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Spatial Analysis of Income Inequality: The Case of Sumatra Island, Indonesia
(*Analisis Spatial Ketidaksamaan Pendapatan: Kes Pulau Sumatra, Indonesia*)

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ABSTRACT

This study aims to examine the convergence of income inequality (Gini) and to investigate its determinants and spillover effects. This study used panel data from 10 provinces in Sumatra Island, Indonesia, spanning the years 2015-2022, sourced from the Statistics Indonesia and the Indonesian Ministry of Environment and Forestry. The Generalized Method of Moment was utilised to analyse the occurrence of convergence, while the Spatial Autoregressive model with Autoregressive Disturbances model was used to examine its direct effects and spillover effects. The results indicate that there is convergence in income inequality across provinces. Environmental quality, per capita income, and democracy directly reduce income inequality, whereas the industrial sector exacerbates it. There is a strong spillover effect whereby an increase in real per capita income of the observed province reduces inequality in neighbouring provinces. However, the expansion of the industrial sector across regions further increases inequality. Additionally, environmental quality, industry, and democracy do not have significant spillover effects. The study discovered convergence of income inequality (Gini) across provinces. We adopted the spatial econometric methods at the island scale, which have not previously been used in the Indonesian context. It also contributes to understanding the direct effects of democracy, environment, industry, and spillover effects of real income per capita on income inequality. The convergence results imply a process towards equilibrium in the performance of the determinant variables in each province. The spillover effect of real GRDP per capita highlights the role of the central government in strengthening inter-regional connectivity in Sumatra. Provincial governments play a role in providing direct effects that further strengthen democracy, environment, and income, as well as addressing ongoing industrial policies. Prudence in promoting growth needs to be pursued to ensure that the small industry sector can advance and contribute to broader equity, without compromising the environment.

Keywords: Income inequality; convergence; spillover; spatial; Indonesia

ABSTRAK

Kajian ini bertujuan untuk mengkaji pemusatan ketidaksamaan pendapatan (Gini) dan menyiasat penentu serta kesan limpahannya. Kajian ini menggunakan data panel dari 10 wilayah di Pulau Sumatra, Indonesia, dalam tahun 2015-2022, yang diperoleh daripada Statistik Indonesia dan Kementerian Lingkungan Hidup dan Kehutanan Indonesia. Kaedah kaedah dinamik panel momen teritlak digunakan untuk menganalisis berlakunya pemusatan, manakala model Autoregresif Spatial dengan Gangguan Autoregresif digunakan untuk mengkaji kesan langsung dan kesan limpahan. Hasil kajian menunjukkan bahawa terdapat pemusatan dalam ketidaksamaan pendapatan di seluruh wilayah. Kualiti alam sekitar, pendapatan per kapita, dan demokrasi secara langsung mengurangkan ketidaksamaan pendapatan, manakala sektor industri memperburuknya. Terdapat kesan limpahan yang kuat di mana peningkatan pendapatan per kapita benar di wilayah yang diperhatikan akan mengurangkan ketidaksamaan di wilayah-wilayah jiran. Walau bagaimanapun, pengembangan sektor industri di merentasi wilayah semakin meningkatkan ketidaksamaan. Selain itu, kualiti alam sekitar, industri, dan demokrasi tidak mempunyai kesan limpahan yang signifikan. Kajian ini mendapati pemusatan ketidaksamaan pendapatan (Gini) di merentas wilayah. Kami mengguna pakai kaedah ekonometrik spatial pada skala *pulau, yang belum pernah digunakan dalam konteks Indonesia. Kajian ini juga menyumbang kepada pemahaman kesan langsung demokrasi, alam sekitar, industri, dan kesan limpahan pendapatan per kapita benar terhadap ketidaksamaan pendapatan. Keputusan pemusatan ini menunjukkan suatu proses menuju keseimbangan dalam prestasi pemboleh ubah penentu di setiap wilayah. Kesan limpahan GRDP benar per kapita menonjolkan peranan kerajaan pusat dalam memperkukuh keterhubungan antara wilayah di Sumatra. Kerajaan wilayah memainkan peranan dalam menyediakan kesan langsung yang lebih memperkuat demokrasi, alam sekitar, dan pendapatan, serta menangani dasar industri yang sedang berlangsung. Kebijaksanaan dalam mempromosikan pertumbuhan perlu diteruskan untuk memastikan sektor industri kecil dapat berkembang dan menyumbang kepada kesaksamaan yang lebih luas, tanpa menjejaskan alam sekitar.*

Kata kunci: Ketaksamaan pendapatan; pemusatan; limpahan; spatial; Indonesia

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INTRODUCTION

The issue of income inequality has received increasing attention since the COVID-19 pandemic (World Bank 2023). Income inequality is related to the development of democracy, environment, industry, and income (Acheampong et al. 2023; Rahman et al. 2023; Zhang et al. 2023). There is a trade-off between economic growth and income equality, especially in the early stages of development (Kuznets 1955). The phenomenon of rising income alongside decreasing poverty actually widens the inequality gap, and strengthens the issue of inclusive growth (Klasen 2010). When the focus is more towards pro-poor growth, it does not significantly help in reducing inequality. This is because the middle class, disadvantaged regions, certain ethnic groups, gender, and other marginalised groups receive less attention, while only the lowest and highest income groups tend to benefit.

Myrdal (1957) argued that there was an adverse impact from the increasing gap between developing and developed countries. The backwash effect tends to be greater than the spread effect, leading to regional or urban-rural disparities. Negative impacts are also observed in growth centres, with increasing inequality gaps resulting from imbalanced interactions in the labour market. However, positive effects of this phenomenon may arise from the expansion of economic activity centres into relatively underdeveloped areas, due to the increased demand for agricultural products. Indonesia is an exception, since many industrial and agricultural products are actually imported from abroad, and relationships between large and small companies remain weak (Kuncoro 2016).

The increasing dominance of the industrial sector in the economy is often used as a benchmark for a region's progression towards high-income status. In recent decades, accelerated industrialization, energy consumption, and changes in lifestyle have triggered environmental problems (Maryam et al. 2017), and also impacted income inequality (Rahman et al. 2023; Wu & Id 2020). In his study, Mehic (2018) stated that the decline in manufacturing production has had a very significant impact on increasing income inequality in industrialized countries. Meanwhile, Zhang et al. (2023) identified an inverted U-shaped relationship between industrial agglomeration and inequality.

Studies on the link between the environment and inequality are becoming increasingly intense. Wu and Id's (2020) study on the mechanism of the impact of air pollution on income inequality concluded that, firstly, an increase in air pollution exacerbates income inequality. Secondly, the spatial spillover effect of air pollution plays a relatively more important role in the total impact of air pollution on income inequality compared to its direct impact. The direct impact findings are in line with those of Khan et al. (2023) and Rahman et al. (2023). However, Ali (2023) suggests a causal relationship between the two, while other studies argue that inequality affects the environment (Uddin et al. 2020; Wu & Xie 2020).

The current democratic trajectory raises questions about the link between decision-making and people's quality of life. Acemoglu et al. (2015), in their book, explored the influence of the market economy on the quality of income distribution. The market system itself is a concrete manifestation of the political system, which produces institutions and policies. Policy decisions related to sustainable development issues are influenced by the distribution of power in society, moulded by various interests mobilized by aggregate preferences.

The key issue in political economy lies in the relationship between economic development and democracy, which results in two conflicting mechanisms. Some real-world examples reveal the implementation of policies that benefit the politically powerful at the expense of the weak, as documented in Wilse-Samson's (2013) study of Apartheid in South Africa. In another perspective, Meltzer and Richard (1981) constructed a model which suggests that a shift in middle-class voters towards poorer segments of the population could reduce income inequality. A recent study by Acheampong et al. (2023) however showed that democracy actually increases income inequality in some African regions.

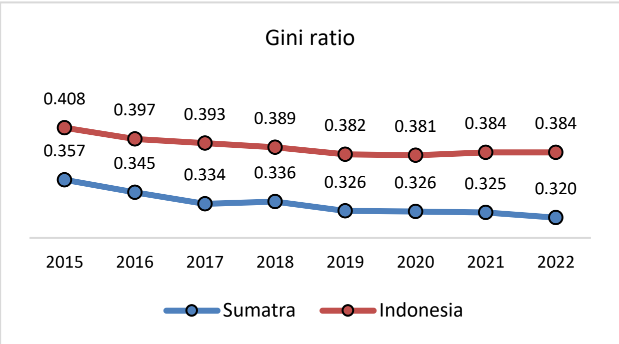
This study aims to elucidate the convergence of income inequality and its determinants, as well as the spillover effects. We use the Generalized Method of Moment to analyse the occurrence of convergence, together with the Spatial Autoregressive Model with AutoRegressive Disturbances to test for direct and spillover effects. The results confirm the convergence of income inequality across provinces. We find that environmental quality, per capita income, and democracy directly improve income inequality. In contrast, the industrial sector exacerbates income inequality. Increasing real per capita income in the observed province reduces inequality in neighbouring provinces.

This study identifies convergence in income inequality (Gini ratio) across provinces. In the methodology, we adopted spatial econometrics at the island scale, which has not been used before in the Indonesian context. This study also contributes to explaining the direct impact of democracy, the environment, industry, and spillover effects of real per capita income on income inequality. In contrast to Islam (2003) and Akita et al. (2011), who used the real Gross Regional Domestic Product (GRDP) per capita data to reveal regional inequality and convergence, we adopted Gini ratio data which lead to a different interpretation of the results. This study can be interpreted as evidence of convergence in income inequality (Gini ratio) across provinces, whereas Islam (2003) and Akita et al. (2011) demonstrated a convergence in income per capita disparities between provinces. "Gini" convergence in Sumatra cannot be interpreted as a reduction in inequality, but rather as the detection of variations in the Gini index for each province. The results of convergence using this concept provide an entry point for assessing how closely the inequality levels in each province are converging, and the variation in their equalization performance in relation to the determinants. The island of Sumatra shows relatively lower levels of inequality compared to Java, Sulawesi, and Papua. By considering this and other factors that are not at extremes, such as population density, education, health, it is expected that the interaction of the determinants included in this study can help minimize the complexity of the conditions and reduce the risk of confounding the calculations.

The interaction between democracy, industry, income, environment and inequality recorded in previous studies has yielded relatively different outcomes. The limited number of past studies that examine these dynamics from a spatial perspective is what this study aims to address in the context of Sumatra, Indonesia.

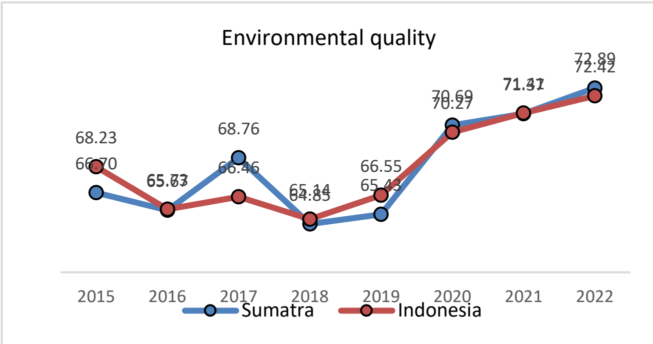
BACKGROUND OF THE STUDY

Data trends in income inequality (Figure 1), environmental quality (Figure 2), real GRDP per capita (Figure 3), democracy index (Figure 4), and industry sector distribution (Figure 5) between Sumatra Island and the national level show relatively similar pattern, although in certain periods they appear to diverge.



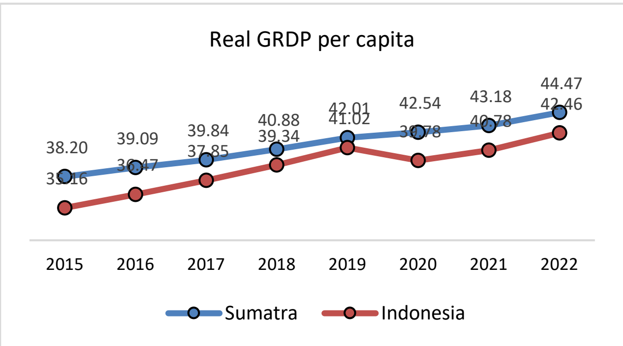
Source: BPS-Statistics Indonesia, (2023b)

FIGURE 1. Income inequality trends in Sumatra and Indonesia



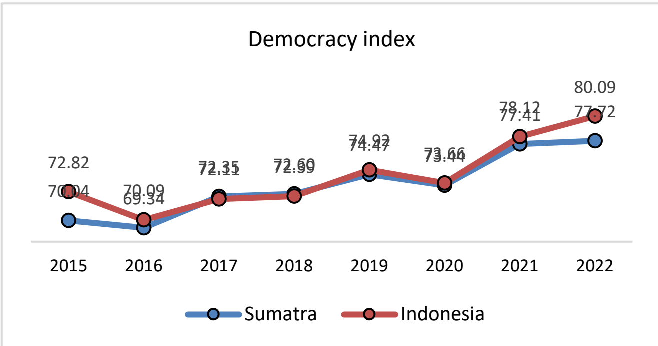
Source: (BPS-Statistics Indonesia, 2023b)

FIGURE 2. Environmental quality trends in Sumatra and Indonesia



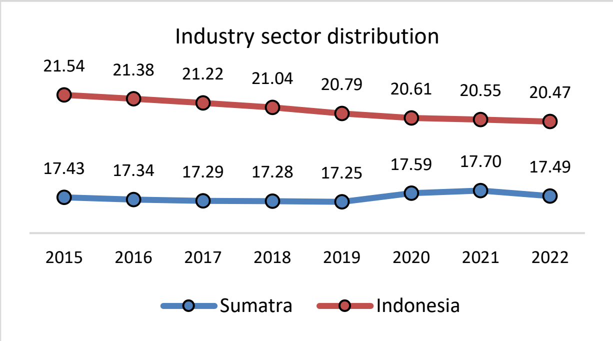
Source: BPS-Statistics Indonesia, (2023b)

FIGURE 3. Real GRDP per capita trends in Sumatra and Indonesia



Source: BPS-Statistics Indonesia, (2023b)

FIGURE 4. Democracy index trends in Sumatra and Indonesia



Source: BPS-Statistics Indonesia, (2023b)
FIGURE 5. Industry sector distribution Trends in Sumatra and Indonesia

The development of income inequality in Sumatera Island and at the national level exhibits a generally decreasing trend. During the Covid-19 pandemic, income equality in Sumatra consistently improved, although the progress was relatively restrained. The agriculture, forestry and fisheries sectors in Sumatra played a crucial role in mitigating economic shocks as social restrictions were implemented during the pandemic. In terms of environmental quality indicators, the trends in Sumatra and the Nation appear nearly identical. Significant improvements in environmental quality have been observed since 2020, along with the onset of the pandemic and the growing emphasis on sustainable development. This development has produced positive impact on environmental quality. Regarding the real GRDP per capita indicator, national progress showed significant improvement and aligned more closely with the trend in Sumatra until 2019. In 2020 however, there was a decline in the national real GRPD per capita, whereas Sumatra's continued to increase, but at a slower rate. The democracy index in Sumatra showed a decline in 2022, while the national index exhibited upward progress.

LITERATURE REVIEW

DEMOCRACY AND INCOME INEQUALITY

Income inequality has been extensively studied in relation to global political polarization. Gu and Wang (2022) observed a tendency for the need for democracy to increase in tandem with the widening of inequality between nations. Novokmet et al. (2017), in an earlier study, analysed income inequality in Russia between 1905-2016, demonstrated that inequality in Russia increased significantly more than in other former communist countries in Eastern Europe, including China. In general, welfare levels have improved since the fall of communism, but inequality has concurrently increased. Acheampong et al. (2023) in their study established that democracy contributes to increasing income inequality in West, Central, and Southern Africa, but exhibits a neutral effect on inequality in East Africa. In their 2024 book, Seo & Kang argue that institutions, policies, and laws significantly shape income inequality and redistribution, with the political system is determined by the distribution of power between societal groups.

Indonesia adheres to a democratic system, where sovereignty rests with the people and is implemented in accordance with the Constitution (Perubahan Ketiga Undang-Undang Dasar Negara Republik Indonesia Tahun 1945, 2001). In its implementation however, democracy varies with the local governments. Strengthening the democratic environment, particularly when accompanied by a reduction in inequality in a specific region, has the potential to inspire other regions and should serve as a best practice for democratic implementation. Based on previous studies and the current context in Indonesia, our hypothesis posits that an increase in the interprovincial democracy index will contribute to reduction in income inequality.

ENVIRONMENT AND INCOME INEQUALITY

There is substantial research that have explored the relationship between environmental issues and income inequality. The Environmental Kuznets Curve (EKC) framework suggests that environmental degradation initially increases with the growth of per capita income, before finally reaching a turning point where it begins to decline as per capita income increases (Badunenko et al. 2023). Grossman & Krueger (1991) showed that pollution levels decrease at high GDP per capita, but conversely pollution concentrations increase at lower income levels. Further studies confirmed the EKC phenomenon in G20 countries (Chen et al. 2020) although. Galeotti (2007) argues that the EKC hypothesis is weak. Furthermore, Nikensari et al. (2019) found that the EKC for Indonesia is U-shaped, since environmental indicators in this case are based on the environmental quality index instead of environmental degradation.

Research conducted by Khan et al. (2023) and Rahman et al. (2023) concluded that enhancing environmental quality can reduce income inequality. Ali (2023) examined this relationship across 42 middle-income countries, and discovered a reciprocal relationship between inequality and environmental degradation.

Based on prior studies and conditions on the island of Sumatra, we anticipate that improving environmental quality across provinces will contribute to a reduction in income inequality. This expectation is based on the observation that environmental exploitation typically benefits only a select few, while more equitable approach to environmental resources utilization can potentially generate economic benefits for the wider public, thus fostering a more equitable economic distribution.

INDUSTRY AND INCOME INEQUALITY

Research conducted by Hanna (2007) demonstrates a negative effect of industry contributions on income levels and property values. An increase in local income may significantly reduce pollution. However, this study is still considered as being subject to endogeneity bias. Mehic (2018) focuses on the effect of industry contributions, particularly in terms of employment on income inequality. The study, based on data from 27 countries spanning 1991 to 2014, established a strong negative correlation between industrial employment and income inequality.

According to Zhang et al. (2023), industrial agglomeration and income inequality exhibit an inverted "U-shape" relationship, with income inequality rising as the degree of industrial agglomeration intensifies, and subsequently declining after reaching a critical value. Rauf et al. (2021) in their study on Morowali and Banggai districts, indicated that income inequality worsened when these regions experienced significant economic growth, especially with the commencement of operations by major mining companies.

Industrial development in Indonesia is still dominated by large-scale enterprises driven mainly by high technology. This dominance indicates that the benefits of development have not been equitably distributed, as a result of economic competition fostered within a democratic framework. Our hypothesis posits that a broader distribution of the industrial sector across provinces may contribute to increasing income inequality.

INCOME PER CAPITA AND INCOME INEQUALITY

Concerns regarding income inequality came to the fore with Kuznets's (1955) finding that inequality tends to widen in the initial phase of economic growth, as societies transition from pre-industrial to industrial phases, then stabilizes for a time before narrowing as growth progresses. The widening of income inequality is related to the shift from agriculture and rural areas to industry and urban centres. Once the initial turbulence of industrialization and urbanization subsides, various forces align to improve the economic position of low-income groups in urban areas. Simon Kuznets (1955) hypothesized the existence of an inverted U-curve, whereby income distribution becomes more unequal as development begins, but after reaching a certain level of development threshold, it becomes more equal (Kuncoro 2016).

Hassan (2021) notes that several Indian states have achieved high levels of per capita income while simultaneously reducing inequality. The finding suggests that equity need not be compromised for the sake of higher growth. By adopting a more naturally distributed growth pattern, higher growth can be achieved while reducing inequality.

Riveros-gavilanes et al. (2022) meanwhile concluded that an inverted U-shaped relationship between income inequality and economic development can be observed in East Asia and the Pacific and Latin America and the Caribbean. In contrast, Sub-Saharan Africa, South Asia, Europe, and Central Asia, the data exhibit a N-shaped relationship. In the Middle East and North Africa, the data reveals a negative correlation, while in North America, inequality appears to increase alongside rising real per capita income.

The growth in per capita income in neighbouring provinces, especially in underdeveloped and developing provinces, serves as an indication of increased equity, which is believed to have a diffusion effect that can help reduce inequality itself. This dispersion of income is expected to reduce the aggregate level of inequality. The study seeks to test this hypothesis. Consequently, we expect that an increase in real per capita income across provinces will diminish income inequality, and contribute to the convergence of income inequality across Sumatera Island.

LITERATURE GAP

This study seeks to fill several gaps identified in prior research. One such concerns is the need for further clarification is the relationship between democracy and inequality. Acheampong et al. (2023) found that democracy tends to exacerbate inequality across much of Africa, with the exception of East Africa. In contrast, Gu & Wang (2022) suggest that the demand for democracy tends to increase as inequality rises. It remains to be seen whether an improved democratic climate can foster greater equity, and this study seeks to explore this issue.

Additionally, there appears to be some inconsistency between the results of Mehic (2018) and Rauf et al. (2021) concerning the interaction between the industrial sector and inequality. Zhang et al. (2023) attempts to mediate this debate by proposing an inverted U-shaped relationship between industrial development and inequality. This study will evaluate whether industrial progress on Sumatra Island has contributed to reducing inequality, or conversely contribute to its increase.

In terms of convergence method, this study adopts a different approach from the previous ones through employing the Gini coefficient to measure the degree of convergence in inequality across regions, whereas Akita et al. (2011) and Islam (2003) used per capita income to assess convergence. Almuazam and Sirait (2022) and earlier researchers, examined the spatial effects of income inequality interaction among city districts at the provincial. However, few studies have explored the spatial effects of determinant variables, used at an island-wide scale. This study aims to address this gap through enhancing the understanding of inequality dynamics within the context of Sumatra Island, Indonesia.

METHODOLOGY

This study employs a descriptive quantitative approach to analyse the convergence of income inequality and the impact of predictor variables, considering the direct effect and the spillover effects. The study used two methodologies; first, the generalized method of moments (GMM) to determine the convergence of inequality between provinces. The second approach involves spatial regression to examine the direct and spillover effects of the determinant variables. These predictor variables include environmental quality index, real income per capita, democracy index, and industrial sector distribution as predictors, with the Gini ratio as the dependent variable. The study was conducted on 10 provinces in Sumatra Island spanning 2015-2022. Data on per capita income, democracy index, industrial sector distribution, and Gini ratio were sourced from BPS-Statistics Indonesia (2020, 2023b, 2023a), while data on environmental quality were obtained from the Ministry of Environment and Forestry, RI (2020).

VARIABLE OPERATIONAL DEFINITION

The variables used in this study include the Gini ratio, Indonesia democracy index, environmental quality (IKLH), GRDP per capita, and industrial sector distribution. The following outlines the definition of variables and data sources, calculations and units associated with each variable:

Table 1. Operational definition of variables

Variable	Definition	Indicator	Unit
Gini ratio	The Gini ratio is a proxy indicator of income inequality, calculated using an expenditure approach. The data are sourced from the National Socio-Economic Survey (Susenas) conducted by Statistics Indonesia. A ratio value closer to 0 indicates low inequality, while a value closer to 1, reflects high inequality. Data units are transformed into natural logarithmic form, to enable interpretation in percentage terms.	$$GR = 1 - \sum_{i=1}^{N} F_{pi}(F_{ci} + F_{ci-1})$$ GR is Gini ratio, F_{pi} is the cumulative proportion of the population for the i-expenditure class, F_{ci} is the cumulative proportion of expenditure in class-i.	%
Environmental quality (IKLH)*	The environmental quality index (IKLH) measures water quality (IKA), air quality (IKU) and land cover quality (IKTL) across 10 provinces in Sumatra. Data sourced from the Ministry of Environment of the Republic of Indonesia, were transformed into natural logarithmic form.	$$IKLH = (30\%\ x\ IKA) + (30\%\ x\ IKU) + (40\%\ x\ IKTL)$$	%
Real GRDP per capita	Real income per capita is measured through dividing the Gross Regional Domestic Product (GRDP) at constant prices by the mid-year population in each province. Data sourced from the Statistics Indonesia, are transformed into natural logarithmic form.	$$Real\ GRDP\ per\ capita = \frac{GRDP\ at\ constant\ prices}{total\ population}$$	%
Indonesia Democracy Index (IDI)	The IDI is an indicator used to assess the level of democratic development in Sumatra. It is evaluated according to three key aspects; political rights, civil liberties, and the development of democratic institutions. The data were sourced from document review, local newspaper analysis, Focus Group Discussions, and interviews. The index ranges from 0 to 100, with higher values indicating stronger democratic development in the province under observation. The data, sourced from the Statistics Indonesia, were transformed into natural logarithmic form.	The study employs a combination of quantitative and qualitative approaches, with specific calculations incorporated to ensure mutual validation of the two methods. The weights for different aspects, variables, and indicators were derived through the Analytical Hierarchy Process (AHP), which involved the expertise of judges from academia, research, industry, government, NGOs, and the media.	%
Industry sector distribution	Data on the manufacturing sector's contribution to GRDP at current prices of each province is also sourced from Statistics Indonesia, and has been transformed into natural logarithmic form.	$$Ind = \frac{value\ added\ of\ ADHB\ processed\ industry}{GRDP\ at\ current\ prices} x100$$	%

Source: BPS-Statistics Indonesia, (2023), Ministry of Environment and Forestry RI, (2020)

CONVERGENCE MEASUREMENT

Convergence refers to a reduction in differences among observed regions. Barro & Martin (2004) identify two approaches to calculate convergence; namely, beta convergence and sigma convergence. The sigma convergence approach examines the development of the deviation in the logarithm of inequality between regions. If there is a significant tendency for dispersion to decrease, then sigma convergence is said to occur. To assess whether income inequality convergence exists among provinces on Sumatera Island, we use the first difference GMM as an analytical tool. The observation period spans from 2015 to 2022. The formula of β-convergence is as follows (Barro & Xavier 1992):

$$\frac{\ln Y_{i.T} - \ln Y_{i.t-1}}{T} = \alpha + \beta \ln Y_{i.t-1} + \mu_{i,t} \quad (1)$$

The the context of the study, $\mathbf{ln}\, \boldsymbol{Y_{i.T}}$ is the income inequality in period $\boldsymbol{t}$, and $\mathbf{ln}\, \boldsymbol{Y_{i.t-1}}$ is the inequality in the period before $\boldsymbol{t}$. If $-1 < \beta < 0$, income inequality convergence is confirmed; otherwise, it is not. The absolute convergence model used in this study, as implemented through GMM technique, is as follows:

$$gini_{i.t} = \alpha + \beta 1\, gini_{i.t-1} + \mu_{i,t} \quad (2)$$

Where $\boldsymbol{gini_{i.t}}$ is Gini ratio of province $\boldsymbol{i}$ in year $\boldsymbol{t}$, $\boldsymbol{gini_{i.t-1}}$ is Gini ratio of province *i* in the previous year, and $\boldsymbol{\mu_{i,t}}$ is error term.

If convergence is found, the convergence speed is calculated to analyse the rate or speed of convergence that occurs. The speed of convergence describes how long it will take for income inequality to approach a common point between observation areas (Barro dan Martin, 2004).

The formula for calculating the half-life value of convergence is as follows:

$$t = \frac{-\ln(0.5)}{\beta} \text{ or } t = \frac{Ln\,(2)}{\beta} \quad (3)$$

GENERALIZED METHOD OF MOMENT

We use the Generalized Method of Moment (GMM) to trace the convergence of income inequality across Sumatera Island following the approach used in previous studies to detect convergence in GRDP (Budiman et al. 2018). Arellano & Bond (1991) stated that the GMM estimator is effective in revealing all linear moment conditions, based on some underlying assumptions. The residuals of the GMM are used to test for serial correlation and this is compared with the Sargan test to limit over-identification. In this dynamic panel, we compare the coefficients of the GMM with those obtained from OLS estimation, to avoid upward biased results (Hsiao 2010). The GMM coefficients are also compared with those from the fixed effects to avoid downward bias (Judson et al. 1999, in Firdaus & Yusop 2009).

In the context of First Differences-Generalized Method of Moments (GMM), downward bias can arise due to the presence of unobserved variables or insufficiently addressed endogeneity, leading to coefficient estimates that are lower than their actual values. Although FD-GMM can reduce the bias caused by endogenous variables, the model is still susceptible to downward bias if the instruments used are not fully valid or if there is a strong correlation between the instruments and the model errors. Therefore, to validate the results of the FD-GMM estimation, we compare them with the coefficients obtained from within-group or fixed-effects models. The coefficient is believed to be consistent if its value is above that of the fixed-effects coefficient but below the value of the pooled least squares coefficient (Bond et al. 2001; Firdaus et al. 2024). The equation of the dynamic panel data model estimated through GMM is as follows (Hayakawa, 2009):

$$\begin{aligned} y_{it} &= \propto y_{it-1} + \beta\chi_{it} + \eta_i + v_{it} \\ &= \delta' \, w_{it} + \eta_i + v_{it} \end{aligned} \quad (4)$$

where $\boldsymbol{w_{it}}$is $(\boldsymbol{y_{it-1}}\, \boldsymbol{\chi_{it}})'$, $\boldsymbol{\delta}'$ is $(\propto \boldsymbol{\beta})'$, and $\boldsymbol{\delta}$ is the parameter of interest with $|\alpha| < 1$, then $\boldsymbol{\eta_i}$ is the unobservable heterogeneity with E(ηi) = 0 and var(ηi) = σ2η, and *vit* is the error term with E(vit) = 0 and var(vit) = σ2v. n this study, the motivation of utilizing GMM is only to calculate the coefficient value of $\boldsymbol{gini_{t-1}}$ so that the equation becomes:

$$gini_{it} = \propto gini_{it-1} + \eta_i + v_{it} \quad (5)$$

Where the $\boldsymbol{w_{it}}$ value is $(\boldsymbol{gini_{it-1}})'$. The assumption that the model is correctly specified is based on the consistency results and the asymptotic distribution of the generalized instrumental variable estimator. To assess for consistency between the data and the moment conditions, which, if properly identified, result in $\boldsymbol{1/N\Sigma_i\hat{\varepsilon}_i z_i}$ sufficiently close to zero, specification testing can be performed using the Sargan test. This is achieved by multiplying N by the R^2 from an auxiliary regression of the IV residuals $\hat{\boldsymbol{\varepsilon}}_i$ on the full set of instruments $\boldsymbol{z}_i$. Furthermore, the Arellano-Bond test can be employed to verify the consistency of the dynamic panel data models (Verbeek 2017).

SPATIAL PANEL DATA MODEL

The static panel data regression method is utilised as an initial stage to detect the presence of cross-sectional dependence in the constructed mode. This study only chooses two models of panel data regression, with the following equation (Gujarati & Porter 2009):

Fixed Effects Least-Squares Dummy Variable Model (one way):

$$gini_{it} = \beta_{1i} + \beta_2 democracy_{it} + \beta_3 industry_{it} + \beta_4 percapita_{it} + \beta_5 iklh_{it} + u_{it} \quad (6a)$$

Random Effects Model (with Generalized Least Square):

$$gini_{it} = \beta_1 + \beta_2 democracy_{it} + \beta_3 industry_{it} + \beta_4 percapita_{it} + \beta_5 iklh_{it} + w_{it} \quad (6b)$$

Where $\boldsymbol{gini}$ is the gini ratio, $\boldsymbol{iklh}$ is the environmental quality index, $\boldsymbol{democracy}$ is the democracy index of each province, $\boldsymbol{industry}$ is the contribution of the industrial sector to GRDP, $\boldsymbol{percapita}$ is the real GRDP per capita, $\boldsymbol{i}$ is each province in Sumatra, $\boldsymbol{t}$ is the period 2015-2022, and $\boldsymbol{w}$ is the combined error, consisting of both individual-specific and idiosyncratic errors.

The first step in this model is to determine the best panel regression method using the Hausman test. After selecting the superior model, either random effects or fixed effects, the next step is to detect whether there is a correlation between individuals in the cross-sectional elements (spatial correlation) by employing the Pesaran test and Breusch-Pagan LM test. Should there be a strong indication of cross-sectional dependence in the model, the next step is to construct the weight matrix.

The weight matrix is based on the K-Nearest Neighbour (KNN) assumption, by determining the weight of each neighbour in the process of calculating the distance between the data points, while considering the Moran test value, the significance level of the spatial model, and the Akaike Information Criterion (AIC) value, in order to determine the optimal number of neighbours. These weights reflect the importance of the distance between the tested data and its neighbours in deriving the final result (Anselin 2007; Anselin & Rey 2010; Firdaus et al. 2024).

The Moran's I test reveals the presence or absence of spatial effects within the data by incorporating a weighted element in the calculation. The formula is as follows (Anselin & Rey 2010):

$$\boldsymbol{I} = \frac{\boldsymbol{n} \sum \sum \boldsymbol{W}_{ij}(\boldsymbol{x}_i - \bar{\boldsymbol{x}})(\boldsymbol{x}_j - \bar{\boldsymbol{x}})}{\boldsymbol{W} \sum (\boldsymbol{x}_i - \bar{\boldsymbol{x}})} \quad (7)$$

Where $\boldsymbol{I}$ is the Moran index, $\boldsymbol{n}$ is the number of provinces, $\boldsymbol{x}_i$ is the value in province $\boldsymbol{i}$, $\boldsymbol{x}_j$ is the value in province $\boldsymbol{j}$, $\bar{\boldsymbol{x}}$ is the average value of $\boldsymbol{x}_i$ from n provinces, and $\boldsymbol{W}_{ij}$ is the element in the standardized weight between provinces $\boldsymbol{i}$ and $\boldsymbol{j}$. Moran's I test performed in R studio computation (Anselin 2007).

The calculation of the inverse distance matrix is as follows:

$$w_{ij} = \frac{w_{ij}*}{\sum_j w_{ij}*} \quad (8)$$

Where $\boldsymbol{w}_{ij}*$ is the inverse value of the distance between the spatial unit of province i and the spatial unit of province j ($\boldsymbol{d}_{ij}$), or, alternatively, it can be expressed as $\boldsymbol{w}_{ij}* = 1/\boldsymbol{d}_{ij}\boldsymbol{\alpha}$, with $\boldsymbol{\alpha}$ being a power of 1, 2, ..., n. The Akaike's information criterion (AIC) value was used to select the best of the three models. This criterion is based on the maximum likelihood method, with the formulation expressed in logarithm as follows:

$$AIC = e^{2k/2} \frac{SSR}{n} \quad (9)$$

Where k is the number of estimated parameters, n is the number of observations, e = 2.718, and SSR is $\sum(\boldsymbol{gini}_i - \widehat{\boldsymbol{gini}})^2$. The model with the smallest AIC value is deemed the best model (Widarjono 2018).

The spatial-autoregressive (SAR) model captures the interactions between units, allowing disturbances to arise as spatial lags of exogenous variables. In comparison, the SARAR model combines the SAR model with spatial autoregressive disturbances. Some spatial models to be employed in this study are as follows (Drukker & Prucha 2013;

Firdaus et al. 2024; Irawan 2023):

Spatial Autoregressive:

$$gini_{it} = \delta \sum_{j=1}^{N} W_{ij} gini_{jt} + \alpha_n + percapita_{it}\beta + iklh_{it}\beta + democracy_{it}\beta + industry_{it}\beta + \varepsilon_{it} \quad (10a)$$

Spatial Error Model:

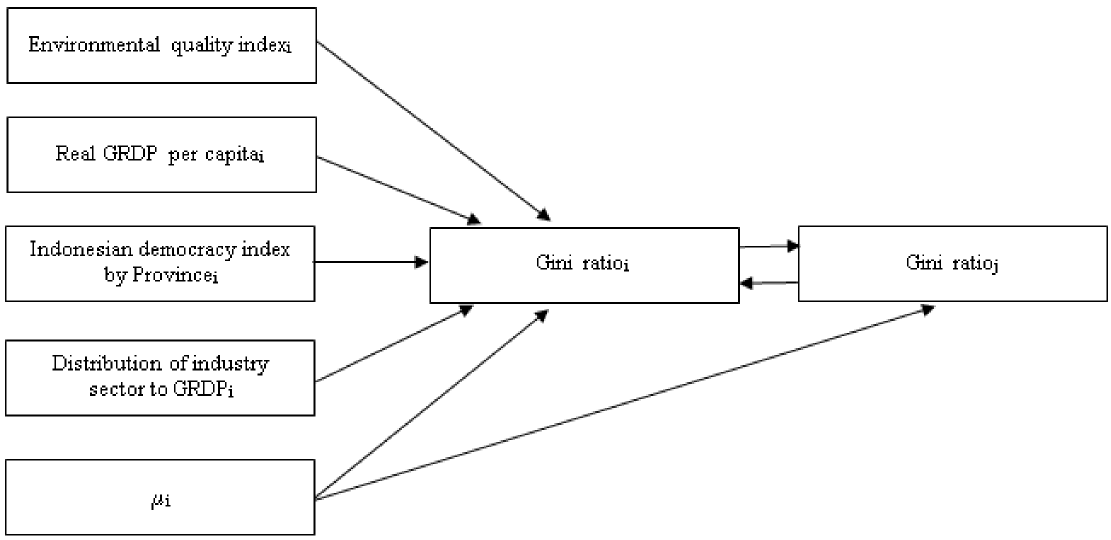
$$gini_{it} = \alpha_n + percapita_{it}\beta + iklh\beta + democracy_{it}\beta + industry_{it}\beta + \lambda Wu + \varepsilon_{it} \quad (10b)$$

Spatial Autoregressive Disturbance (SARAR):

$$gini_{it} = \delta \sum_{j=1}^{N} W_{ij} gini_{jt} + \alpha_n + percapita_{it}\beta + iklh_{it}\beta + democracy_{it}\beta + industry_{it}\beta + \lambda Wu + \varepsilon_{it} \quad (10c)$$

Where w_{ij} is standardized spatial weight of i row of j column, $gini$ is the Gini ratio, $percap$ is real GRDP per capita, $iklh$ is environmental quality index, $democracy$ is provincial democracy index, $industry$ is industrial sector distribution, β is coefficient of independent variable, δ is coefficient of spatial lag parameter in spatial lag panel data model, and ε is error vector.

The value of the spatial lag coefficient (δ) indicates whether the Gini ratio in a given province will increase or decrease, based on the δ value multiplied by the average Gini ratio of its neighbouring provinces. The value is the coefficient of the direct effect of each determinant variable on the Gini ratio in the province under observation. The spillover effect coefficient, which reflects changes in the determinant variable, is obtained from the interaction between the direct effect coefficient of each determinant variable and the value of δ, λ, and the structure of the spatial weight matrix W (Anselin 1988; Yasin et al. 2020). The interaction of the SARAR model can be illustrated as follows:



Source: Author

FIGURE 2. Interaction of SARAR model

Figure 2 above illustrates the flow of effects of the SARAR model, where changes in the independent variables in location *i* have a direct effect on income inequality (Gini ratio) in location *i* as well as a spillover effect on inequality in location *j* (the neighbouring location of *i*). Changes in the unobserved variables in location *i* have a direct effect on inequality in location *j* (a neighbour of location *i*) while also exerting an indirect effect on inequality in location *i* (Fitriani & Efendi 2019).

RESULTS AND DISCUSSION

CONVERGENCE OF INCOME INEQUALITY

We use first differences for data transformation, and employ a two-step GMM iterative approach to examine the convergence or divergence of income inequality process among provinces in Sumatera Island. The observation period is limited to 2015-2022. The results from GMM data processing are consistent, where the AR2 probability value from the Arellano Bond Serial Correlation Test exceeding 5%, specifically 0.7389. Further, the convergence test results are validated by a J-Statistic probability value (Sargan test) of 0.3507, which also exceeded 5% probability. The coefficient value from the GMM calculation is smaller than that from OLS but larger than that from the Fixed Effect model, indicating that the GMM prediction is neither upwardly nor downwardly biased.

TABLE 2. FD-GMM feasibility test results

Test	Results	Description	Decision
Arellano-Bond Serial Correlation Test (AR2)	0.739	Value above 0.05	The estimation results are consistent
Prob. J-Statistic	0.351	Value above 0.05	Valid instrument
OLS Coefficient	0.908	Upward bias estimation	Bias
FD-GMM Coefficient	0.658	Estimates are between OLS and Fixed Effect coefficients	Unbiased
Fixed Effect Coefficient	0.625	Downward bias estimation	Bias

Source: Author's data processing results

The table below shows the effect of the previous Gini ratio on the observed period, with a coefficient of 0.6582. A coefficient value below 1 indicates a process of income inequality convergence between provinces, where future values are predicted to decrease until convergence is achieved. The effect of the previous Gini in the current Gini is significant at an error level below 1%.

TABLE 3. Gini convergence test results 2015-2022 through first difference GMM

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GINI(-1)	0.658	0.012	55.249	0.000
Mean dependent var	-0.004	S.D. dependent var		0.009
S.E. of regression	0.012	Sum squared resid		0.008
J-statistic	9.996	Instrument rank		10
Prob(J-statistic)	0.351			

Source: Author's data processing results

The half-life value represents the time required for the convergence process to reduce inequality by half. This value is obtained using the formula 1- β Gini(-1) or 1-0.6582, yielding a β value of 0.3418. The next step is to input the value into the formula Ln(2)/0.3418 resulting is 2.0279. This means that reducing half of the inequality in the Gini ratio between provinces will take approximately two years, multiplied by the number of observation periods (eight years), thus resulting in a total of about 16 years to halve the inequality. It takes about 32 years to eliminate inequality entirely (Budiman et al. 2018; Zulham et al. 2019).

DIRECT EFFECT AND SPILLOVER EFFECT

The initial step to detect the presence or absence of spatial dependency in the panel data model is to conduct a cross-section dependence test. Prior to this, we conducted the Hausman test to determine the most appropriate panel model. The resulting p-value was 2.2e-16 or below 5% level, indicating that the fixed effects regression model should be employed to test for spatial dependence. Subsequently, an autocorrelation test was conducted, revealing absence of correlation between time in the residuals as indicated by a p-value of 0.07. Based on the cross-section dependence test using the Breusch-Pagan LM test, the p-value was 0.000256, which is below the 5% threshold, confirming that the model exhibits spatial dependence. However, the Pesaran CD test produced a large p-value of 0.446, indicating that there is no spatial dependency effect in the model.

TABLE 4. Panel model selection, autocorrelation test and spatial dependence test

Test	p-value Results	Decision
Best panel model (Hausman test)	2.2e-16	Fixed effect model
Serial correlation (Breusch-Godfrey/Wooldridge test)	0.071	No serial correlation
Cross-section dependence (Breusch-Pagan LM test)	0.000	There are spatial dependence
Cross-section dependence (Pesaran CD test)	0.446	No spatial dependence

Source: Author's data processing results

To further confirm the spatial dependence in the model, a Moran test is conducted. This test requires the use of a weight matrix, for which we employed a distance matrix using the K-Nearest Neighbour approach. We assumed three to five nearest neighbours for each observation province, considering the geographical layout of interprovincial boundaries. Some provinces have relatively few boundaries, such as Aceh Province, which only borders North Sumatra. Lampung Province borders South Sumatra and Bengkulu while North Sumatra, Riau and South Sumatra each share borders with three provinces. Meanwhile, Jambi and Bengkulu Provinces have four neighbouring provinces. The Riau Islands and

Bangka Belitung, being island provinces, have the closest neighbours in Riau and Lampung. On average, selecting three nearest neighbours was considered ideal, while also taking into account the Akaike Information Criterion (AIC) values generated.

The results of the Moran test, whether using KNN-3, KNN-4, or KNN-5, shows the presence of spatial dependence in the model, with p-values of 5.76E-11, 7.33E-12, and 2.57E-12, all below the 5% threshold. In the SAR model using KNN-3, 4, and 5 with random effects, the lambda p-value was 0.00 or below the 5% level. The results indicate that the SAR model is significant across the three types of matrices, with the lowest AIC value observed for KNN-4, at -293.687. The SEM model however, was not significant across any of the neighbour count options, with Rho values for KNN-3, 4, and 5 exceeding 5%. In the SARAR model, using random effects, with KNN-3, 4, and 5, the lambda values were below 5% threshold level, confirming the significance of the model in explaining the spillover effect. The lowest AIC values were found in the SARAR model with KNN-3 and KNN-4 matrices, at -297.008 and -297.965 respectively. Considering the average number of nearest neighbours of each province and the minimal difference in AIC values between the them, we selected KNN-3 as the weighting matrix to use.

Table 5. Selection of weight matrix and spatial model selection

Tests	p-value KNN-3	p-value KNN-4	p-value KNN-5	KNN-3 Decision	KNN-4 Decision	KNN-5 Decision
Moran test	5.76E-11	7.33E-12	2.57E-12	There are spatial dependencies	There are spatial dependencies	There are spatial dependencies
			SAR Model			
Hausman test	0.940	0.823	0.689	Random Effect	Random Effect	Random Effect
Lambda	0.002	0.000	0.004	Model significant	Model significant	Model significant
AIC	-291.189	-293.687	-290.043	2	2	1
			SEM Model			
Hausman test	0.133	1.26E-09	1.37E-01	Random Effect	Fixed Effect	Random Effect
Rho	0.566	0.446	0.548	Model not significant	Model not significant	Model not significant
AIC	-283.457	-225.333	-283.442	3	3	3
			SARAR Model			
Hausman test	0.415	0.4849	0.006	Random Effect	Random Effect	Random Effect
Lambda	1.361e-07	1.817e-08	0.006	Model significant	Model significant	Model significant
AIC	-297.008	-297.965	-286.963	1	1	2

Source: Author's data processing results

Table 6 shows the coefficient values of the direct effect, spillover effect, and total effect of the determinant variables on income inequality. Table 7 illustrates the significance levels. The direct effect coefficient value illustrates the effect of independent variables on income inequality in each province on Sumatra Island. According to Table 7, Environmental quality, represented by environmental quality index (IKLH), exerts a significant negative effect on the Gini ratio at the 10% level. Table 6 provides the coefficient values, with the IKLH coefficient at -0.069. This indicates that a 1% improvement in environmental quality in the observed province results in a 0.069% reduction in income inequality in the province. Enhancing environmental quality helps sustain the ecosystems, which in turn confer economic benefit from available natural resources to a wider population, thus leading to greater equity. This finding is in line with Wu & Id (2020) and Rahman et al. (2023) who explain the mechanism through which air pollution and environmental quality affect income inequality. Likewise, Chen et al. (2020) revealed the effect of reducing inequality on improving environmental quality, especially in developing regions. These results contradict the findings of Khan et al. (2023) who reported the opposite outcome.

Real income per capita also has a significant negative effect on the Gini ratio at the 1% level, indicating that a 1% increase in real income per capita in the observed province will reduce income inequality by 0.191%. The direct effect of real per capita income is the largest among the predictor variables. The convergence of economic inequality across Sumatra Island and the so-called “catch-up” effect, where the real incomes of developing regions began to approach those of more developed areas, has resulted in a more even income inequality distribution across the island. On average, economic improvements help reduce inequality. One of the key factors is the development of transportation infrastructure, that increasingly connects provinces, in addition to the increasingly intense efforts of developing provinces to enhance their social economic infrastructure.

Furthermore, an improved democratic climate will reduce income inequality with a p-value at the 10% level. This is in line with the findings of Gu and Wang (2022) who highlighted the strengthening of political polarization and democratic issues as income inequality increases. The development of democracy in the Sumatra region has been able to address aspects of economic equality. The various channels of democracy in Sumatra are able to operate with the spirit of redistribution. Strong bargaining from labour unions in voicing workers' rights, especially in advocating wage adjustments, is believed to be the key factor in reducing income inequality across different communities. The wider political participation of various community groups in voicing their economic concerns was effectively translated into policies that increasingly connect the underprivileged population with development activities. This interaction resulted in an increase in the income of the low-income groups, thereby narrowing the inequality gap.

The contribution of the industrial sector however, has a significant but positive effect at the 10% level, as shown in Table 6, where a 1% increase leads to a 0.092% increases the Gini ratio. This finding however contrasts with that of Mehic (2018) who reported the opposite effect. Large industries contribute more economically than small-scale industries since they have the advantages from economies of scale which enhance efficiency and profitability. As a result, it becomes harder for small firms in Sumatra Island to compete, thus exacerbating inequality. On the other hand, the growing process of industrialization has led to increasing levels of migration. However, not all job seekers succeed in securing employment, since supply of labour exceeds demand. This leads to two conditions, where those fortunate enough to have the required skills can secure better-paid jobs, while others are trapped in low-wage employment or unemployment.

TABLE 6. Results of direct and spillover effects of predictor variables on income inequality with random effect SARAR model KNN-3 weight matrix

Variable	Direct Effect	Spillover Effect	Total Effect
Log(iklh)	-0.069*	-0.071	-0.139
Log(real income percapita)	-0.191***	-0.196*	-0.387***
Log(democracy)	-0.098*	-0.101	-0.199
Log(industry)	0.092**	0.094	0.186*

Source: Author's data processing results

There is a strong spillover effect from an increase in real GRDP per capita in the observed province, which results in the reduction in inequality in the three neighbouring provinces. Table 6 indicates that a 1% increase in this variable in the observed province will result in a 0.196% reduction in the Gini ratio in the three neighbouring provinces. Table 7 shows that the effect of total income per capita has a p-value of 0.006, significant at the 1% level, suggesting that an increase in real GRDP per capita on Sumatra Island can reduce inequality more widely by 0.387%. This finding supports the convergence in income inequality, driven more equitable development across provinces, especially the accelerated growth of developing regions. These results are in line with the findings of Rahman et al. (2023). The growth of small and medium-sized cities also contribute to higher incomes, which assist in reducing the income gap between different groups in Indonesia (Rahman et al. 2023).

Increased industrial activity on Sumatra Island may however increase the wider inequality effect. As shown in Table 7, the p-values of both IKLH and democracy variables in relation to spillover and total effects are above the 10% threshold, suggesting weak spillover effects. The decline in inequality in the observed provinces, as influenced by their interaction with environmental quality and democracy, does not significantly contribute to the decline in inequality in the surrounding provinces.

The factors shaping environmental quality in each province of Sumatra Island have unique geographical characteristics, where environmental quality enhances the utilization of natural resources into economic added value. However, its impact is largely limited to each administrative area, indicating that changes do not significantly affect the surrounding provinces. The democracy in Sumatra exhibits a similar trend. The nature of democratic implementation, along with decentralization that promotes regional competition, tends to produce effects that benefit individual provinces more than neighbouring areas. The trend also includes the effect on inequality.

TABLE 7. P-value results of direct and spillover effects of predictor variables on income inequality with random effect SARAR model KNN-3 weight matrix

Variable	Direct Effect	Spillover Effect	Total Effect
Log(iklh)	0.090*	0.171	0.117
Log(real income percapita)	2.19e-05***	0.056*	0.006***
Log(democracy)	0.097*	0.203	0.137
Log(industry)	0.042**	0.144	0.074*

Author's data processing results

CONCLUSION

This study found a convergence of income inequality (Gini) among provinces in Sumatra Island. Improvements in environmental quality, real income per capita, and stronger democracy within an observed province help reduce income inequality, while growth in the industrial sector tends to increase it. Of all the factors, higher real income per capita has the strongest direct and spillover effects in reducing inequality. Conversely, increased contribution of the industrial sector across the region contributes to rising inequality in Sumatra. However, the spillover effects of environmental quality, industry, and democracy in neighbouring provinces have no significant impact on both inequality in neighbouring areas and the overall effect.

The convergence of income inequality levels across provinces illustrates that there is a movement towards equilibrium in the performance of the determinant variables in each province. The “catch-up” effect of the developing provinces and the deceleration of performance in the more developed ones converge, reducing inequality at the point of convergence.

The spillover effect of real GRDP per capita illustrates the role of the central government in strengthening inter-regional connectivity across Sumatra. The massive infrastructure development projects, such as the construction of the Trans-Sumatra Toll Road, airports and ports further strengthen these spillover effects, and contributes to the observed convergence in Gini coefficients. Provincial governments play a crucial role in delivering direct effects to further enhance democracy, environmental quality, and income increment, as well as addressing issues in industrial policy. Policy efforts need to focus on increasing productivity through strengthening infrastructure under provincial authority, developing potential and superior key regional products, ensuring equal opportunities for all groups, and optimizing production capabilities. Prudence should be exercised in promoting growth to empower the small-industry sector to upgrade and contribute to broader equity without compromising environmental sustainability.

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