_LAND | Average rental farmland | Rai/HH | ( + ) |
| **Physical condition** | | | |
| IRR_AREA/ALL_LAND | Irrigation land/provincial area | % | ( - ) |
| IRR_BEN/ALL_LAND | Irrigated land/provincial area | % | ( - ) |
| IRR_QUANT | Available water storage | Million $m^3$ | ( - ) |
| IRR_IN | Averaged irrigated land per farm | Rai/HH | ( - ) |
| **Natural condition** | | | |
| FOREST/ALL_LAND | Public forestland/provincial area | % | ( - ) |
| COM_FOREST/ALL_LAND | Community forest/provincial area | % | ( - ) |
| SWAMP_AREA | Area of natural water storage (wetland, swamp, etc) | Rai | ( - ) |
| SWAMP | Number of natural water storage | Number | ( - ) |
| DR_SWAMP | Number of natural water storage used in dry season | Number | ( - ) |
| CANAL | Number of natural rivers, canals | Number | ( - ) |
| DR_CANAL | Number of natural rivers, canals, streams used in dry season. | Number | ( - ) |
| PV_ARTE | Number of private shallow wells | Number | ( - ) |
| DR_PV_ARTE | Number of private shallow wells used in dry season | Number | ( - ) |
| PUB_ARTE | Number of public shallow wells | Number | ( - ) |

| Explanatory variables | Description | Unit | Relation |
|---|---|---|---|
| **Natural condition** | | | |
| DR_PUB_ARTE | Number of public shallow wells used in dry season | Number | ( - ) |
| **Human condition** | | | |
| LOW_EDU_H | % farmer HH head with minimum eduction (primary to below primary level) | % | ( - ) |
| MID_EDU_H | % farmer HH head with moderate education (secondary to below secondary level) | % | (+,-) |
| HIGH_EDU_H | % farmer HH head with high education (above secondary level) | % | ( - ) |
| MEM_H | No. farmer HH head who are member of agri group/association | Person | ( - ) |
| TRAIN_H | No. farmer HH head who attend agri training | Person | ( - ) |
| **Policy condition** | | | |
| DISASTER_LAW | Year established of Disater Prevention and Mitigation Act (1=2007 and after, 0=otherwise) | Dummy | ( - ) |
| MONEY_HP | Amount of compensated money to farmer victims | THB | ( - ) |

[1]The study uses the conversion rates of THB33 to USD1 and 1rai to 0.16 ha throughout the paper.