**EU-ERA**
DISCUSSION PAPER SERIES
EU-ERA DP 24/2023

# The Effects of Climate Change on Crime in Indonesia

**Muzafar Shah Habibullah**
**Sugiharso Safuan**

The Future
Centre for Future Studies Berhad
EU ERA
ISSN 2785-9096
9 772785 909007

## About EU-ERA Discussion Paper Series

This discussion paper is a product of the EIS-UPMCS Centre for Future Labour Market Studies (EU-ERA), Office of Employment Insurance System (EIS), Social Security Organisation (SOCSO). It is part of a larger effort by the EU-ERA to provide open access to its research and contribute to the scientific and development policy discussions in Malaysia.

The EU-ERA Discussion Paper Series disseminates data, information, and findings of work in progress to encourage the exchange of ideas and elicit comment and feedback about Malaysia's labour and development issues. The series aims to get the findings out quickly, even if the presentations are less than fully polished and later may be modified for final publication.

The findings, interpretations, and conclusions expressed in this paper are entirely those of the authors. They do not necessarily represent the views of the Office of Employment Insurance System, SOCSO or its Board of Governors or the ministry they represent.

## About EU-ERA

Centre for Future Labour Market Studies (EU-ERA) is a state-of-the-art research centre in Malaysia that focuses on the labour market research and analytics. EU-ERA operates as a nucleus division within The Future Studies Berhad (THE FUTURE). At THE FUTURE, we are dedicated to conducting cutting edge research and analysis on the rapidly changing economic and labor market landscapes, with the goal of informing policymakers, businesses, and the public about the implications of these changes.


## Contact us

+603 8927 5103

enquiry@euera.org

www.euera.org


## Follow us on

Centre For Future Labour Market Studies

EU-ERA Discussion Paper Series

EU-ERA DP 24/2023

# The Effects of Climate Change on Crime in Indonesia

---

**Muzafar Shah Habibullah**
Centre for Future Labour Market Studies, THE FUTURE
&
Putra Business School, Malaysia

**Sugiharso Safuan**
Faculty of Economics and Business, Universitas Indonesia, Indonesia

Disember 2023

# Abstract

**Motivation and aim:** In Indonesia, studies on the economics of crime have been proliferated in recent years. Studies have found that (macro)economic variables such as unemployment rate, poverty rate, income (GDP per capita), population density, human development index, income inequality, minimum wage, good governance, urbanisation, foreign direct investment, domestic investment, life expectancy, education level or years of schooling, and police personnel were affecting crime rates in Indonesia. Nonetheless, a study that take into account the role of climate change affecting criminal activity in Indonesia is rather lacking. Thus, the purpose of the present paper is to investigate the effects of climate change, in particular the role of rainfall on crime rates in Indonesia. The novelty of the present study is three folds: First, to the best of our knowledge, this is the first paper to study how climate change affect crime rates in Indonesia. Secondly, the present study would provide a better predictive model for criminal behaviour in Indonesia by taking into account the role of climate change (rainfall) as additional explanatory variables. And finally, in this study we test the nonlinear relationship between rainfall and crime rate in Indonesia.

**Methods and material:** In this study, we employed four estimators, namely, Ordinary Least square (OLS-robust), Autoregressive Distributed Lag (ARDL), Robust regression with M-estimation and Fully Modified OLS (FMOLS). We test for both linear and nonlinear impact of rainfall on criminal activity. The study uses annual data spanning from 1990 to 2021.

**Key findings:** Our results suggest that the relationship between criminal activity and rainfall is nonlinear, and in fact exhibit an inverted U-shape curve. This nonlinear relationship implies that at low level of rainfall, crime rate increases, however, until to a certain optimal point, thereafter, further downpour (worst weather conditions) or very high or extreme rainfall, criminal activity in Indonesia decreases.

**Policy implications:** Results of our study can be translated into some practical implications. First, a government should consider placing more police personnel during rainy seasons so as to policing criminal activities that would lurking during this period of time, in particular in prone-crime area. Secondly, the government should set up more monitoring mechanism such closed-circuit television facilities in strategic areas, policing facilities in public areas and workplaces to enhance the safety of the people in some prone-crime areas.



**JEL Classifications:**
O13, Q54, R23

**Keywords:**
Climate change; Rainfall; Crime rate; Inverted U-shaped curve, Indonesia

**[Tajuk]**

## 1. INTRODUCTION

Crime is a worldwide phenomenon. It crosses from domestic crime, organised crime and transnational crime to international crime. According to Becker (1968), people commit crime because the expected benefits of committing crime outweigh the expected costs. The expected costs are the probability of being apprehended, convicted and incarcerated. In Indonesia, studies on the economics of crime have been proliferated in recent years. The more recent studies on determining criminal behaviour in Indonesia include Hardiawan et al. (2018), Nguyen (2019), Purnomo et al. (2023), Rahman and Prasetyo (2018), Trisnawati et al. (2019), Sugiharti et al. (2023), Sigiharti et al. (2022), Veranita and Yudhistira (2022), Saleemi and Amir-ud-Din (2019), Armin and Idris (2019), and Notapiri et al. (2022). These studies have found that (macro)economic variables such as unemployment rate, poverty rate, income (GDP per capita), population density, human development index, income inequality. minimum wage, good governance, urbanisation, foreign direct investment, domestic investment, life expectancy, education level or years of schooling, and police personnel were affecting crime rates in Indonesia.

Nonetheless, a study that take into account the role of climate change affecting criminal activity in Indonesia is rather lacking. The global international studies have recognised that climate change indicator such as temperature and rainfall do affect criminal behaviour. The heat aggression theory argues that changes in temperature affect crimes by increasing irritability and anger, and in response, people commit crime (Cohn, 1990; Cohn & Rotton, 1997). On the other hand, the routine activities theory argues that pleasant weather increases outdoor activity, thus exposing more people to offenders and leaving home unprotected and with the absence of policeman around, premises are easy target to criminals (Cohen & Felson, 1979). In fact, studies in Singapore by Pakiam and Lim (1984), and Malaysia by Habibullah (2017) found that climate change affect crime in these two countries.

Thus, the purpose of the present paper is to investigate the effects of climate change, in particular the role of rainfall on crime rates in Indonesia. The novelty of the present study is three folds: First, to the best of our knowledge, this is the first paper to study how climate change affect crime rates in Indonesia. Secondly, the present study would provide a better predictive model for criminal behaviour in Indonesia by taking into account the role of climate change (rainfall) as additional explanatory variables, thus, the authority will be more alert and prepared when there is extreme hot weather or extreme bad weather, to mitigate crime in their respective areas. And finally, in this study we test the nonlinear relationship between rainfall and crime rate in Indonesia.

To address the above contention, the paper is organized as follows. In Section 2, we provide a brief discussion on the related literature linking climate change and crime. Section 3 describes the data and method used in the analysis. In Section 4 we discuss the empirical results, and lastly, we conclude in Section 5.

## 2. LITERATURE REVIEW

### Theoretical Background

Global warming is the price for economic development. Rapid industrialization produces greenhouse gases that trap the heat and make the earth warmer. The rise in temperature and changes in precipitation resulted in extreme weather conditions. Global climate change affects physical and biological environments, people's behaviour and economic growth. An interesting line of research on climate change has explored the impact of climate change on criminal behaviour. In fact, voluminous of literatures have related the incidences of changing weather or climate change to criminal activities (Agnew, 2011).

In the crime-weather literature, there are three well known theories linking the effect of weather conditions on criminal activities. The Negative Affect Escape Model (NAAM) proposed by Baron (1972), Baron and Bell (1976), and Bell and Baron (1976) contend that aggressive behaviour increases with increases in temperature because of the increase in the negative affect such as irritation, annoyance and discomfort. However, the increase in aggression as temperature increases only up to a certain level, thereafter, further increase in temperature results in the decrease in aggression because the motivation to escape uncomfortable situations outweighs the aggressive motives. This curvilinear, inverted-U shaped relationship between crime and weather has been supported by among others; Andersan and Anderson (1984), Cohn and Rotton (1997), Van de Vliert et al. (1999), Horrocks and Menclova (2011), and Gamble and Hess (2012).

On the other hand, Anderson et al. (1995) put forward the General Affective Aggression Model (GAAM) that postulate higher temperatures facilitate affective aggression. The model predicts that hot temperature produced increases in hostile affect, hostile cognition and physiological arousal. According to Anderson et al. (1995), a person's acute situational variables such as pain, discomfort, and frustration determine a person's arousal (e.g., psychological, perceived), state of affect (e.g., hostility, anger) and cognitions (e.g, hostile thoughts, hostile memories). For example, hot temperature will affect acute situational variables of a person, such as discomfort. Uncomfortable conditions should arouse negative affect (such as hostility or anger), heightens physiological arousal, and primes aggressive thoughts and most likely this will lead to aggressive behaviour such violent acts (Rotton and Cohn, 2003).

The Routine Activity (RA) theory proposed by Cohen and Felson (1979) assert that a criminal event requires three elements: a motivated offender, a suitable target, and the absence of capable guardians. The guardian in this sense is not necessarily the police but includes families, relatives, friends, or neighbours or even bystanders. The suitability of a target is governed by its value, visibility and accessibility to the possible offender, and the perceived net benefits of committing crime. Thus, for a crime to happen a suitable target must be available, a capable guardian is absence, and a motivated offender must be present. Relating this to weather, Cohn (1990) explains that during warm weather, people are more likely to stay away from their homes to public places, resulting in greater opportunities for personal interaction and lead more people being victimized. The increase in the number of empty dwellings will therefore increase the likelihood of burglaries (Cohn and Rotton, 2000; Butke and Sheridan, 2010).

**Rainfall and Crime**

Majority of the weather-crime related studies have been focusing on the role of temperature affecting crime, in particular violent crime. For example, earlier studies by Anderson (1989), Anderson and Anderson (1984), Cohn (1990), and Cotton (1986) show evidence that temperature has a positive effect on violent crime and other types of aggressive behaviour. The heat hypothesis popularized by Anderson (1989) suggests that hot temperatures cause physiological changes, thereby increasing the probability of hostile and aggressive behaviour. Anderson (2001) observes that rates of violent crime increased during the hottest times of the year, and were higher in the regions with hotter climates. On the other hand, rainfall and cold weather reduces crime. This is because, during cold and wet weather, people tend to stay indoors and/or at home.

Nevertheless, the research on the impact of rainfall on crime is less extensive than that on temperature. Furthermore, while the routine activities perspective would suggest that rainfall is more likely to push people inside and away from potential crime opportunities (Chen & Ng, 2012), much of this research provides mixed results depending on crime type. Studies have found that the impact of rainfall on assault and violence appears to be consistently negative. When examining the impact of rainfall on property crime, studies have found contrasting results.

A study by Ranson (2014) based on a 30-year of monthly crime by using a semi-parametric bin estimator, found that burglary and vehicle theft increase in months with many rains and snowy days. On similar account, by evaluating 60 primary studies that have examined 45 different conflict data sets, Hsiang et al. (2013) also found that rainfall increases the frequency of intergroup conflict and interpersonal violence. A positive relationship between rainfall and property crime was also found by Mehlum et al. (2006) in the 19th century Germany. On one hand, Blakeslee and Fishman (2014) found that property crime rates including burglary, banditry, thefts and robberies respond positively in excessively rainy years; while violent crimes (riots, murders, rape, and kidnapping) show no statistically significant response with abundant rain. On the other hand, in New Zealand, the relationship between rainfall and violence is negative, but there is a positive relationship between rainfall and property crime (Horrocks & Menclova, 2011). Further results with quadratic specification for rainfall in the violent crime model suggest a U-shape curve, which imply that at lower-rainfall, crime decreases and at extreme rainfall, violent crime increases.

Trujillo and Howley (2021) found a negative impact of rainfall on interpersonal violence in a torrid urban zone in Barranquilla, Colombia. In Tshwane in South Africa, Schutte and Breetzke (2018) found that violent and sexual crimes decrease on high-rainfall days, while property crime increases slightly on heavy rainfall days. Negative impact of rainfall on violent and property crimes was also detected in a study by Jacob et al. (2007) using crime data from the FBI's National Incident Based Reporting System (NIBRS). Similarly, the study by Ankel-Peters et al. (2022) on South Africa also found that rainfall has a negative effect on both violent and property crime. Hart et al. (2022) also found that negative impact of rainfall on crime in Norway. A negative relationship was also found between rainfall and theft in Singapore (Pakiam & Lim, 1984). For Malaysia, Habibullah (2017) found that rainfall affect positively on property crime but found no significant effect on violent crime.

Interestingly, some studies find no connection between precipitation and crime at all (Perry & Simpson, 1987]. For example, no association between several crime types and rainfall levels was found in England and Wales (Field, 1992), and in Los Angeles no link between rainfall and violent crime was found (Simister & Cooper, 2005). Wu et al. (2019) could not find any meaningful relationship between rainfalls with all types of crime in the Metropolitan area in Virginia, USA. Similarly, Baysan et al. (2019) found no statistically significant effect of rainfall on either intergroup or interpersonal violence in Mexico. For a study on Brisbane, Australia on the effect of weather on crime, Corcoran and Zahnow (2021) found that rainfall was not found to be significant in predicting risk of assault.

## 3. METHODOLOGY

To model the impact of rainfall on crime rate in Indonesia, we specify the following long-run model,

$$\mathrm{crime}_t = \phi_0 + \theta_1 \mathrm{rain}_t + \gamma_j \mathrm{control}_{jt} + \epsilon_t \quad (1)$$

where $\mathrm{crime}_{jt}$ is the measure of criminal activity measure using two indicators, j, that is, the number of total crimes reported, and crime rate measure using the number of total crimes reported per 100,000 population. The variable, $\mathrm{rain}_t$ is rainfall or precipitation in millilitres (mm). In this study, we include control variables such as national income, governance, globalisation, education, urbanisation and openness. All these macroeconomics variables were recognised as important factors affecting crime behaviour (Kizilgol & Selim; Ghosh et al., 2016; Anser et al., 2020). Parameters $\phi_0$, $\theta_1$ and $\gamma_j$ are coefficients to be estimated; and $\epsilon_t$ is the disturbance term which is assume to exhibit zero mean and constant variance.

For the control variables: we measure national income using real Gross Domestic Product (GDP) per capita; governance using “government effectiveness”, one of the six governance indicators proposed by Kaufman et al. (2008); globalisation is measure using KOF Globalization index; Education is measure using tertiary enrolment as percentage of gross enrolment; urbanisation is the growth in urbanisation population as percentage of total population; and openness is the total trade (export plus import) divided by GDP. It is expected that real GDP per capita and globalisation will affect crime rate positively; while education, urbanisation and openness will affect crime rate negatively in Indonesia.

### 3.1 Nonlinear Effects of Rainfall on Crime Rates

Taking the suggestion by Horrocks and Menclova (2011), Sanchez et al. (2023) and Hendrix and Salehyan (2012), we posited that the relationship between crime rates and rainfall could be nonlinear, thus, we also estimate the following regression,

$$\text{crime}_t = \phi_0 + \theta_1 \text{rain}_t + \theta_2 \text{rain}_t^2 + \gamma_j \text{control}_{jt} + \epsilon_t \quad (2)$$

We would expect that when $\theta_1 > 0$ and $\theta_2 < 0$, the nonlinear relationship between crime rate and rainfall is supported. The quadratic form for rainfall with $\theta_1 > 0$ and $\theta_2 < 0$, will exhibit an inverted U-shaped curve between crime rate and rainfall. Equation (2) suggests that rainfall has a positive effect on crime rate because it allows criminals to increase their criminal activities there are a smaller number of policemen around to policing the prone crime areas due to bad weather. However, as bad weather become worst, that is, too much rain, this will prevent criminal to advance their criminal activities in this very bad weather, and in turn the number of crimes will drop. Thus, the relationship between crime rates and rainfall should display an inverted U-shape curve. The optimal amount of rainfall can be calculated from Equation (2), after taking first derivative with respect to rainfall as, optimal rain $= -\theta_1/2\theta_2$.

### 3.2 Method of Estimations

The conventional Ordinary Least Square (OLS) procedure is not appropriate due to the fact that the time series variables are most likely autocorrelated and heteroscedastic in nature. To estimate Equations (1) and (2), we employ the Ordinary Least Square (OLS) with robust standard error due to Newey-West (Newey & West, 1987) procedure. Newey-West standard error method is a robust method/estimator which is very accurate when there is presence of heteroskedasticity and autocorrelation. Due to the fact that the time series variables are nonstationary and most likely the regressions results will be spurious, we test the model for the presence of cointegration. To test for cointegration, we employ the conventional cointegration test proposed by Engle and Granger (1987). The two-step Engle-Granger cointegration test is done by first estimating Equation (1) using OLS. In the second step, the residuals are saved and then tested for the presence of unit root. The rejection of a unit root in the residuals would suggest cointegration. If the variables are found to be cointegrated in Equations (1) to (2), the estimated long-run models are said to be valid, the OLS estimation is efficient and the results are nonspurious.

We also employ the Autoregressive distributed lag (ARDL) proposed by Pesaran, Shin and Smith (2001) to double check on the cointegration test. ARDL procedure is robust to a mixed of I(0) and

I(1) variables, small sample properties and endogeneity with good enough lags structure in the model. According to Pesaran et al. (2001), the validity of the long-run model as per Equation (1) and Equation (2) can be tested using cointegration Bound F-test. If Equation (1) and Equation (2) exhibit cointegration, then the long-run model is non-spurious. To test for cointegration, Pesaran et al. (2001) proposed estimating the bound F-test statistics by running the following conditional error-correction model (ECM) model as follows;

$$\Delta \text{crime}_t = \alpha_0 + \alpha_1 \text{crime}_{t-1} + \alpha_2 \text{rain}_{t-1} + \delta_j \text{control}_{jt-1} + \sum_{i=1}^{p} \psi_{1i} \Delta \text{crime}_{t-i} + \sum_{i=0}^{q} \psi_{2i} \Delta \text{rain}_{t-i} + \sum_{i=0}^{r} \psi_{3ji} \Delta \text{control}_{jt-i} + \upsilon_t \quad (3)$$

The Bound-F test was tested on whether $\alpha_1 = \alpha_2 = \delta_j = 0$ (null hypothesis) versus $\alpha_1 \neq \alpha_2 \neq \delta_j \neq 0$ (alternative hypothesis). The long-run cointegrating relationship is identified when the computed F-statistic is compared with the bound critical value tabulated by Narayan (2005) for small sample size. The null hypothesis of no cointegration is rejected when the computed F-statistic exceeds the upper bounds of critical value that the variables are cointegrated. On the other hand, the variables are not cointegrated if the null hypothesis of no cointegration is not rejected where the estimated F-statistic falls below the lower bounds of critical value. If the calculated F-statistic falls between the upper and lower bounds of critical values, the decision is inconclusive. Rejection of the null hypothesis meaning that there is cointegration and the long-run model as per Equation (1) is valid. Equation (3) must pass the non-serial correlation test with optimum lag length chosen using the Akaike criteria.

According to Pesaran et al. (2001), the long-run model as per Equation (1) can be derived from model (3). Note that in the long run, $\Delta = 0$ and $\text{crime}_{t-1} = \text{crime}_t$ and so on, after rearranging terms, thus we have,

$$\text{crime}_t = -\frac{\alpha_0}{\alpha_1} - \frac{\alpha_2}{\alpha_1} \text{rain}_t - \frac{\delta_j}{\alpha_1} \text{control}_{jt} - \frac{1}{\alpha_1} \nu_t \quad (4)$$

And we have,

$$\text{crime}_t = \phi_0 + \theta_1 \text{rain}_t + \gamma_j \text{control}_{jt} + \varepsilon_t \quad (1')$$

where $\phi_0 = -\frac{\alpha_0}{\alpha_1}$, $\theta_1 = -\frac{\alpha_2}{\alpha_1}$, $\gamma_j = -\frac{\delta_j}{\alpha_1}$, and $\epsilon_t = -\frac{1}{\alpha_1} \nu_t$.

Once we have estimated the long-run model, we can also estimate the short-run model, that is. the error-correction model as follows,

$$\Delta \mathrm{crime}_t = \varphi_0 + \pi \mathrm{ECT}_{t-1} + \sum_{i=1}^{p} \varphi_{1i} \Delta \mathrm{crime}_{t-i} + \sum_{i=0}^{q} \varphi_{2i} \Delta \mathrm{rain}_{t-i} + \sum_{i=0}^{r} \varphi_{3ji} \Delta \mathrm{control}_{jt-i} + \mu_t \quad (5)$$

where $\mathrm{ECT}_{t-1} = \epsilon_{t-1} = \mathrm{crime}_{t-1} - [\phi_0 + \theta_1 \mathrm{rain}_{t-1} + \gamma_j \mathrm{control}_{jt-1}]$. Equation (5) must pass the non-serial correlation test. The significance and the negative values of the estimated coefficient, $\pi$ would indicate cointegration. The estimated parameter $\pi$, would lies between 0 and -2 (see Fromentin & Leon, 2019; Samargandi, Fidrmuca, & Ghosh, 2015; Loayza & Rancière, 2006).

According to Pesaran et al. (2001), as in MICROFIT, the long-run model (Equation 1) was derived from the following ARDL model in levels,

$$\mathrm{crime}_t = \beta_0 + \sum_{i=1}^{p} \beta_{1i} \mathrm{crime}_{t-i} + \sum_{i=0}^{q} \beta_{2i} \mathrm{rain}_{t-i} + \sum_{i=0}^{r} \beta_{3ji} \mathrm{control}_{jt-i} + \eta_t \quad (6)$$

where the long-run model can be derived as,

$$\mathrm{crime}_t = \frac{\beta_0}{1-\sum \beta_{1i}} + \frac{\sum \beta_{2i}}{1-\sum \beta_{1i}} \mathrm{rain}_t + \frac{\sum \beta_{3ji}}{1-\sum \beta_{1i}} \mathrm{control}_{jt} + \frac{1}{1-\sum \beta_{1i}} \eta_t, \text{ and we have,}$$

$$\mathrm{crime}_t = \phi_0 + \theta_1 \mathrm{rain}_t + \gamma_{2j} \mathrm{control}_{jt} + \varepsilon_t \quad (2")$$

where $\phi_0 = \frac{\beta_0}{1-\sum \beta_{1i}}$, $\theta_1 = \frac{\sum \beta_{2i}}{1-\sum \beta_{1i}}$, $\gamma_2 = \frac{\sum \beta_{3i}}{1-\sum \beta_{1i}}$, and $\epsilon_t = \frac{1}{1-\sum \beta_{1i}} \eta_t$. Equation (6) must pass the non-serial correlation test with optimum lag length.

### 3.3 Robustness Tests

In this study, we also employ the Fully Modified OLS (FMOLS) procedure and Robust regression with M-estimator to estimate the long-run models as per Equations (1) to (2). The FMOLS is more efficient and robust than the OLS, particularly for small samples and to work with models with heteroscedasticity, autocorrelation, and non-normality of errors. On the other hand, the Robust regression is robust to the presence of outliers. Barnett and Lewis (1994) have stated that the presence of outliers can lead to inflated error rates and substantial distortions of parameter and statistical estimates when using either parametric or non-parametric tests. Statistically, the increase in error variance will reduce the power of the statistical tests, decrease normality, and seriously bias or influence parameter estimates (Perez et al., 2013). According to Rousseeuw (1984), robust regression is the best method to detect outliers and provides results that are resistant to the outliers. The most common general method of robust regression is the M-estimation method introduced by Huber (1964).

### 3.4 Data Sources

In this study, we use annual time series data for the period 1990 to 2021. Data for crime and crime rate was collected from the various issues of the Statistical Yearbook of Indonesia published by BPS-Statistics Indonesia, and the International Statistics on Crime and Justice published by United Nations Office on Drugs and Crime (UNODC). Data on precipitation or rainfall was collected from the Climate Change Knowledge Portal, a World Bank database on climate indicators which is available at https://climateknowledgeportal.worldbank.org/

Data on real Gross Domestic Product per capita (GDPpc), school enrolment (tertiary) to gross enrolment (%), percentage of urban population to total population, percentage of total trade to GDP was compiled from the World Development Indicator, a World Bank database which is available at https://data.worldbank.org/indicator?tab=all. For the governance indicator, we are using "voice and accountability" which captures perceptions of the extent to which a country's citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association, and a free media. This variable is collected from the Worldwide Governance Indicator which is available at https://databank.worldbank.org/source/worldwide-governance-indicators. On the other hand, data on KOF globalisation index was taken from KOF Swiss Economic Institute available at https://kof.ethz.ch/en/forecasts-and-indicators/indicators/kof-globalisation-index.html.

All variables were transformed into logarithm, such that all estimated coefficients are elasticities. For variables having negative values, we employ the formula $\log y_i = \log\left[y_i + \sqrt{(y_i^2 + 1)}\right]$ to transform the series into logarithm (Busse & Hefeker, 2007). By employing this method, we maintain the sign of $y_i$.

## 4. EMPIRICAL RESULTS

Before we proceed in estimating Equation (1), the descriptive statistics of all the variables involve in the study is presented in Table 1. In general, the mean for all series (except governance) is positive, meaning that the series are trending upwards, and positive values outweigh the negative values. For the crime and crime rate variables, the maximum number of recorded crimes is 250,870 and 107.5 respectively. The maximum and minimum rainfall for the period 1990 to 2021 in Indonesia is 3,289 millilitres and 2,275 millilitres, respectively. In all cases, we have positive value of skewness (except crime rate and rainfall for having negative skewness) for all variables, while kurtosis with size greater than 3 is only shown by openness. Nevertheless, the Jarque-Bera test for normality of the series was rejected for globalisation and openness.

In Table 2, we present the correlation matrix for the dependent variable (crime and crime rate) and all the independent variables. Generally, except for variables rain and rain-square, all other independent variables demonstrate strong correlation with the dependent variable. The correlation between crime and crime rate with income, governance, globalisation, education, urbanisation and openness were highly significant at the 1% level. The correlation between crime and crime rate with income, governance, globalisation, and education are positive; while with urbanisation and openness is negative.

Next, we test for cointegration for Equations (1) and (2). However, before we do that, we test the order of integration for each variable. We employed the standard augmented Dickey-Fuller (ADF, Dickey & Fuller, 1980) unit root test to determine the integration of the variables. The results of the unit root test for the order of integration of the series using ADF procedure is presented in Table 3. The unit root test results clearly indicate that all variables are I(1), that is the series achieved stationarity after differencing once. These results suggest that all variables are non-stationary in levels and their first-differences are stationary, that is, they are I(0). Thus, a consequence of regressing such integrated variables will produce spurious regression results. Spurious regression results will imply that inferences cannot be made and hypothesis testing will be invalid. Thus, estimating Equation (1) using OLS will result in spurious regression unless the variables are cointegrated. A cointegrating regression implies a long-run model for crime model as specified in Equation (1). It also implies that there are long-run relationships between criminal activity and its determinants. Since all variables are I(1), that is they are of the same order of integration we can then proceed for the test of cointegration among the variables by using the Engle-Granger two-steps procedure for the OLS-robust, and Bound

F-test for ARDL. For OLS, we indicate the DF test t-statistics, and we presented both the F-Bounds statistics and the ECT_(t-1) t-statistics for ARDL.

The results of our regression analyses are presented in Table 4. In columns (2) and (3) are results for crime; while columns (4) and (5) are the results for the crime rates. For the variable crime, for results from the OLS-robust and ARDL clearly suggest that cointegration is established between crime and its determinants as shown by the significant of the DF t-statistics, Bound F-statistics and the ECT t-statistics. Similarly, cointegration is also found for the crime rate models. These results imply that there is long-run relationship between crime and crime rate with its determinants – rainfall, real GDP per capita, governance, globalisation, education, urbanisation and openness. The results also suggest that the regression estimates are not spurious, and thus, the long-run model is valid.

Interestingly, the results indicate that all variables are statistically significant at least at the 10% level. Variable rainfall shows positive impact on crime behaviour. A 1% increase in rainfall will increase crime activity by 0.65% to 0.72 %. On the other hand, our control variables suggest that real GDP per capita and globalisation affect criminal behaviour positively. On the other hand, increase in governance, education level, growth in urbanisation and openness will reduce crime in Indonesia.

In Table 5, we present the nonlinear impact of rainfall on crime and crime rate in Indonesia. The OLS-robust regression results suggest that the relationship between crime and rainfall exhibits an inverted U-shape curve; implying that at a lower amount of rainfall will increase criminal activity, but after some optimal rainfall, criminal activity will decrease as bad weather become worst. Our estimate of the optimal amount of rainfall is about 30 centimetres (cm). The ARDL model also indicate the nonlinear relationship between rainfall and criminal activity, although both variables are not statistically significant.

Our robustness tests using Robust regression and FMOLS are shown in Table 6 for linear and in Table 7 for nonlinear between crime and rainfall. In Table 6, all variables are statistically significant at the 1% level. Rainfall has a positive impact on crime, implying that increase in rainfall will increase criminal activities in Indonesia. On the other hand, in Table 7, rainfall has a nonlinear impact on crime: at lower level of rainfall, crime increases, but at some optimal level of rainfall, thereafter, crime slows down. The optimal level of rainfall is between 29 and 30 cm. This implies that during very heavy downpour, such that the amount of rain reaches more than 30 cm, criminal activity will decrease.

## 5. CONCLUSION

In this study, we investigate the impact of rainfall on crime rate, using annual time series that spans from 1990 to 2021 for Indonesia. Our results indicate that the relationship between criminal activity and rainfall is nonlinear, and in fact exhibit an inverted U-shape curve. This nonlinear relationship implies that as the amount of rainfall increases, crime rate will increase as well, however, until to a certain optimal point, thereafter, further downpour (worst weather conditions) that increase the amount rain to more than 30 cm will result in reduction in criminal activity in Indonesia. This relationship is robust with respect to the four estimators (namely, OLS-robust, ARDL, Robust regression M-estimation, and FMOLS) that we used in uncovering the nonlinear relationships.

Results of our study can be translated into some practical implications. First, a government should consider placing more police personnel during rainy seasons so as to policing criminal activities that would lurking during this period of time, in particular in prone-crime area. Secondly, the government should set up more monitoring mechanism such closed-circuit television facilities in strategic areas, policing facilities in public areas and workplaces to enhance the safety of the people in some prone-crime areas.

We have provided a simple analysis in establishing the causal effects of rainfall on criminal activity by using annual time series data from 1990 to 2021 for Indonesia. Our results indicate that the Indonesian government can play a role in mitigating crime rates by taking action in policing criminal activities during rainy seasons. Nevertheless, to further ascertain our findings, future research should make an effort to provide the impact of other climate change indicator such temperature, and pollution on criminal behaviour with richer time series data and countries, say in a panel data setting.

## REFERENCES

Agnew, R. (2012). Dire forecast: A theoretical model of the impact of climate change on crime. *Theoretical Criminology*, 16(1), 21-42. https://doi.org/10.1177/1362480611416843

Anderson, C. A. (1989). Temperature and aggression: Ubiquitous effects of heat on occurrence of human violence. *Psychological Bulletin*, *106*(1), 74-96. DOI: 10.1037/0033-2909.106.1.74

Anderson, C. A. (2001). Heat and violence. *Current Directions in Psychological Science*, *10*(1), 33-38. DOI: 10.1111/1467-8721.00109

Anderson, C. A., & Anderson, D. C. (1984). Ambient temperature and violent crime: Tests of the linear and curvilinear hypotheses. *Journal of Personality and Social Psychology*, *46*(1), 91-97. DOI: 10.1037//0022-3514.46.1.91

Anderson, C. A., Deuser, W. E., & DeNeve, K. M. (1995). Hot temperatures, hostile affect, hostile cognition and arousal: Tests of a general model of affective aggression. *Personality and Social Psychology Bulletin*, *21*(5), 434-448. https://doi.org/10.1177/0146167295215002

Ankel-Peters, J., Bruederle, A., & Roberts, G. (2022). Weather and crime – cautious evidence from South Africa. *Q Open*, 3, 1-22. https://doi.org/10.1093/qopen/qoac033

Anser, M.K., Yousaf, Z., Nassani, A.A., Alotaibi, S.M., Kabbani, A., & Zaman, K. (2020). Dynamic linkages between poverty, inequality, crime, and social expenditures in a panel of 16 countries: two-step GMM estimates. *Journal of Economic Structures*, 9(4), 1-25. https://doi.org/10.1186/s40008-020-00220-6

Armin, F., & Idris. (2019). Analysis of the effects of education, unemployment, poverty and income inequality on crime in Indonesia. *Advances in Economics, Business and Management Research*, 124, 368-374.

Barnett, V., & Lewis, T. (1994). *Outliers in Statistical Data*. New York: Wiley. https://www.wiley.com/en-us/Outliers+in+Statistical+Data%2C+3rd+Edition-p-9780471930945

Baron, R. A. (1972). Aggression as a function of ambient temperature and prior anger arousal. *Journal of Personality and Social Psychology*, *21*(2), 183-189. https://doi.org/10.1037/h0032892

Baron, R. A., & Bell, P. A. (1976). Aggression and heat: The influence of ambient temperature, negative affect and a cooling drink on physical aggression. *Journal of Personality and Social Psychology*, *33*(3), 245-255. DOI: 10.1037//0022-3514.33.3.245

Bayson, C., Burke, M., Gonzalez, F., Hsiang, S., & Miguel, E. (2019). Non-economic factors in violence: Evidence from organized crime, suicides and climate in Mexico. *Journal of Economic Behavior and Organization*, 168, 434-452. https://doi.org/10.1016/j.jebo.2019.10.021

Becker, G.S. (1968). Crime and punishment: An economic approach. *Journal of Political Economy*, 76, 169-217. https://www.jstor.org/stable/1830482

Bell, P. A., & Baron, R. A. (1976). Aggression and heat: The mediating role of negative affect. *Journal of Applied Social Psychology*, *6*(1), 18-30. https://doi.org/10.1111/j.1559-1816.1976.tb01308.x

Blakeslee, D., & Fishman, R. (2014). Weather shocks, crime, and agriculture: Evidence from India. Working Paper, New York Univ. Abu Dhabi. http://dx.doi.org/10.2139/ssrn.2428249

Busse, M., & Hefeker, C. (2007). Political risk, institutions and foreign direct investment. Eur *Journal of Political Economy*, 23, 397–415. https://doi.org/10.1016/j.ejpoleco.2006.02.003

Butke, P., & Sheridan, S. C. (2010). An analysis of the relationship between weather and aggressive crime in Cleveland, Ohio. *Weather, Climate and Society*, *2*, 127-139. https://doi.org/10.1175/2010WCAS1043.1

Chen, L., & Ng, E. (2012). Outdoor thermal comfort and outdoor activities: A review of research in the past decade. *Cities*, 29(2), 118–125. https://doi.org/10.1016/j.cities.2011.08.006

Cohen, L.E., & Felson, M. (1979). Social change and crime rate trends: A routine activities approach. *American Sociological Review*, 44, 588-608. https://doi.org/10.2307/2094589

Cohn, E. G. (1990). Weather and crime. *British Journal of Criminology*, *1*(30), 51-64.

Cohn, E. G., & Rotton, J. (1997). Assault as a function of time and temperature: A moderator-variable time-series analysis. *Journal of Personality and Social Psychology*, *72*(6), 1322-1334. https://doi.org/10.1037/0022-3514.72.6.1322

Cohn, E. G., & Rotton, J. (2000). Weather, seasonal trends and property crimes in Minneapolis, 1987-1988. A moderator-variable time-series analysis of routine activities. *Journal of Environmental Psychology*, *20*(3), 257-272. https://doi.org/10.1006/jevp.1999.0157

Cohn, E.G. (1990). Weather and crime. *The British Journal of Criminology*, 30(1), 51-64.

Cohn, E.G., & Rotton, J. (1997). Assault as a function of time and temperature: A moderator-variable time-series analysis. *Journal of Personality and Social Psychology*, 72(6), 1322-1334. DOI: 10.1037/0022-3514.72.6.1322

Corcoran, J., & Zahnow, R. (2021). The effect of weather on assault. *Environment and Behavior*, 1-27. https://doi.org/10.1177/00139165211014629

Cotton, J. L. (1986). Ambient temperature and violent crime. *Journal of Applied Social Psychology*, *16*(9), 786-801. https://doi.org/10.1111/j.1559-1816.1986.tb01168.x

Dickey, D.A., & Fuller, W.A. (1981). Likelihood ratio statistics for autoregressive time series with a unit root. *Econometrica*, 49: 1057-1077. https://doi.org/10.2307/1912517

Engle, R.F., & Granger, C.W.J. (1987). Co-integration and error correction: Representation, estimation and testing. *Econometrica*, 55, 251-276. https://doi.org/10.2307/1913236

Field, S. (1992). The effect of temperature on crime. *British Journal of Criminology*, 32(3), 340–351. https://www.jstor.org/stable/23637533

Fromentin, V., & Leon, F. (2019). Remittances and credit in developed and developing countries: A dynamic panel analysis. *Research in International Business and Finance*, 48, 310–320. https://doi.org/10.1016/j.ribaf.2018.12.010

Gamble, J. L., & Hess, J. J. (2012). Temperature and violent crime in Dallas, Texas: Relationships and implications of climate change. *Western Journal of Emergency Medicine*, *13*(3), 239-246. doi: 10.5811/westjem.2012.3.11746

Ghosh, A., Robertson, P.E., & Robitaille, M-C. (2016). Does globalisation affect crime? Theory and evidence. *The World Economy*, doi: 10.1111/twec.12422

Habibullah, M.S. (2017). The effects of weather on crime rates in Malaysia. *International Journal of Business and Society*, 18(2), 263-270. DOI: 10.33736/ijbs.482.2017

Hardiawan, D., Yusuf, A.A., & Muljarijadi, B. (2018). The impact of expenditure, inequality and socioeconomic on crime rates in Indonesia. Cross sectional study using spatial econometrics and geographically weighted regression. *Advances in Social Science, Education and Humanities Research* (ASSEHR), 216, 150-169. DOI: 10.2991/assdg-18.2019.14

Hart, R., Pedersen, W., & Skardhamar, T. (2022). Blowing in the wind? Testing the effect of weather on the spatial distribution of crime using Generalized Additive Models. Crime Science, 11, 9. https://doi.org/10.1186/s40163-022-00171-2

Hendrix, C.S., & Salehyan, I. (2012). Climate change, rainfall and social conflict in Africa. *Journal of Peace Research*, 49(1), 35-50. https://doi.org/10.1177/0022343311426165

Horrocks, J., & Menclova, A. K. (2011). The effects of weather on crime. *New Zealand Economic Papers*, *45*(3), 231-254. DOI: 10.1080/00779954.2011.572544

Hsiang, S.M., Burke, M., & Miguel, E. (2013). Quantifying the influence of climate on human conflict. *Science*, 341. DOI: 10.1126/science.1235367

Huber, P.J. (1964). Robust estimation of a location parameter. *Annals of Mathematical Statistics*, 35, 73–101 https://link.springer.com/chapter/10.1007/978-1-4612-4380-9_35

Jacob, B., Lefgren, L., & Moretti, E. (2007). The dynamics of criminal behavior evidence from weather shocks. *Journal of Human Resources*, 42(3), 489–527. https://www.jstor.org/stable/40057316

Kaufman, D., Kraay, A., & Mastruzzi, M. (2008). Governance matters VII: governance indicators for 1996-2007. *World Bank Policy Research*. The World Bank, Washington DC. http://documents.worldbank.org/curated/en/810501468338351727/Governance-matters-VII-aggregate-and-individual-governance-indicators-1996-2007

Kizilgol, O., & Selim, S. (2017). Socio- economic and demographic determinants of crime by panel count data analysis: The case of EU 28 and Turkey. *Journal of Business, Economics and Finance* (JBEF), 6(1), 31-41. http://doi.org/10.17261/Pressacademia.2017.383

Loayza, N.V., & Rancière, R. (2006). Financial development, financial fragility, and growth. *Journal of Money, Credit and Banking*, 38(4), 1051-1076. https://www.jstor.org/stable/3838993

Mehlum, H., Miguel, E., & Torvik, R. (2006). Poverty and crime in 19th century Germany. *Journal of Urban Economics*, 59, 370–388. https://doi.org/10.1016/j.jue.2005.09.007

Narayan, P.K. (2005). The saving and investment nexus for China: Evidence from cointegration tests. *Applied Economics*, 37(17), 1979–1990. https://doi.org/10.1080/00036840500278103

Newey, W.K., & West, K.D. (1987). A simple, positive semi-definite, heteroskedasticity and autocorrelation consistent covariance matrix. *Econometrica*, 55(3), 703-708. https://doi.org/10.2307/1913610

Nguyen, H.T.M. (2019). Do more educated neighbourhoods experience less property crime? Evidence from Indonesia. *International Journal of Educational Development*, 64, 27-37. https://doi.org/10.1016/j.ijedudev.2018.12.005

Notapiri, T., Toharudin, T., & Suparman, Y. (2022). Modeling of crime rate in Indonesia during the Covid-19 pandemic from a macroeconomic perspective: Using Robust regression with S-estimation. *Journal of Mathematics and Computer Science*, 12(118), 1-11. https://doi.org/10.28919/jmcs/7217

Pakiam, J.E., & Lim, J. (1984). Crime and weather in Singapore. *International Journal of Comparative and Applied Criminal Justice*, 8(1-2), 209-220. https://dx.doi.org/10.1080/01924036.1984.9688799

Perez, B., Molina, I., & Pena, D. (2013). Outlier detection and robust estimation in linear regression models with fixed group effects. *Journal of Statistical Computing & Simulation*, 84, 2652–2669. https://doi.org/10.1080/00949655.2013.811669

Perry, J.D., & Simpson, M.E. (1987). Violent crimes in a city: Environmental determinants. *Environment and Behavior*, 19(1), 77–90. https://doi.org/10.1177/0013916587191004

Pesaran, M.H., Shin, Y., & Smith, R.J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics*, 16(3), 289–326. https://doi.org/10.1002/jae.616

Purnomo, S.D., Supriyo, D.A., Rusito, Anindito, T., Hariadi, W., & Jati, D. (2023). How economic indicator drive crime? Empirical study in developing country, Indonesia. *International Journal of Economics and Financial Issues*, 13(3), 94-99. https://doi.org/10.32479/ijefi.14309

Rahman, Y.A., & Prasetyo, A.D. (2018). Economics and crime rates in Indonesia. *Journal of Economics and Policy*, 11(2), 401-412. https://doi.org/10.15294//jejak.v11i.216060

Ranson, M. (2014). Crime, weather and climate change. *Journal of Environmental Economics and Management*, 67, 274–302. http://dx.doi.org/10.1016/j.jeem.2013.11.008

Rotton, J., & Cohn, E. G. (2003). Global warming and U.S. crime rates: An application of routine activity theory. *Environment and Behavior*, *35*(6), 802-825. https://doi.org/10.1177/0013916503255565

Rousseeuw, P.J. (1984). Least median of squares regression. *Journal of American Statistical Association*, 79, 871–880. https://doi.org/10.1080/01621459.1984.10477105

Saleemi, M.W., & Amir-ud-Din, R. (2019). How does quality of governance influence occurrence of crime? A longitudinal analysis of Asian countries. MPRA Paper No.94142. https://mpra.ub.uni-muenchen.de/94142/

Samargandi, N., Fidrmuca, J., & Ghosh, S. (2015). Is the relationship between financial development and economic growth monotonic? Evidence from a sample of middle-income countries. *World Development*, 68, 66–81. https://doi.org/10.1016/j.worlddev.2014.11.010

Sanchez, A., Fernandez, A., & Gonzalez, J.B. (2023). Conservancies, rainfall anomalies and communal violence: Subnational evidence from East Africa. *Journal of Modern African Studies*, 61(1), 91-115. https://doi.org/10.1017/S0022278X22000416

Schutte, F.H., & Breetzke, G.D. (2018). The influence of extreme weather conditions on the magnitude and spatial distribution of crime in Tshwane (2001–2006). *South African Geographical Journal*. DOI: 10.1080/03736245.2018.1498384

Simister, J., & Cooper, C. (2005). Thermal stress in the USA: Effects on violence and on employee behaviour. *Stress and Health: Journal of the International Society for the Investigation of Stress*, 21(1), 3–15. https://doi.org/10.1002/smi.1029

Sugiharti, L., Esquivias, M.A., Shaari, M.S., Agustin, L., & Rohmawati, H. (2022). Criminality and income inequality in Indonesia. *Social Sciences*, 11, 142. https://doi.org/10.3390/socsci11030142

Sugiharti, L., Purwono, R., Esquivias, M.A., & Rohmawati, H. (2023). The nexus between crime rates, poverty and income inequality: A case study of Indonesia. *Economies*, 11, 62. https://doi.org/10.3390/economies11020062

Trisnawati, D., Khoirunurrofik, & Ismail, D.S. (2019). Inter-provincial spatial linkages of crime pattern in Indonesia: Looking at education and economic inequality effects on crime. *Indonesian Journal of Geography*, 51(2), 106-113. https://dx.doi.org/10.22146/ijg.34026

Trujillo, J.C., & Howley, P. (2021). The Effect of Weather on Crime in a Torrid Urban Zone. *Environment and Behavior*, 53(1), 69–90. DOI: 10.1177/0013916519878213

Van de Vliert, E., Schwartz, S. H., Iiuismans, S. E., Hofstede, G., & Daan, S. (1999). Temperature, cultural masculinity and domestic political violence: A cross-national study. *Journal of Cross-Cultural Psychology*, *30*(3), 291-314. https://doi.org/10.1177/0022022199030003002

Veranita, G., & Yudhistira, M.H. (2022). The effect of density on crime: Evidence from Indonesia. The Indonesian Journal of Development Planning, 6(3), 292-303. https://doi.org/10.36574/jpp.v6i3.342

Wu, C.Y.H., Lee, H.F., & Liu, H. (2019): Effect of temperature and precipitation change on crime in the metropolitan area in Virginia, USA, *Asian Geographer*, DOI:10.1080/10225706.2019.1678046

Table 1: Descriptive statistics

| Variables | Unit | Mean | Max | Min | S.D. | Skewness | Kurtosis | Jarque-Bera | Obs |
|---|---|---|---|---|---|---|---|---|---|
| Crime | Persons | 250869.5 | 357197.0 | 119965.4 | 76740.0 | 0.00 | 1.51 | 2.97 | 32 |
| Crime rate | % | 107.5 | 143.1 | 58.6 | 24.8 | -0.05 | 1.79 | 1.96 | 32 |
| Rain | mm | 2786.5 | 3289.4 | 2275.0 | 215.4 | -0.17 | 2.85 | 0.19 | 32 |
| Rain-square | mm | 7809261.0 | 10819955.0 | 5175534.0 | 1193985.0 | 0.04 | 2.93 | 0.01 | 32 |
| Income | Rupiah Mil | 26058551.0 | 40620816.0 | 15480907.0 | 8004453.0 | 0.55 | 1.93 | 3.15 | 32 |
| Governance | Index | -0.28 | 0.38 | -0.71 | 0.31 | 0.66 | 2.64 | 2.00 | 26 |
| Globalisation | Index | 58.0 | 64.0 | 43.0 | 5.9 | -1.05 | 2.93 | 5.70* | 31 |
| Education | % | 19.6 | 36.4 | 8.4 | 9.1 | 0.62 | 2.03 | 3.03 | 29 |
| Urbanisation | % | 2.0 | 3.4 | 1.1 | 0.9 | 0.61 | 1.65 | 4.26 | 31 |
| Openness | % | 53.1 | 96.2 | 33.2 | 12.0 | 1.33 | 6.44 | 25.27*** | 32 |

Notes: Income is real Gross Domestic Product per capita; Crime rate is percentage crime per 100,000 persons; Education is School enrolment, tertiary (% gross); Urbanisation is Urban population (% of total population); and Openness is Trade (% of GDP).

Table 2: Correlation matrix

| Variables | Crime | Crime rate | Rain | Rain-square | Income | Governance | Globalisation | Education | Urbanisation | Openness |
|---|---|---|---|---|---|---|---|---|---|---|
| Crime | 1 | | | | | | | | | |
| Crimerate | 0.9909*** | 1 | | | | | | | | |
| | (33.685) | | | | | | | | | |
| Rain | 0.3127 | 0.3351 | 1 | | | | | | | |
| | (1.5088) | (1.6297) | | | | | | | | |
| Rain-square | 0.2773 | 0.2986 | 0.9981*** | 1 | | | | | | |
| | (1.3225) | (1.4338) | (74.281) | | | | | | | |
| Income | 0.7781*** | 0.6935*** | 0.1058 | 0.1142 | 1 | | | | | |
| | (5.6758) | (4.4110) | (0.4875) | (0.5265) | | | | | | |
| Governance | 0.7397*** | 0.6608*** | 0.2882 | 0.2867 | 0.8671*** | 1 | | | | |
| | (5.0370) | (4.0349) | (1.3790) | (1.3715) | (7.9751) | | | | | |
| Globalisation | 0.8772*** | 0.8440*** | 0.3139 | 0.2950 | 0.7325*** | 0.8132*** | 1 | | | |
| | (8.3735) | (7.2124) | (1.5153) | (1.4149) | (4.9314) | (6.4038) | | | | |
| Education | 0.8366*** | 0.7588*** | 0.1862 | 0.1638 | 0.9667*** | 0.8765*** | 0.8410*** | 1 | | |
| | (6.9988) | (5.3381) | (0.8685) | (0.7609) | (17.298) | (8.3456) | (7.1241) | | | |
| Urbanisation | -0.9027*** | -0.8668*** | -0.1633 | 0.2123 | -0.7790*** | -0.7329*** | -0.7928*** | -0.8218*** | 1 | |
| | (-9.6151) | (-7.9657) | (-0.7585) | (0.9955) | (-5.6927) | (-4.9360) | (-5.9613) | (-6.6084) | | |
| Openness | -0.6300*** | -0.5595*** | -0.0407 | -0.02851 | -0.8491*** | -0.6836*** | -0.4377** | -0.7862*** | 0.6645*** | 1 |
| | (-3.7172) | (-3.0935) | (-0.1865) | (-0.1307) | (-7.3659) | (-4.2921) | (-2.2308) | (-5.8298) | (4.0746) | |

Notes: All variables are in logarithm.

Table 3: Results of unit root tests

| Variables | Level: Intercept | Intercept+trend | First-difference: Intercept | Intercept+trend |
|---|---|---|---|---|
| Crime | -0.96 (0) | -0.50 (0) | -3.65**(0) | -3.65**(0) |
| Crime rate | -0.93 (0) | -0.65 (0) | -3.67***(0) | -3.65**(0) |
| Rain | -2.61 (3) | -2.86 (3) | -8.01***(0) | -7.86***(0) |
| Rain-square | -2.61 (3) | -2.86 (3) | -8.01***(0) | -7.86***(0) |
| Income | -0.27 (0) | -1.53 (0) | -4.14***(0) | -4.07***(0) |
| Governance | 0.69 (1) | -1.04 (1) | -6.94***(0) | -7.10***(0) |
| Globalisation | -2.24 (2) | -1.26 (2) | -4.19***(0) | -4.72***(0) |
| Education | -0.43 (0) | -2.11 (0) | -5.46***(0) | -5.34***(0) |
| Urbanisation | -1.14 (0) | -1.47 (0) | -5.38***(0) | -5.45***(0) |
| Openness | -1.98 (0) | -2.40 (1) | -5.93***(1) | -6.03***(1) |

Notes: Asterisks ***, ** and * denote statistically significant at the 1%, 5% and 10% level, respectively. Figures in round, (…) brackets are optimal lag length.

Table 4: Cointegration results for linear models

| Independent variables | Dependent variable: Crime | | Dependent variable: Crime rate | |
|---|---|---|---|---|
| | OLS-robust | ARDL(4,1,1,1,1,1,1,1) | OLS-robust | ARDL(4,1,1,1,1,1,1,1) |
| Constant | -25.151** | -47.318*** | -30.533*** | -53.014** |
| | (-2.3860) | (-4.7552) | (-3.0609) | (-5.6814) |
| Rain | 0.6602** | 0.7243*** | 0.6511** | 0.7159** |
| | (2.3110) | (2.9437) | (2.3790) | (3.3169) |
| Income | 0.7776* | 1.8365*** | 0.7050* | 1.7735** |
| | (2.0168) | (3.3417) | (1.9324) | (3.4598) |
| Governance | -0.6301*** | -1.4992** | -0.6628*** | -1.5880* |
| | (-4.2588) | (-2.4484) | (-4.4439) | (-2.7786) |
| Globalisation | 5.6964*** | 7.4545*** | 5.4578*** | 7.2315** |
| | (4.7100) | (5.6897) | (4.7495) | (6.2579) |
| Education | -0.6384 | -1.2537*** | -0.7147 | -1.3097** |
| | (-1.5210) | (-4.4814) | (-1.8171) | (-5.1888) |
| Urbanisation | -20.863*** | -23.803*** | -17.288*** | -19.688** |
| | (-3.7338) | (-4.1010) | (-3.2796) | (-3.8046) |
| Openness | -0.5368** | -1.0195** | -0.5206** | -0.9999* |
| | (-2.5422) | (-2.3412) | (-2.6201) | (-2.4656) |
| $adjR^2$ | 0.903 | 0.995 | 0.854 | 0.994 |
| $DF_{t-statistic}$ | -5.08***(0) | | -5.06***(0) | |
| $Bound_{F-statistics}$ | | 26.24*** | | 30.27*** |
| $ECT_{t-statistics}$ | | -29.42*** | | -31.60*** |

Notes: Asterisks ***, ** and * denote statistically significant at the 1%, 5% and 10% level, respectively. Figures in round, (…) brackets are t-statistics.

Table 5: Cointegration results for nonlinear models

| Independent variables | Dependent variable: Crime | | Dependent variable: Crime rate | |
|---|---|---|---|---|
| | OLS-robust | ARDL(3,1,1,1,1,1,1,1) | OLS-robust | ARDL(3,1,1,1,1,1,1,1) |
| Constant | -268.43*** | -537.05 | -263.46*** | -556.43 |
| | (-3.5153) | (-2.4189) | (-3.4386) | (-2.6267) |
| Rain | 61.065*** | 123.26 | 58.484*** | 126.81 |
| | (3.1839) | (2.2112) | (3.0292) | (2.3821) |
| Rain-square | -3.8145*** | -7.7398 | -3.6521*** | -7.9632 |
| | (-3.1443) | (-2.2051) | (-2.9907) | (-2.3762) |
| Income | 0.9377** | 1.5601 | 0.8583** | 1.4762 |
| | (2.4712) | (2.4116) | (2.4253) | (2.4782) |
| Governance | -0.7289*** | -1.5726 | -0.7575*** | -1.6143 |
| | (-4.8834) | (-2.1414) | (-5.0071) | (-2.3629) |
| Globalisation | 6.2066*** | 11.085** | 5.9464*** | 10.792** |
| | (5.4882) | (3.3977) | (5.5668) | (3.5509) |
| Education | -0.7432* | -1.9512** | -0.8150** | -1.9967** |
| | (-1.9590) | (-4.2043) | (-2.3219) | (-4.6741) |
| Urbanisation | -17.190*** | -29.461 | -13.770** | -1.7648 |
| | (-3.2017) | (-2.8459) | (-2.7112) | (-2.3155) |
| Openness | -0.6450** | -1.7988 | -0.6242** | -25.563 |
| | (-2.7383) | (-2.2018) | (-2.8073) | (-2.6122) |
| $adjR^2$ | 0.908 | 0.996 | 0.863 | 0.994 |
| $DF_{t-statistic}$ | -4.81***(0) | | -4.78***(0) | |
| $Bound_{F-statistics}$ | | 19.31*** | | 20.10*** |
| $ECT_{t-statistics}$ | | -32.59*** | | -33.25*** |
| Optimal rainfall (mm) | 2972.8 | 2934.8 | 2985.9 | 2933.0 |

Notes: Asterisks ***, ** and * denote statistically significant at the 1%, 5% and 10% level, respectively. Figures in round, (…) brackets are t-statistics. The optimal point is calculated as $-\hat{\theta}_1/2\hat{\theta}_2$.

Table 6: Long-run linear models using Robust regression and FMOLS

| Independent variables | Dependent variable: Crime | | Dependent variable: Crime rate | |
|---|---|---|---|---|
| | Robust regression | FMOLS | Robust regression | FMOLS |
| Constant | -30.402*** | -34.373*** | -39.356*** | -39.386*** |
| | [-3.6438] | (-4.4105) | [-5.7018] | (-5.1301) |
| Rain | 0.8113*** | 0.8439*** | 0.9415*** | 0.8259*** |
| | [3.5534] | (3.7142) | [4.9844] | (3.6897) |
| Income | 0.9997*** | 1.2329*** | 0.9987*** | 1.1315*** |
| | [2.7959] | (3.3641) | [3.3765] | (3.1341) |
| Governance | -0.5410*** | -0.7413*** | -0.6542*** | -0.7745*** |
| | [-3.0340] | (-4.8118) | [-4.4342] | (-5.1029) |
| Globalisation | 5.8341*** | 6.1578*** | 6.0301*** | 5.9559*** |
| | [5.9044] | (7.1803) | [7.3768] | (7.0497) |
| Education | -0.9039*** | -1.0342*** | -1.0593*** | -1.0931*** |
| | [-3.4625] | (-4.2046) | [-4.9049] | (-4.5115) |
| Urbanisation | -27.001*** | -17.713*** | -22.518*** | -13.813*** |
| | [-5.7772] | (-4.4078) | [-5.8239] | (-3.4890) |
| Openness | -0.3719** | -0.7360*** | -0.4398*** | -0.7233*** |
| | [-2.0680] | (-4.8244) | [-2.9560] | (-4.8131) |
| $adjR^2$ / $adjRw^2$ | 0.985 | 0.864 | 0.984 | 0.795 |

Notes: Asterisks ***, ** and * denote statistically significant at the 1%, 5% and 10% level, respectively. Figures in round brackets (…) and square brackets […] are t-statistics and z-statistics, respectively. $adjR^2$ denotes adjusted R-square measures goodness of fit in the OLS; while $Rw^2$ measures goodness of fit for the Robust regressions.

Table 7: Long-run nonlinear models using Robust regression and FMOLS

| Independent variables | Dependent variable: Crime | | Dependent variable: Crime rate | |
|---|---|---|---|---|
| | Robust regression | FMOLS | Robust regression | FMOLS |
| Constant | -220.76*** | -621.17*** | -215.36*** | -642.91*** |
| | [-4.5349] | (-5.4493) | [-3.7768] | (-5.8711) |
| Rain | 49.028*** | 149.07*** | 46.416*** | 153.26*** |
| | [4.0658] | (5.3812) | [3.2862] | (5.7593) |
| Rain-square | -3.0653 | -9.3351*** | -2.9004*** | -9.5982*** |
| | [-4.0256] | (-5.3546) | [-3.2518] | (-5.7312) |
| Income | 1.1068*** | 0.7441*** | 1.0187*** | 0.6248* |
| | [7.5065] | (2.0542) | [5.8983] | (1.7955) |
| Governance | -0.3322*** | -0.9757*** | -0.3596*** | -1.0301*** |
| | [-4.4616] | (-7.2480) | [-4.1242] | (-7.9660) |
| Globalisation | 5.5202*** | 7.4665*** | 5.2035*** | 7.3002*** |
| | [13.443] | (11.641) | [10.818] | (11.848) |
| Education | -0.9121*** | -0.6557*** | -0.9649*** | -0.6983*** |
| | [-8.5117] | (-2.8877) | [-7.6872] | (-3.2013) |
| Urbanisation | -24.544*** | -19.143*** | -20.666*** | -15.276*** |
| | [-12.154] | (-5.0995) | [-8.7365] | (-4.2362) |
| Openness | -0.2944*** | -0.6972*** | -0.2796*** | -0.6862*** |
| | [-3.8979] | (-5.4291) | [-3.1600] | (-5.5619) |
| $adjR^2$ / $adjRw^2$ | 0.998 | 0.736 | 0.996 | 0.551 |
| Optimal rainfall (mm) | 2993.9 | 2871.9 | 3001.6 | 2870.5 |

Notes: Asterisks ***, ** and * denote statistically significant at the 1%, 5% and 10% level, respectively. Figures in round brackets (…) and square brackets […] are t-statistics and z-statistics, respectively. adj$R^2$ denotes adjusted R-square measures goodness of fit in the OLS; while $Rw^2$ measures goodness of fit for the Robust regressions. The optimal point is calculated as $-\hat{\theta}_1/2\hat{\theta}_2$.

# About the Authors

**Muzafar Shah Habibullah** is a Professor at Putra Business School and Senior Economist at the EIS-UPMCS Centre for Future Labour Market Studies (EU-ERA). He holds a Ph.D. in Economics from the University of Southampton, United Kingdom. His area of specialization includes Applied Macroeconomics, Monetary Economics, and Banking. Throughout his career, he has published more than 500 academic documents including journal articles, books, edited books, chapters in books, and chapters in proceedings.
E-mail: muzafar@putrabs.edu.my; muzafar@upm.edu.my

**Sugiharso Safuan** is a Professor in the Department of Economics, University of Indonesia. He holds a Ph.D in Economics from the University of Southampton, United Kingdom. His area of research includes Applied Macroeconomics, International Economics, and Monetary Economics.
E-mail: sugiharso.safuan@gmail.com