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You Can't Live Alone: Spatial Climate Change Shock and Economic Growth in the Largest Archipelagic State

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ABSTRACT

This study explores the effect of province-specific temperature and precipitation, which are expressed as deviancies of temperature and precipitation from historical data using the spatial Mankiw, Romer, and Weil (MRW) growth model. Performing a panel data set of 34 provinces covering the period from 2006 to 2022, this study predicts the nonlinear impact of climate change on per capita real output growth. We also show the inverted U-shaped curve from persistent changes in the temperature and precipitation on per capita real output growth either above or below its historical data. In the absenteeism of mitigation strategies, we found that an insistent increase in the average temperature or precipitation per year diminishes per capita real output growth. This study also explores climate change's spatial impacts on economic growth performance through spatial lambda and rho parameters. We discovered the significant provincial spillover effect of climate change on economic growth. We also identify that increasing temperature and precipitation in provincial neighbors further decreased economic growth. Furthermore, this study conducts a robustness test by employing an open economy to meet the consistency of the baseline model. We reconfirm the empirical results of the baseline model.

Keywords: Climate Change, Economic Growth, Spatial Econometrics
JEL Classifications: C33, C51, O47, Q54

1. INTRODUCTION

Since global temperatures have revealed a fleet change in the last few decades (WMO, 2022; NOAA, 2022), climate change has been a topic of heated debate among scientists and policymakers. The scientific debate about climate change gave rise to two main streams of academic literature. The first stream concentrates on the factors that cause climate change (Acaroğlu and Güllü, 2022; Crowley, 2000; Hegerl et al., 2019; Manabe, 2019; Raza et al., 2023; Stern and Kaufmann, 2014). While the second stream focuses on the effects of climate change. The literature discussing the effects of climate change extends from agricultural production (Abeysekara et al., 2023; Bomdzele and Molua, 2023; Chandio et al., 2022; Crost et al., 2018; Ju et al., 2013), employment (Chen et al., 2023; Dodman et al., 2023; Godinho, 2022; Huang et al., 2020; Liu and Lin, 2023; Sangeetha and Usha, 2022), energy demand (Arndt, 2023; Campagna and Fiorito, 2022; Jbir, 2021; Lam et al., 2022; Lipson et al., 2019), financial stability (Battiston et al., 2021; Capasso et al., 2020; Chabot and Bertrand, 2023; Liu et al., 2024; Monasterolo, 2020), and economic activity (Alagidede et al., 2016; Farajzadeh et al., 2023; Petrović, 2023; Sequeira et al., 2018; Stern and Stiglitz, 2023).

The influence of climate change on economic growth is of interest to academics for at least two reasons (Benhamed et al., 2023). Firstly, economic growth serves as the most precise gauge of the overall well-being of the economy. Secondly, the existence of a substantial time series of economic growth has motivated researchers to concentrate on the consequences of climate change on economic growth, given that climate change is a protracted phenomenon (Kahn et al., 2021; Kumar and Maiti, 2024). A review of the present literature shows that recent observed studies apply regular panel data techniques to test whether climate change significantly impacts economic growth, namely Koubi et al. (2012) using fixed effect vector decomposition, Alagidede et al. (2016) employing panel cointegration techniques, Acevedo et al. (2020) using the impulse response function, and Kahn et al. (2021) Utilizing the autoregressive panel distributed lag method. While the empirical methodology has many benefits, a notable drawback is its disregard for the worldwide aspect of climate change and its failure to account for spatial relationships. Prior research failed to account for interconnections between different areas and made the assumption that shared causes did not impact the correlation between climate change and economic growth. Subsequently, disregarding spatial connections will amplify the bias of the deleted variables.

This analysis has some novelty when compared to previous literature. This research fills in previous literature gaps by inspecting the complex association between climate change and economic growth, emphasizing spatial dimensions, and using spatial panel data models to capture complex dynamics. This study is a forerunner that deliberates the impact of climate change, as restrained by changes in temperature and rainfall, on economic growth by considering spatial impacts in Indonesia. Therefore, in addition to direct impacts, research will explore indirect impacts (spillover) and the total impact of climate change on economic growth. The observed analysis of spatial impact is based on a distance weight matrix. For the robustness test, the study analysis includes the open economy model.

The rest of the study is controlled as follows. Part 2 reviews related empirical literature, while Part 3 discusses theoretical models of economic growth. Section 4 sets forth research methods and data. Empirical findings and robustness testing of the model are conferred in Section 5. Finally, Section 6 accomplishes the research and postulates some policy advice.

2. LITERATURE REVIEW

The literature illustrates diverse views on the relationship between climate change and economic performance. The current rapidly growing literature study attempts to estimate the impact of climate change on economic performance, particularly related to agricultural production, labor productivity, commodity prices, health, conflict, and economic growth (Burke et al., 2015; Dell et al., 2012; 2014; Duan et al., 2022; Henseler and Schumacher, 2019; Kahn et al., 2021; Song et al., 2023; Stern and Stiglitz, 2023; Tol, 2024).

The development of literature has since Montesquieu (1750) emphasized the negative impact of climate change on economic productivity. Although policymakers and experts acknowledge the devastating impact of rising temperatures on economic growth, the topic remains an interesting issue, particularly concerning ways of assessing such impacts. In fact, estimating the macroeconomic effects of climate change presents a major challenge due to the variety of climate change mechanisms that can be traced in affecting the economy. Batten et al. (2020) suggest two types of climate change risks: physical risks and transition risks. Physical risks come from extreme weather, which can diminish an economy's production capacity. Transition risks include the effects of transitioning to a low-carbon economy that can reduce economic growth.

The current literature concentrates on the impact of climate change on various sectors of the economy. The impact of climate change on agriculture has been investigated by Adams et al. (1990), Mendelsohn et al. (2001), Deschênes and Greenstone (2007), Malhi et al. (2021), Nugroho et al. (2023), Huang et al. (2020), Lu et al. (2020), Ding and Xu (2023), Ansari et al. (2023), and Khairulbahri (2021). Next, Dell et al. (2012), Sahin (2022), Ciccarelli and Marotta (2024) highlight that the impact of climate change on macroeconomics can be delighted through its impact on agriculture, industry, investment, labor markets, labor productivity, and business cycles. Moreover, Rosselló-Nadal (2014), Semenza and Ebi (2019), Ghosh et al. (2024), Cavallaro et al. (2021), Pathak et al. (2021), and Dogru et al. (2019) asserts that the negative upshots of climate change on economic growth may be diffused through tourism. Climate change could also disparagingly impact bank productivity and financial immovability (Caby et al., 2022; Chabot and Bertrand, 2023; Le et al., 2023; Liu et al., 2024; Liu et al., 2021; Weber, 2024). It is worth perceiving that climate change can have different effects in the long term than the short term. Climate change can lead to various long-term consequences, including alterations in groundwater, soil quality, and sea level, which can result in more significant negative economic effects. (Barbieri et al., 2023; Lal, 2012; Liang et al., 2024; Meehl et al., 2004; Roberts, 2024; Ross and Randhir, 2022; Roy et al., 2023; van der Laan et al., 2023). However, it is worth noting that the long-term consequences of climate change may not be as significant as the short-term consequences. This is because implementing climate change adaptation techniques can help mitigate the negative effects of climate change on the short-term economy. Hence, it is imperative to conduct an examination of the short-term and long-term effects of climate change.

On the experimental side, although there is a compromise on the adverse effects of climate change on economic growth, there is a difference of opinion on the extent to which climate change hinders economic growth. Dell et al. (2012) show a substantial adverse impact of temperature alterations on output growth in low-income countries but does not significantly affect growth in high-income countries. Then, Dell et al. (2012) state rainfall changes do not have a major economic effect in all countries. A study in the US conducted by Colacito et al. (2019) show that temperature significantly adversely impacts aggregate and sectoral levels. Kahn et al. (2021) found that persistent temperature changes above or below its historical temperature would hurt real GDP growth per capita. Letta and Tol (2019) shows significant negative impacts of climate change in low-income countries, but not statistically significant in high-income countries. Henseler and Schumacher (2019) expanding research Letta and Tol (2019) to analyze the effect of temperature on total factor productivity and capital stock and employment. Henseler and Schumacher (2019) shows that high temperatures in low-income countries negatively impact economic variables more than in high-income countries.

Kim et al. (2021) examined the macroeconomic effect of extreme weather events in the US employing the ST-VAR model from 1963 to 2019. They suggest that climate change reduces output and employment growth and the long-term impacts of extreme weather events outweigh the short-term impacts. Kim et al. (2022) also inspected the macroeconomic consequences of extreme weather events in seven Central American countries between 2001 and 2019. They point out that climate disasters lessen monthly economic activity by about 0.5-1% point. Sequeira et al. (2018) examine the influence of climate change on the economic development of across nations between 1950 and 2011. The analysis indicates that temperature fluctuations typically do not significantly impact both short-term and long-term economic growth.

Nevertheless, certain evidence exists of the devastating effects of escalating temperatures in the poorest countries. Parallel results were also achieved by Zhao et al. (2018) concluding the adverse effects on economic growth. Moreover, they revealed temperature change effect will be greater when considering domestic variability. Hernandez and Madeira (2022) analyze the impact of climate change on output at the sectoral level in Chile from 1985 to 2017. They proved that changes in rainfall do not significantly impact GDP, while higher summer temperatures adversely affect the agricultural-silvicultural and fisheries sectors. Deryugina and Hsiang (2014) confirmed the devastating impact of temperature on the economy as productivity decreases by about 1.7% for every 1°C rise in temperature above 15°C. Burke et al. (2015) conducted research on the nonlinear effect of temperature on output and concluded that global economic output has a nonlinear relationship with average temperature. Finally, Donadelli et al. (2022) showed economic growth's response to temperature varies widely between countries. Despite the rapid development of literature on the impact of climate change on economic growth, the spatial aspects of this relationship have not been explored much (Benhamed et al., 2023).

3. THEORETICAL MODEL OF ECONOMIC GROWTH

The following Hicks-neutral Cobb-Douglas production function describes each provincial economy

$$Y_{it} = A_{it} K_{it}^{\alpha_K} H_{it}^{\alpha_H} L_{it}^{1-\alpha_K-\alpha_H} \tag{1}$$

Where i is the province and t is the time. Y is output, K is physical capital, H is human capital, L is labor, and A is technological knowledge. Exponents α_K dan α_H is the elasticity of output to physical and human capital. As (Mankiw et al., 1992), we assume $\alpha_K, \alpha_H > 0$ dan $\alpha_K + \alpha_H < 1$ yang mengimplikasikan tingkat pengembalian yang menurun.

All variables are assumed to be in a continuous time. The employment rate in the economy is growing at a rate of n_i. Each economy adds to its physical and human capital stock at a constant level of investment, respectively s_i^K dan s_i^H, while both stocks depreciate at the same rate δ. This induces the capital accumulation equation in the form

$$\dot{K}_{it} = s_i^K Y_{it} - \delta K_{it} \tag{2a}$$

$$\dot{H}_{it} = s_i^H Y_{it} - \delta H_{it} \tag{2b}$$

Equation (1) is normalized to

$$y_{it} = A_{it} k_{it}^{\alpha_K} h_{it}^{\alpha_H} \tag{3}$$

In line with (Ertur and Koch, 2007), this study modeled A_{it} as follows

$$A_{it} = \Omega_t k_{it}^{\phi_K} h_{it}^{\phi_H} \prod_{j=1}^{n} A_{jt}^{\gamma w_{it}} \tag{4}$$

The evolution of output per worker in region i is governed by the dynamic equations for k, h, and cc given by

$$\dot{k}_{it} = s_i^K y_{it} - (\delta + n_i) k_{it} \tag{5a}$$

$$\dot{h}_{it} = s_i^H y_{it} - (\delta + n_i) h_{it} \tag{5b}$$

$$\dot{cc}_{it} = s_i^{cc} y_{it} - (\delta + n_i) cc_{it} \tag{5c}$$

where s_i^K is the share of output in region i invested in physical capital, s_i^H is the share of output invested in human capital, s_i^K is the share of output in region i invested in physical capital, s_i^{cc} is the share of output in region i affected by climate change, n_i is the rate of population growth and δ is a constant and identical depreciation rate.

4. RESEARCH METHODS AND DATA

4.1. Spatial Econometrics

The spatial panel data model is an appropriate analytical framework for understanding the relationship between climate change and economic growth at the regional level. The model integrates time-series and cross-sectional data, considering spatial dependencies between regions. Taking into account the endogenous relationship between climate change variables and economic growth and the impact of spatial lag, the model offers a comprehensive perspective. To identify cross-sectional dependency (CSD) issues, we operate the Breusch-Pagan Lagrange Multiplier (LM) test (Breusch and Pagan, 1980), Pesaran Scaled LM tests, Pesaran CD test (Pesaran, 2021), and bias-corrected Scaled LM test (Baltagi et al., 2012). The subsequent phase detects the spatial autocorrelation following Moran's I Field (Moran, 1948) and Geary's C Field Moran (1948) and Geary (1954).

4.1.1. Spatial weight matrix specification

This study uses a spatial weighting matrix determined through the geographic distance method to represent spatial economic dependence. The benefits of geographic distance matrices are exogenous to the model and thus exclude identification problems and inverse causality (Ahmad and Hall, 2017; Amidi and Majidi, 2020). In the spatial weighting matrix of N × N (N is the number of provinces in Indonesia), each component diagonally aligned $\frac{1}{d_{ij}}$ or $\frac{1}{d_{ij}^{\alpha}}$ and set to zero. d_{ij} is the distance between the center point of the province i to the province j.

4.1.2. Spatial model specification

According to Anselin (1988), LeSage and Pace (2009), Elhorst (2014), and Golgher and Voss (2016), the relationship between climate change and inverse U-shaped economic growth based on equation (3) - (5) is, then in the same direction as Fischer (2011), constructed into general equation (6) as below:

$$\Delta lny_{it} = \alpha_{iN} - \beta_1 lny_{it-1} + \beta_2 \mathcal{T}_{it} + \beta_3 \mathcal{T}_{it}^2 + \beta_4 \mathcal{P}_{it} + \beta_5 \mathcal{P}_{it}^2 + \beta_6 lnk_{it} + \beta_7 HC_{it} - \beta_8 \left(n+g+d\right) + \rho W \Delta lny_{it} - \varnothing_1 W lny_{it-1} + \varnothing_2 W \mathcal{T}_{it} + \varnothing_3 W \mathcal{T}_{it}^2 + + \varnothing_4 W \mathcal{P}_{it} + \varnothing_5 W \mathcal{P}_{it}^2 + \varnothing_6 W lnk_{it} + \varnothing_7 HC_{it} - \varnothing_8 W \left(n+g+d\right) + \mu_t + v_i + \varepsilon_{it} \therefore \varepsilon_{it} = \lambda W \varepsilon_{it} + \mu_{it} \quad (6)$$

where ∅, λ, and ρ is a spatial parameter. It has five models for forecasting (Belotti et al., 2017), If $\rho = 0$, $\emptyset = 0$ and $v_i = \vartheta W v_i + \eta_i$, the Generalized Spatial Panel Random Effect (GSPRE). If $\lambda = 0$ and $\emptyset = 0$, Spatial Autoregressive Model (SAR)/Spatial lag Model (SLM). If $\emptyset = 0$, Spatial Autocorrelation (SAC)/Generalized Spatial Model (GSM). If $\rho = 0$ and $\emptyset = 0$, Spatial Error Model (SEM). If $\lambda = 0$, Spatial Durbin Model (SDM).

To interpret spatial panel data, we take the derivative of the direct and indirect spatial effect (Anselin, 1988; LeSage and Pace, 2009). The direct effect indicates that the local economic growth (Δlny) is driven by the changes in the local province's explanatory variables (lny_{it-1}, T, T^2, P, P^2, lnk, HC, and [n + g + d]). While, the indirect effect indicates the local economic growth (Δlny) is induced by the discrepancies in the neighbor local province's explanatory variables (lny_{it-1}, T, T^2, P, P^2, lnk, HC, and [n + g + d]). In addition, we identify the feedback effect function of exogenous variables through neighboring provinces and back to the economic growth of local provinces.

4.2. Data

This empirical research uses temperature (T) and precipitation (P) as a basis to face the challenge of measuring the level of climate change in each province in Indonesia. Real per capita income is the gross regional domestic product per capita (GDRPPC) valued constantly in 2010 at billions of rupiahs. The GDRPPC value is converted to the natural logarithm (lny). Logarithmic differences GDRPPC (Δlny) symbolizes the economic growth rate. The average length of schooling measures human capital (HC). Investment (lnk) is the constant domestic fixed capital formation (DFCF) in 2010 amounting to billions of rupiah. The study also combined population growth rates, exogenous technical advances, and depreciation rates ($n + g + d$). In line with Mankiw et al. (1992), assumed $g + d = 0.5$ inter-province. Because spatial econometrics requires highly balanced panel data, we took North Kalimantan into account before 2015; As such, we were able to operate a comprehensive data panel covering 34 provinces from 2006 to 2022 that was officially available to the public in www.bps.go.id. The study also applied robustness checks by utilizing a data set of pure high school enrollment rates as a proxy for human resources (HC2), and we also expanded the closed economy model to the open economy macroeconomic model by introducing foreign direct investment (lnFDI) as an alternative measure of physical capital, and openness of trade (TO).

5. DISCUSSION AND ANALYSIS

5.1. Cross-sectional and Spatial Dependency Verification

Table 1 reports CSD tests using the Breusch-Pagan LM test, the Pesaran Scaled LM test, the Bias-Corrected Scaled LM test, and the Pesaran CD test. The CSD test presents a significant probability value (P = 0.000) in all cases for different CSD tests. The CSD test results rejected the null hypothesis of the absence

Table 1: Cross-sectional dependency test results and spatial autocorrelation

Variables	Cross-sectional dependence test				Global spatial autocorrelation tests	
	Breusch-Pagan LM test	Pesaran Scaled LM test	Bias-corrected Scaled LM test	Pesaran CD test	Moran's I	Geary's C
lny	3495.6750*** (0.0000)	87.6120*** (0.0000)	86.5495*** (0.0000)	37.8595*** (0.0000)	−0.0240*** (0.0010)	0.3540*** (0.0000)
T	1766.2760*** (0.0000)	35.9823*** (0.0000)	34.9199*** (0.0000)	22.5062*** (0.0000)	−0.0080* (0.0660)	0.4990*** (0.0000)
P	1772.5810*** (0.0000)	36.1706*** (0.0000)	35.1081*** (0.0000)	22.7005*** (0.0000)	0.0070 (0.1050)	0.3580*** (0.0000)
Ink	3584.3540*** (0.0000)	90.2594*** (0.0000)	89.1969*** (0.0000)	44.3219*** (0.0000)	−0.0120*** (0.0040)	0.6160*** (0.0000)
HC	3442.4820*** (0.0000)	86.0240*** (0.0000)	84.9615*** (0.0000)	36.7511*** (0.0000)	−0.0760*** (0.0000)	0.7280** (0.0030)
lnFDI	2859.8770*** (0.0000)	68.6309*** (0.0000)	67.5684*** (0.0000)	26.9856** (0.0000)	0.0600*** (0.0000)	0.8520** (0.0340)
TO	3324.9570*** (0.0000)	82.5154*** (0.0000)	81.4529*** (0.0000)	26.2019** (0.0000)	−0.0750*** (0.0000)	1.1060* (0.0730)
n+g + d	1957.2440*** (0.0000)	41.6835*** (0.0000)	40.6211*** (0.0000)	8.9494** (0.0000)	0.0170** (0.0040)	0.4370*** (0.0000)

*, **, and *** signify P<0.1, P<0.05, and P<0.01, respectively. And P-values are in the parentheses. Source: Author's Calculations

Table 2: Results of climate change estimation and economic growth

Variables	GSPRE	SAC	SEM		SAR		SDM	
	Randomeffect; (1)	Fixedeffect; (2)	Fixedeffect; (3)	Randomeffect; (4)	Fixedeffect; (5)	Randomeffect; (6)	Fixedeffect; (7)	Randomeffect; (8)
Constant	−0.0217**			−0.0218**		−0.0354***		0.0208
	(0.0108)			(0.0107)		(0.0105)		(0.1014)
$\ln y_{t-1}$	−0.0576***	−0.1172***	−0.1143***	−0.0578***	−0.1177***	−0.0507***	−0.1089***	−0.0649***
	(0.0081)	(0.0130)	(0.0136)	(0.0080)	(0.0132)	(0.0104)	(0.0139)	(0.0088)
T	0.0196***	0.0601***	0.0596***	0.0196***	0.0605***	0.0276***	0.0428***	0.0201***
	(0.0040)	(0.0072)	(0.0089)	(0.0040)	(0.0075)	(0.0054)	(0.0106)	(0.0041)
T^2	−0.0004***	−0.0011***	−0.0011***	−0.0004***	−0.0011***	−0.0006***	−0.0008***	−0.0004***
	(0.0001)	(0.0001)	(0.0002)	(0.0001)	(0.0001)	(0.0001)	(0.0002)	(0.0001)
P	0.0024	0.0019	0.0047	0.0024	0.0029	0.0010	0.0038	0.0023
	(0.0084)	(0.0082)	(0.0084)	(0.0084)	(0.0083)	(0.0086)	(0.0086)	(0.0085)
P^2	−0.0004	−0.0000	−0.0004	−0.0004	−0.0001	−0.0002	−0.0004	−0.0003
	(0.0007)	(0.0007)	(0.0007)	(0.0007)	(0.0007)	(0.0007)	(0.0008)	(0.0007)
lnk	0.0476***	0.0678***	0.0662***	0.0479***	0.0688***	0.0346***	0.0722***	0.0550***
	(0.0074)	(0.0073)	(0.0082)	(0.0074)	(0.0076)	(0.0075)	(0.0086)	(0.0079)
HC	−0.0005	−0.0158***	−0.0168**	−0.0006	−0.0171***	−0.0057	−0.0023	−0.0007
	(0.0027)	(0.0053)	(0.0069)	(0.0027)	(0.0056)	(0.0038)	(0.0080)	(0.0029)
n+g + d	−0.6131***	−0.5901***	−0.6204***	−0.6131***	−0.5997***	−0.6062***	−0.6102***	−0.6135***
	(0.0539)	(0.0518)	(0.0530)	(0.0539)	(0.0521)	(0.0543)	(0.0529)	(0.0538)
W*$\ln y_{t-1}$							−0.1305*	−0.0251
							(0.0770)	(0.0432)
W*T							0.0696	0.0224
							(0.0441)	(0.0257)
W*T^2							−0.0014	−0.0005
							(0.0008)	(0.0005)
W*P							−0.0135	−0.0122
							(0.0362)	(0.0363)
W*P^2							0.0014	0.0012
							(0.0028)	(0.0028)
W*lnk							0.0539	0.0078
							(0.0352)	(0.0242)
W*HC							−0.0111	−0.0139
							(0.0178)	(0.0133)
W* n+g + d							0.4234	0.4981
							(0.3037)	(0.3096)
$\emptyset$	0.2067							
	(0.7563)							
λ	0.7681***	−0.2861	0.6695***	0.7682***				
	(0.0417)	(0.2670)	(0.0576)	(0.0417)				
ρ		0.7069***			0.6241***	0.6811***	0.5357***	0.5991***
		(0.0744)			(0.0549)	(0.0526)	(0.0734)	(0.0636)
Observations	578	578	578	578	578	578	578	578
R-squared	0.1825	0.1488	0.1204	0.1821	0.1403	0.1933	0.2589	0.3503
Number of id	34	34	34	34	34	34	34	34
LNL	1273.58	1331.47	1329.09	1273.55	1330.95	1262.13	1338.78	1284.63
AIC	−2521.17	−2640.93	−2638.18	−2523.10	−2641.91	−2500.26	−2641.56	−2529.27

*, **, and ***imply significance at 10%, 5%, and 1% level. The numbers in the parentheses are standard errors. Source: Author's calculation

Table 3: Results of direct, indirect/spillover impacts, totals, and Feedback from the fixed effects of spatial durbin model during 2006-2022

Variables	Using distance spatial matrix			
	Direct effects; (1)	Indirect effects; (2)	Total effects; (3)	Feedback effect; (4)
$\ln y_{t-1}$	−0.1173***	−0.3933***	−0.5106***	0.0084
	(0.0145)	(0.1418)	(0.1448)	
T	0.0466***	0.1931**	0.2397***	−0.0038
	(0.0106)	(0.0810)	(0.0813)	
T^2	−0.0009***	−0.0037**	−0.0046***	0.0001
	(0.0002)	(0.0015)	(0.0015)	
P	0.0032	−0.0214	−0.0181	0.0006
	(0.0087)	(0.0832)	(0.0863)	
P^2	−0.0004	0.0022	0.0018	0.0000
	(0.0008)	(0.0062)	(0.0064)	
lnk	0.0768***	0.1934***	0.2701***	−0.0046
	(0.0084)	(0.0688)	(0.0704)	
HC	−0.0032	−0.0270	−0.0303	0.0009
	(0.0077)	(0.0372)	(0.0370)	
n+g + d	−0.6070***	0.1985	−0.4084	−0.0032
	(0.0506)	(0.6726)	(0.6852)	

** and *** imply significance at 5% and 1% level. The numbers in the parentheses are SE. Source: Author's calculations. SE: Standard errors

of cross-sectional dependence. This finding confirms the existence of cross-sectional dependencies between provinces and involves spatial econometrics.

5.2. Results and Discussion

This empirical analysis uses comprehensive datasets covering climate and economic indicators across multiple regions to reveal compelling insights into the spatial dimensions of the climate-growth relationship. As discussed in the methodology framework section, this study used dynamic spatial panel data. The estimation models used are GSPRE, SAC, SAR, SEM, and SDM, with fixed and random effects for each dynamic spatial panel data, Table 2.

Tables 2 show the nonlinear impact of climate change, temperature, and rainfall, on economic growth. Our findings show that temperature significantly impacts economic growth rates for all models, as presented in columns (1) - (8). Our results show that the temperature coefficient and temperature square are positive and negative respectively, and have a significant role in economic growth at the level of 1%. Furthermore, although rainfall and the square of rainfall are positive and negative, respectively, they do not have a significant role in economic growth. The main finding of these findings is that rising temperatures have accelerated economic growth to a certain extent, but high-temperature levels have reduced economic growth. In other words, the study found that intermediate temperature levels lead to better economic growth. These findings are quantitatively known as an inverted U-shaped temperature curve. The main results show that the rate of economic growth deteriorates at low temperatures as well as at high-temperature levels.

In addition, the spatial parameters λ for GSPRE, SAC, and SEM models are positive and very significant, while ρ for SAR and SDM models are very significant and negative and positive respectively. This suggests a convincing spatial dependence. Based on the results of Table 2, an increase in neighboring economic growth of 1% led to an increase in local economic growth of 0.7681% (column 1), 0.7682% (column 4), 0.6811% (column 6), and 0.5991% (column 8). Since we cannot directly interpret the coefficient of temperature in Table 2, then, we show the direct, indirect, total, and feedback effects in Table 3. For temperature, until a certain point, the direct effects of temperature are significant at a 1% level. Such a degree increase in temperature accelerates local economic growth by 0.0466%, but after a certain point, the local economic growth diminishes by 0.0009. In addition, the indirect effects of temperature show that an increase of a degree in neighboring temperature headed to local economic growth by 0.1931%, but after a certain point, led to a dwindle in local economic growth by 0.0037%. The feedback effect implies that an increase in one degree of temperature in a local province spreads to neighboring provinces and is subsequently acted upon once more to shrink the local economic growth by 0.0038%. Thus, the empirical results show that provincial economic growth in Indonesia is interconnected with space and spreads from one province to another. Based on these findings, we argue that a province's economic growth affects adjacent provinces' economic growth, which also depends on the distinctive features of the province's climate change. Our findings confirm the existence of the spatial effect examined by Benhamed et al. (2023) who argued the presence of indirect spillover in the low-middle-income countries.

5.3. Robustness Test

To reassure the main empirical findings in Table 2, we extend the basic model displayed by closed economies to open economies. The stress check steps follow the basic model exactly. The robustness tests in Table 4 validate the nonlinear relationship between climate change and economic growth. The empirical results show that Indonesia's climate change level significantly impacts the economic growth rate for all models, as presented in columns (1) - (8). The temperature coefficient and the square of temperature have a positive and negative, respectively, and statistically significant influence on economic growth.

Based on the results of Table 4, an increase in regional economic

Table 4: The robustness checks of climate change and economic growth

Variables	GSPRE	SAC	SEM		SAR		SDM	
	Randomeffect; (1)	Fixedeffect; (2)	Fixedeffect; (3)	Randomeffect; (4)	Fixedeffect; (5)	Randomeffect; (6)	Fixedeffect; (7)	Randomeffect; (8)
Constant	−0.0484***			−0.0468***		−0.0693***		−0.1366
	(0.0139)			(0.0124)		(0.0119)		(0.1019)
lny_{t-1}	−0.0286***	−0.0920***	−0.0916***	−0.0298***	−0.0795***	−0.0314***	−0.0954***	−0.0280***
	(0.0059)	(0.0123)	(0.0122)	(0.0062)	(0.0112)	(0.0062)	(0.0132)	(0.0056)
T	0.0238***	0.0707***	0.0701***	0.0258***	0.0587***	0.0286***	0.0734***	0.0232***
	(0.0047)	(0.0091)	(0.0088)	(0.0050)	(0.0074)	(0.0047)	(0.0109)	(0.0046)
T^2	−0.0004***	−0.0013***	−0.0013***	−0.0005***	−0.0011***	−0.0005***	−0.0013***	−0.0004***
	(0.0001)	(0.0002)	(0.0002)	(0.0001)	(0.0001)	(0.0001)	(0.0002)	(0.0001)
P	−0.0005	0.0015	0.0014	−0.0013	0.0008	−0.0017	0.0029	−0.0004
	(0.0083)	(0.0082)	(0.0083)	(0.0084)	(0.0082)	(0.0084)	(0.0085)	(0.0086)
P^2	−0.0001	−0.0002	−0.0002	−0.0000	−0.0001	0.0001	−0.0004	−0.0001
	(0.0007)	(0.0007)	(0.0007)	(0.0007)	(0.0007)	(0.0007)	(0.0008)	(0.0007)
HC	0.0043	0.0104*	0.0109*	0.0034	0.0140***	0.0015	0.0101	0.0053*
	(0.0027)	(0.0060)	(0.0057)	(0.0029)	(0.0045)	(0.0025)	(0.0074)	(0.0028)
lnFDI	0.0018***	0.0015***	0.0015***	0.0017***	0.0019***	0.0016***	0.0013***	0.0018***
	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0004)	(0.0004)	(0.0005)	(0.0005)
TO	0.0197***	0.0300***	0.0301***	0.0205***	0.0300***	0.0226***	0.0314***	0.0199***
	(0.0036)	(0.0036)	(0.0035)	(0.0036)	(0.0036)	(0.0035)	(0.0037)	(0.0036)
n+g + d	−0.6107***	−0.6461***	−0.6460***	−0.6378***	−0.6281***	−0.6223***	−0.6518***	−0.6437***
	(0.0540)	(0.0515)	(0.0516)	(0.0535)	(0.0513)	(0.0529)	(0.0518)	(0.0538)
$W*lny_{t-1}$							0.0767	−0.0113
							(0.0521)	(0.0343)
$W*T$							−0.0609*	0.0110
							(0.0362)	(0.0245)
$W*T^2$							0.0010	−0.0003
							(0.0007)	(0.0005)
$W*P$							0.0195	0.0153
							(0.0346)	(0.0355)
$W*P^2$							−0.0014	−0.0010
							(0.0026)	(0.0027)
W*HC							−0.0103	0.0023
							(0.0181)	(0.0125)
W*lnFDI							−0.0002	−0.0012
							(0.0017)	(0.0016)
W*TO							0.0018	0.0039
							(0.0192)	(0.0184)
W*n+g + d							0.5328*	0.6116**
							(0.2987)	(0.3095)
$\emptyset$	0.5409							
	(0.4211)							
λ	1.2226***	0.7129***	0.6848***	0.7028***				
	(0.0422)	(0.0959)	(0.0514)	(0.0504)				
ρ		−0.0815			0.6485***	0.6669***	0.6302***	0.6252***
		(0.2625)			(0.0530)	(0.0527)	(0.0594)	(0.0608)
Observations	578	578	578	578	578	578	578	578
R^2	0.2183	0.1418	0.1445	0.2231	0.1773	0.2315	0.1539	0.3037
Number of id	34	34	34	34	34	34	34	34
LNL	1267.68	1340.29	1340.25	1275.86	1337.52	1275.47	1343.83	1281.33
AIC	−2507.37	−2656.59	−2658.49	−2525.72	−2653.04	−2524.94	−2647.65	−2518.67

*, **, and ***imply significance at 10%, 5%, and 1% level. The numbers in the parentheses are SE. Source: Author's calculations. GSPRE: Generalized spatial panel random effect, SAC: Spatial autocorrelation, SEM: Spatial error model, SDM: Spatial durbin model

Table 5: The Robustness tests for direct, indirect/spillover, total, and feedback impacts from spatial durbin model fixed effects during 2006-2022

Variables	Using distance spatial matrix			
	Direct effects; (1)	Indirect effects; (2)	Total effects; (3)	Feedback effect; (4)
$\ln y_{t-1}$	−0.0935***	0.0521	−0.0414	−0.0019
	(0.0135)	(0.1424)	(0.1447)	
T	0.0717***	−0.0447	0.0270	0.0017
	(0.0108)	(0.0963)	(0.0963)	
T^2	−0.0013***	0.0007	−0.0006	0.0000
	(0.0002)	(0.0018)	(0.0018)	
P	0.0041	0.0525	0.0566	−0.0012
	(0.0090)	(0.0933)	(0.0977)	
P^2	−0.0005	−0.0039	−0.0044	0.0001
	(0.0008)	(0.0070)	(0.0073)	
HC	0.0098	−0.0151	−0.0053	0.0003
	(0.0073)	(0.0491)	(0.0499)	
lnFDI	0.0014***	0.0017	0.0031	−0.0001
	(0.0005)	(0.0044)	(0.0045)	
TO	0.0329***	0.0624	0.0953*	−0.0015
	(0.0040)	(0.0538)	(0.0559)	
n+g + d	−0.6421***	0.2617	−0.3804	−0.0097
	(0.0543)	(0.8299)	(0.8509)	

* and *** imply significance at 10% and 1% level. The numbers in the parentheses are SE. Source: Author's calculations. SE: Standard error

growth of 1% led to an increase in regional economic growth of 1.2226% (column 1), 0.7129% (column 2), 0.7028% (column 4), 0.6669% (column 6), and 0.6252% (column 8). These empirical results confirm Table 2 that provincial economic growth in Indonesia is interconnected with space and spreads from one province to another. Hence, by establishing a model of open economic macroeconomic temperature and economic growth through foreign direct investment and trade openness, these findings convince inverted U-shaped climate change in Indonesia. Since we are not allowed directly to interpret the coefficient of temperature based on the findings in Table 4, we also provide the robustness tests of direct, indirect (spillover), total, and feedback effects in Table 5. The direct effects of temperature are significant at a 1% level. These results confirm the empirical findings in Table 2. A rise of one degree in temperature boosts local economic growth by 0.0717%, but after a certain point, the local economic growth contracts by 0.0013%. In addition, the indirect effects of temperature show that an increase of a degree in neighboring temperature reduced the local economic growth by 0.0447%, but after a certain point, it led to an acceleration in local economic growth by 0.0007%. However, we have not achieved any significant effects from precipitation. These findings are in line with Kahn et al. (2021).

Based on the baseline model and robustness checks, understanding the spatial dimensions of the climate-change-economic growth relationship is critical for appropriate policymaking. Policymakers must consider region-specific vulnerabilities and the potential for coordinated regional strategies to address climate change adaptation and mitigation. These empirical results underscore the importance of incorporating spatial considerations into climate change policy and economic development strategies since Indonesia is the largest archipelagic state. Policymakers must realize that the impacts of climate change are not limited to specific regions, but can spread through spatial interactions. Regional collaboration is essential to develop coordinated approaches that address climate change adaptation and mitigation. As Stern and Stiglitz (2023) argued addressing climate change more forcefully could boost economic expansion. Hence, you can't live alone.

6. CONCLUSION

The study's findings underscore the importance of considering spatial dimensions when analyzing the correlation between climate change and economic growth. As climate change continues to change the economic landscape, spatial insights can guide policymakers in designing tailored strategies to stimulate sustainable development while tackling the challenges of climate change. This research underwrites to present knowledge by inspecting the spatial interaction between climate change and economic growth. The use of spatial panel data models offers a different understanding of how the impacts of climate change may spread across regions, emphasizing the importance of regional collaborative approaches to drive resilience and sustainable development.

Studies have shown an inverted U-shaped curve of persistent fluctuations in temperature and precipitation to per capita real output growth either above or below its historical data. The study traced that a continuous increase in average temperature or annual rainfall due to the absenteeism of mitigation strategies would reduce real output growth per capita. The study also explores the spatial impact of climate change on economic growth performance through lambda and rho spatial parameters. Empirical findings reveal the significant influence of climate change on economic growth at the provincial level. The study also identified that rising temperatures and rainfall in neighboring provinces further degrade economic growth. Hence, regional collaboration is fundamental to developing coordinated approaches that address climate change adaptation and mitigation because you can't live alone.

While this report specifies respected insights into the spatial dynamics of the relationship between clismate change and economic growth, more research is needed to delve deeper into the specific mechanisms driving spatial impacts and the effectiveness of regional policies in driving resilience and sustainable economic growth.

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