Journal of Finance - Marketing Research; Vol. 3, Issue 2; 2025
ISSN: 3030-4296
DOI: https://doi.org/10.52932/jfmr.v3i2e

Journal of Finance - Marketing Research

http://jfm.ufm.edu.vn

THE IMPACT OF FISCAL DECENTRALIZATION, GREEN INNOVATION, AND GEOPOLITICAL RISKS ON SUSTAINABLE DEVELOPMENT

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ARTICLE INFO

DOI: 10.52932/jfmr.v3i2e.843

Received: March 12, 2025

Accepted: July 2, 2025

Published: July 25, 2025

Keywords:
Bayesian regression; Fiscal decentralization; Green innovation; Geopolitical risks; Sustainable development.

JEL codes:
C33, E06, Q01

ABSTRACT

This study employs Bayesian regression to examine the impact of fiscal decentralization, green innovation, and geopolitical risks on sustainable development across 19 developed and 12 emerging economies over the period 2010–2022. The empirical results indicate that fiscal decentralization hinders sustainable development in emerging economies but promotes it in developed countries. Conversely, geopolitical risks act as a driver of sustainable development in emerging markets, while it negatively affects sustainable development in developed economies. Notably, green innovation consistently contributes to the enhancement of sustainable development across all countries examined. Based on these findings, the study proposes several policy implications tailored to the development context of each group of countries.

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1. Introduction

In recent decades, excessive resource consumption, environmental degradation, and socio-economic imbalances have emerged as critical global challenges (UNEP, 2022). In response, sustainable development (SD) has become a shared objective of the international community, driving countries to promote green economy strategies, foster green innovation, and adopt sustainable technologies aimed at minimizing environmental impacts. Concurrently, several countries such as China, the European Union, and the United States have implemented fiscal decentralization (FD) as a policy instrument to advance SD (Zhang et al., 2017). While FD can enhance the efficiency of local governance and optimize resource allocation, it may also lead to unhealthy competition and distort public spending priorities. Therefore, further research is essential to comprehensively assess the effects of FD on SD.

In 2023, the global economy experienced a slowdown following the COVID-19 pandemic; however, the outlook for 2024 appears more optimistic, characterized by transformative shifts in economic growth, energy systems, and food security. Green innovation (GI) has emerged as a central trend, frequently emphasized in international forums and national commitments toward achieving the Sustainable Development Goals (SDGs) (United Nations, 2015). GI encompasses sustainable technologies, processes, and business models that reduce environmental impacts and enhance resilience to climate change. According to the European Commission, green innovation aims to promote efficient resource use, lower ecological footprints, and support sustainable growth. A growing body of research highlights green innovation as a pivotal pathway to SD, underscoring the importance of technological transformation and supportive policy frameworks for green innovation in the context of globalization (Du et al., 2019; Többelmann & Wendler, 2020; Li & Xu, 2023; Udeagha & Muchapondwa, 2023).

In recent years, geopolitical risk (GPR) has emerged as a significant barrier to national progress toward SD, particularly following the Russia–Ukraine conflict in 2022, which substantially heightened GPR levels in several countries. A number of studies provide empirical evidence that effective management of political risks can enhance a country's sustainability performance (Ahmad et al., 2024; Feng et al., 2024; Wang et al., 2024). Conversely, several other studies suggest that rising GPR may exert a positive influence on environmental quality, implying a trade-off between political risk and environmental sustainability (Nawaz et al., 2023; Husnain et al., 2022; Anser et al., 2021). Beyond its direct effects on SD, GPR may also indirectly shape sustainability outcomes by mitigating the adverse impacts of FD on SD (Hoang et al., 2024).

To comprehensively examine the effects of FD, GI, and GPR on SD, this study employs a Bayesian regression approach using panel data from 31 countries over the 2010–2022 period. As Rodríguez-Pose & Gill (2005) argue, in developed economies, subnational governments often enjoy greater autonomy in revenue generation and expenditure management, which enhances policy accountability and effectiveness. In contrast, many emerging economies rely heavily on central transfers, with limited local fiscal discretion, thereby weakening the potential benefits of decentralization for SD. Accordingly, this study divides the sample into two group, 19 developed and 12 emerging countries, for separate analysis.

The main contributions of this study are threefold. First, it provides empirical evidence of the contrasting effects of FD on SD: while FD promotes SD in developed countries, it appears to undermine SD in emerging economies. Importantly, the study adopts a multidimensional approach to SD, encompassing environmental, economic, and social dimensions. Second, GI is shown to consistently enhance SD across both groups of countries. Third, GPR is found to promote SD in emerging economies with a posterior probability of 91.95%, whereas in developed countries, it acts as an impediment to sustainability progress.

2. Literature review

2.1. Impact of fiscal decentralization on sustainable development

Sustainable development (SD) has long been conceptualized as a balanced integration of economic growth, social inclusion, and environmental protection. This multidimensional approach, as first articulated by the World Commission on Environment and Development (WCED, 1987), emphasizes meeting current developmental needs without compromising the capacity of future generations. Within this context, fiscal decentralization (FD) broadly understood as the transfer of fiscal authority and responsibilities from central to subnational governments (World Bank, 2013) has been increasingly examined for its potential influence on sustainable development outcomes. Unlike simplistic notions of revenue sharing, FD involves the strategic and transparent assignment of revenue sources and expenditure responsibilities, thereby affecting governance and service delivery at multiple levels (Davey, 2003).

The theoretical foundations linking FD and SD are grounded in fiscal federalism and public choice theory. Oates (1972) argues that decentralization can improve allocative efficiency by aligning policies with local preferences, enabling jurisdictions to design context-specific sustainability strategies, and fostering innovation and accountability. Conversely, public choice theory cautions against the risks of rent-seeking and inefficient allocation of resources in the absence of robust institutional checks. Downs (1957) introduced the idea of "rational ignorance," wherein limited voter oversight may permit local elites to divert public funds toward private or political interests. Nevertheless, under well-structured governance frameworks, FD can stimulate healthy inter-jurisdictional competition, thereby encouraging environmental stewardship, fiscal discipline, and the adoption of green policies aimed at attracting investment and environmentally conscious populations.

Empirical research offers nuanced insights into the environmental effects of FD. While its contribution to economic growth is well recognized, its environmental impact remains debated (Kuai et al., 2019). Many studies support the view that FD can enhance environmental outcomes. For example, increased fiscal autonomy at the subnational level is linked to improved environmental performance through local actions targeting CO_2 reductions and energy efficiency (Konisky, 2007; Cheng, 2019). Kuai et al. (2019) found that both revenue and expenditure decentralization in Chinese provinces supported environmental improvement, with revenue decentralization having a stronger effect.

Cross-national evidence aligns with these findings. Ji et al. (2021), using the CS-ARDL method in seven decentralized countries, showed that FD reduces CO_2 emissions by empowering local authorities to better regulate polluters, especially when coupled with ecological innovation and renewable energy. Similarly, Khan et al. (2021), in a study of seven OECD countries, confirmed that FD's environmental benefits are enhanced by strong institutions and green technologies. Sun et al. (2022), applying the MMQR approach to

OECD nations, found that FD promotes green investment and renewable energy adoption. Safi et al. (2022), using the Spatial Durbin Model (SDM), observed that although FD may initially raise emissions, it contributes to long-term reductions, supporting carbon neutrality goals. Fang and Fang (2023), analyzing G7 nations with MMQR, found consistent environmental benefits of FD across all levels of ecological footprint. In South Africa, Udeagha & Muchapondwa (2023) emphasized the synergy between FD and green innovation in enhancing ecological sustainability.

However, some research points to adverse environmental effects of FD. Millimet (2003) and Sigman (2014) warn that weak local governance and free-riding behavior can undermine environmental quality. Fell and Kaffine (2014) argue that FD may fail to address environmental challenges altogether. In China, Yang et al. (2020) found, using SDM on 2005–2016 provincial data, that increased FD was linked to higher CO_2 emissions due to growth-first local policies. Yang et al. (2021) extended this result for 2002–2017, while Chen and Liu (2020) confirmed a negative FD-environmental quality relationship in 31 provinces (2003–2017).

Beyond environmental aspects, broader studies on SD show mixed results. Hui & Martinez-Vazquez (2021), using 2SLS and System-GMM for 52 countries (1991–2016), identified an inverted U-shaped link between FD and SD, where too much or too little FD reduces service efficiency. They suggested optimal FD ratios between 0.309 and 0.395, based on NSDI and HDI indicators. Similarly, Jin & Jakovljevic (2023), using data from 50 countries (1991–2020), found that moderate FD boosts efficiency via local knowledge, but excessive decentralization distorts fiscal priorities, weakens macroeconomic control, and reduces public goods efficiency—ultimately hindering national SD. These findings point to the importance of a balanced decentralization approach to support both efficiency and sustainability.

2.2. The impact of green innovatiob on sustainable development

Green innovation (GI), or eco-innovation, is widely recognized as a critical mechanism for addressing environmental challenges while sustaining economic growth and social well-being. Theoretical frameworks such as the neoclassical growth theory (Solow, 1999) and the Green Solow model (Taylor & Brock, 2004) posit GI as a form of technological advancement that enhances productivity and mitigates environmental degradation via investments in R&D, renewable energy, and clean technologies. From an endogenous growth perspective, GI is considered a knowledge-driven process that relies on robust innovation ecosystems and supportive policy environments to generate positive spillovers and foster long-term SD.

Empirical research has yielded mixed findings on the relationship between GI and SD, often shaped by differences in development levels, policy contexts, and methodological choices. Brandão Santana et al. (2015), analyzing G7 and BRICS countries, found that technological innovation positively contributes to all three pillars of SD in BRICS nations, whereas in G7 countries, its influence is significant mainly for social development. This divergence highlights how developmental stages condition the effectiveness of innovation strategies.

Du and Li (2019) examined 71 countries from 1992 to 2012 and found that GI improved environmental outcomes primarily in high-income countries, where scientific infrastructure and financial capacity facilitate the adoption of green technologies. In developing countries, however, high implementation costs and the prioritization of basic needs often inhibit GI's effectiveness. Complementing this, Chang et al. (2023) demonstrated that in China, GI significantly enhances environmental quality when accompanied by strong regulatory frameworks. Similarly, Többelmann and Wendler (2020), using environmental patents and GMM estimations across 27 EU nations, affirmed that GI effectively reduces CO_2 emissions, unlike general innovation. They also noted that GI's impact is more substantial in advanced economies, consistent with the findings of Du and Li (2019).

Taking a broader ecological perspective, Koseoglu et al. (2022) analyzed 20 countries with high GI levels using the ecological footprint as a measure of environmental sustainability. Their study concluded that while economic growth drives environmental degradation, environmental technologies significantly reduce ecological footprints, specifically, a 1% increase in environmental technology corresponds to a 0.129% reduction in footprint. This underscores GI's potential to decouple economic development from environmental harm. Focusing on country-specific evidence, Chien (2023) applied an ARDL model to assess the impact of GI on China's SD from 1991 to 2020, using HDI as the outcome variable. The findings confirmed GI's substantial positive contribution to SD, alongside green investment, R&D, and financial inclusion. Minh Phuong et al. (2023) extended this analysis to Vietnam, using both Dynamic and Bayesian ARDL models, and found that GI, green bonds, and green investment significantly enhance sustainable economic performance.

However, the effects of GI are not uniformly positive over time. Ha (2025) applied wavelet regression techniques to investigate the dynamic relationship between GI and CO_2 emissions in Vietnam (1992–2019), revealing temporal inconsistencies. While GI contributed to emission reductions during 1996–2003 and 2012–2015, it paradoxically increased emissions in other periods, reflecting the complex and evolving nature of the technology-environment nexus.

Collectively, the literature illustrates that GI plays a vital but context-dependent role in advancing SD. Its success is influenced by national innovation capacity, policy enforcement, economic structure, and temporal dynamics, necessitating tailored approaches to harness its full potential across different developmental settings.

2.3. The impact of geopolitical risk on sustainable development

Geopolitical risk (GPR), defined as the uncertainty stemming from political, social, and economic instability, has emerged as a critical challenge to SD (Caldara & Iacoviello, 2022). With increasing globalization, GPR now poses significant threats to the achievement of the Sustainable Development Goals (SDGs), as conflicts, terrorism, and geopolitical tensions disrupt international cooperation and development efforts (Nguyen et al., 2023; Wang et al., 2024). Institutional theory suggests that strong governance and legal systems can mitigate the adverse effects of geopolitical instability, whereas weak institutions often amplify them (DiMaggio & Powell, 1983). Similarly, conflict theory highlights how competition over resources can fuel geopolitical conflict, disrupt economies, degrade the environment, and hinder SD (Marx & Engels, 2019).

Recent studies reflect a growing academic interest in the GPR–SD nexus, particularly in environmental dimensions. Wang et al. (2024) noted that environmental sustainability has been the most studied aspect, especially post–Russia–Ukraine conflict. Ahmad et al. (2024), using CCEMG estimation for OECD countries (1990–2019), found that a 5% improvement in GPR could enhance SD by 0.013%, attributing this to strong institutions and international cooperation. Governance is again emphasized by Feng et al. (2024), who found that improved governance reduces GPR and protects environmental quality.

Several empirical studies confirm the negative environmental impact of GPR. Farooq et al. (2023) showed that political risk in China raises CO_2 emissions and that FDI can exacerbate this effect. Similar findings are reported by Bashir et al. (2023) for BRICS nations and Wang et al. (2024). However, some studies report counterintuitive results. For example, Nawaz et al. (2023) found that GPR helped reduce pollution in Italy. Husnain et al. (2022) observed an 8% decline in CO_2 emissions following a 1% increase in GPR across E7 countries due to decreased investment and altered consumption patterns. Anser et al. (2021) and Zhao et al. (2021) also found that GPR reduced ecological footprints by suppressing energy use and economic activity.

Despite these insights, the literature remains fragmented and largely focused on environmental indicators such as CO_2 emissions or ecological footprint, often neglecting the broader, multidimensional nature of sustainable development. Most studies fail to incorporate social and economic aspects of SD, leaving a gap in the holistic understanding of how GPR affects development outcomes. To address this, the current study adopts a Bayesian regression framework suited for small samples and model uncertainty. It also employs the UN's SDG Index, a composite measure spanning 17 economic, social, and environmental goals, to better capture the complex interplay between GPR, fiscal decentralization, green innovation, and sustainable development.

3. Methodology

3.1. Variables and model specification

Drawing upon the frameworks established by Hui and Martinez-Vazquez (2021), Li and Xu (2023), and Hoang et al. (2024), this study proposes the following empirical models:

Model 1a: The impact of expenditure decentralization, green innovation, and geopolitical risk on sustainable development:

$$SDGI_{i,t} = \beta_i + \beta_1 ED_{i,t} + \beta_2 GI_{i,t} + \beta_3 \text{GPR}_{i,t} + \beta_4 Z_{i,t} + \varepsilon_{i,t} \quad (1)$$

Model 1b: The impact of revenue decentralization, green innovation, and geopolitical risk on sustainable development:

$$SDGI_{i,t} = \beta_i + \beta_1 RD_{i,t} + \beta_2 GI_{i,t} + \beta_3 GPR_{i,t} + \beta_4 Z_{i,t} + \varepsilon_{i,t} \quad (2)$$

where: i = 1, 2,..., N denotes countries and t = 1, 2,..., T represents the time period.

Table 1 below provides detailed descriptions of the variables included in the empirical model, along with data sources and the expected directions of their effects on the dependent variable.

Table 1. Description of variables

Sign	Variable	Description	Signal expectation	Study
Independent variable				
SDGI	Sustainable Development	SDG Index		Oanh (2023), Dinh et al. (2024)

Sign	Variable	Description	Signal expectation	Study
Dependent variable				
ED	Expenditure decentralization	Local spending/ total government spending ratio (%)	+	Yang et al. (2020), Hui & Martinez-Vazquez (2021)
RD	Revenue decentralization	Local revenue/ total government revenue ratio (%)	+	Yang et al. (2020), Hui & Martinez-Vazquez (2021)
GI	Green innovation	The ratio of environmental-related technology patents to total technology patents (%)	+	Du et al. (2019), Udeagha & Muchapondwa (2023)
GPR	Geopolitical risk	The geopolitical risk index, developed by Dario Caldara and Matteo Iacoviello.	-	Hoang et al. (2024)
Control variable				
GDP	Economic Growth	GDP per capita in terms of logarithm	+	Kuai et al (2019), Wang et al. (2023)
TO	Trade Openness	The sum of exports and imports of goods and services (% of GDP)	+	Du & Li (2019), Li & Xu (2023)
FDI	Foreign Direct Investment	Foreign direct investment, net inflows (% of GDP)	+	Töbelmann & Wendler (2020), Chen & Liu (2020)
URBAN	Urbanization rate	Urban population (% of total population)	-	Töbelmann & Wendler (2020), Li & Xu (2023)
SIZE	Government size	Government revenue (% of GDP)	+	Hui & Martinez-Vazquez (2021), Jin & Jakovljevic (2023)

3.2. Methodology

Unlike most previous studies on FD and SD that rely on frequentist methods, this study employs a Bayesian statistical approach. Bayesian inference combines observed data with prior information to estimate posterior distributions of model parameters, offering advantages in small-sample settings (Zondervan-Zwijnenburg et al., 2017).

Bayesian and frequentist methods differ fundamentally: the former treats parameters as random and data as fixed, allowing direct probabilistic interpretations, while the latter assumes parameters are fixed and data arise from repeated sampling.

This study adopts a Bayesian linear regression model:

$$y \sim N(\beta^{T}X, \sigma^{2}I) \tag{3}$$

where y is assumed to follow a normal distribution characterized by a mean and variance. The mean of the linear regression is the transpose of the weight matrix multiplied by the predictor matrix, and the variance is the squared standard deviation (σ) multiplied by the identity matrix.

Not only the outcome variable (y) but also the model parameters are assumed to be generated from a distribution. The posterior probability distribution of the model parameters conditional on the input and output is given by:

$$P(\beta|y, X) = \frac{P(y|\beta, X)\ P(\beta|X)}{P(y|X)} \tag{4}$$

Where P(β|y, X) denotes the posterior probability of the parameters given the data; P(y|β,X) is the likelihood function; P(β|X) is the prior probability; and P(y|X) is a normalization constant which can be omitted. Hence, Equation (4) is often simplified as:

$$P(\beta|y, X) = P(y|\beta, X)\ P(\beta|X) \tag{5}$$

To assess the relationship between SD and explanatory variables, the Bayesian regression proceeds in three steps. First, it assumes normal priors with zero means for all coefficients, implying no directional bias. Second, likelihood functions are based on the normal distribution. Third, posterior distributions are estimated using Markov Chain Monte Carlo (MCMC) with a Gibbs sampler, generating 12,500 draws and discarding the first 2,500 as burn-in. MCMC is a standard method for complex model estimation (Levy, 2020).

This study uses a balanced panel dataset spanning 2010–2022 for 31 countries – comprising 19 developed and 12 emerging economies – yielding only 13 observations per country. Given the small sample size, Bayesian methods are particularly appropriate and offer robustness against model issues such as autocorrelation, heteroskedasticity, and endogeneity.

Due to data limitations, this study is restricted to a balanced panel of 31 countries. Specifically, the geopolitical risk (GPR) index is only available for 44 countries globally, while data on green innovation (provided by the OECD) and fiscal decentralization (from the IMF) are incomplete for many countries during the same period. As such, the study scope is determined by data availability and synchronization to ensure reliability and consistency in the quantitative analysis. Data was collected from the World Bank, IMF, and OECD databases. GPR data were obtained from www.matteoiacoviello.com.

4. Research findings and discussion

4.1. Descriptive statistics of the variables

The descriptive statistics summarized in Appendix 1 (*see Appendix 1 online*) reveal notable disparities between developed and emerging countries across key indicators of sustainable development and fiscal decentralization from 2010 to 2022. On average, developed countries demonstrated a higher SDGI than emerging economies, underscoring a more advanced state of sustainable development. This gap is consistent across the period, with the highest SDGI recorded in Finland and the lowest in South Africa and Israel.

In terms of fiscal decentralization, ED generally exceeded RD across both groups, suggesting that governments are more inclined to devolve spending responsibilities than revenue-generating powers. Although developed countries showed slightly higher average ED levels, some emerging economies, notably China, exhibited exceptionally high ED values, highlighting diverse fiscal structures within this group. Conversely, RD levels were relatively similar across both developed and emerging economies, indicating a shared tendency to centralize revenue control.

Green innovation (GI) displayed an unexpected pattern: emerging economies marginally outperformed developed ones in terms of average innovation rates. While

Denmark and Chile recorded the highest GI values in their respective groups, the wide variation within both groups suggests that green innovation outcomes are not solely determined by a country's development status.

Finally, geopolitical risk (GPR) varied significantly across countries and time, with the highest index value observed in Russia during 2022, coinciding with its escalation of conflict in Ukraine, while the lowest risk was recorded in Chile in 2013. These variations reflect the dynamic and context-specific nature of geopolitical tensions throughout the study period.

4.2. Research findings and discussion

4.2.1. The impact of fiscal decentralization, green innovation, and geopolitical risk on sustainable development

In this study, FD is measured through two dimensions: expenditure decentralization and revenue decentralization. Table 2 presents the Bayesian regression results regarding the impact of expenditure decentralization on SD in 19 developed countries during the period 2010–2022. As shown, the average acceptance rate of the model reaches 0.8152, and the minimum average efficiency is 0.1659, which exceeds the acceptable threshold of 0.01. Therefore, it can be concluded that the model satisfies the necessary statistical requirements.

Table 2. Bayesian regression results of the impact of expenditure decentralization, green innovation, and geopolitical risk on sustainable development in developed countries

SDGI	Mean	Std. Dev.	MCSE	Equal-tailed		Posterior probability		
				[95% cred. interval]		Mean	Std. Dev.	MCSE
ED	0.03010	0.02002	0.00020	-0,00886	0,06913	0.9349	0.2467	0.0025
GI	0.36131	0.08046	0.00081	0,20387	0,51889	1.0000	0.0000	0.0000
GPR	-0.00311	0.00472	0.00005	-0,01241	0,00616	0.7574	0.4357	0.0044
GDP	0.01909	0.00829	0.00008	0,00266	0,03543	0.9882	0.1080	0.0011
FDI	-0.04107	0.02835	0.00028	-0,09669	0,01324	0.9280	0.2585	0.0026
URBAN	-0.07593	0.03039	0.00030	-0,13558	-0,01612	0.9923	0.0874	0.0009
TO	0.01658	0.00745	0.00008	0,00187	0,03090	0.9873	0.1120	0.0011
SIZE	0.23831	0.03077	0.00031	0,17717	0,29876	1.0000	0.0000	0.0000
_cons	4.05878	0.07983	0.00081	3,90295	4,21796			
Avg acceptance rate		0.8152	Avg efficiency: min		0.1659			

Unlike the frequentist approach, which only provides fixed regression coefficients, Bayesian regression employs the Metropolis–Hastings (MH) algorithm to simulate the regression model over 10,000 iterations, with each iteration generating a regression coefficient. As a result, the Bayesian regression output reports the mean and median values of the coefficients based on the full simulation process. Additionally, it provides the equal-tailed 95% credible interval, representing the range within which the parameter lies with 95% probability.

Alongside the standard deviation (Std. Dev) of the coefficient estimates, the output also includes the Monte Carlo Standard Error (MCSE), which helps assess the convergence stability of the MCMC chain. According to Flegal et al. (2008), the closer the MCSE is to zero, the more stable the MCMC chain. An MCSE below 6.5% of the standard deviation is considered acceptable, while values below 5% are considered optimal. The results in Table 1 indicate that MCSE values fall within the optimal range, confirming the robustness of the Bayesian regression model.

The results in Table 2 reveal that expenditure decentralization in developed countries positively contributes to SD, supporting the initial hypothesis. GI also proves to be a key driver of SD in these countries. In contrast, economic growth, trade openness, and government size are found to hinder SD. On the other hand, geopolitical risk, foreign direct investment, and urbanization appear to reduce SD performance.

A major advantage of the Bayesian approach over frequentist methods is its ability to quantify the probability of effects. Therefore, the study proceeds to calculate the posterior probability of the impact of these factors on sustainable development, as presented in Table 2.

The results indicate that the posterior probability of a positive impact of expenditure decentralization (ED) on sustainable development (SD) is 93.49%. This finding aligns with the study's initial hypothesis and is consistent with the theory of fiscal federalism proposed by Oates (1972). Greater fiscal autonomy enables local governments to make more effective, context-specific decisions, enhancing public service delivery and targeted investments in SD-related areas. These findings are consistent with the empirical evidence presented by Fredriksson and Millimet (2002), Konisky (2007), Ji et al. (2021), Sun et al. (2022), Lingyan et al. (2022), Fang and Fang (2023), and Udeagha and Muchapondwa (2023).

In addition, the results show that green innovation significantly promotes sustainable development in developed countries, with a posterior probability of 100%. Rooted in Solow's growth theory and the Green Solow model (Taylor & Brock, 2004), green innovation represents technological progress oriented toward environmental sustainability. By improving energy efficiency and developing cleaner technologies, economies can simultaneously promote productivity and sustainability. This finding is also consistent with endogenous growth theory and is supported by empirical studies such as those by Töbelmann and Wendler (2020), Koseoglu et al. (2022), and Chien et al. (2023).

In contrast, geopolitical risk (GPR) acts as a hindrance to sustainable development (SD) in developed countries, with the posterior probability of this negative impact reaching 75.74% as shown in Table 1. In line with Marx's Conflict Theory, geopolitical tensions disrupt economic stability, social cohesion, and environmental governance, diverting resources from SD initiatives. This interpretation is supported by empirical findings from Farooq et al. (2023), Bashir et al. (2023), Ahmad et al. (2024), Feng et al. (2024), and Wang et al. (2024).

Moreover, the results reveal that GDP growth positively contributes to sustainable development, with a posterior probability of 98.82%. This supports the Environmental Kuznets Curve (EKC) hypothesis, suggesting that economic growth can reduce environmental harm through technological innovation and improved living standards. This result is consistent with the findings of Kuai et al. (2019), Chen and Liu (2020), Yang et al. (2021), Lingyan et al. (2022), and Wang et al. (2023).

On the other hand, foreign direct investment (FDI) is shown to negatively impact sustainable development in developed countries, with a posterior probability of 92.8%. This result supports the "pollution haven" hypothesis. FDI projects, particularly those in pollution-intensive or hazardous waste-generating industries, pose significant environmental and public health risks. These results are consistent with the findings of Farooq et al. (2023) and Nawaz et al. (2023).

Urbanization is found to negatively impact sustainable development, with a posterior probability of 99.23%. High levels of urbanization contribute to resource depletion, pollution, and poor urban planning, which undermine environmental sustainability and climate resilience. This conclusion is in agreement with the analyses by Töbelmann and Wendler (2020), Yang et al. (2020), Chen and Liu (2020), Yang et al. (2021), and Li and Xu (2023).

In contrast, trade openness is shown to promote sustainable development, with a posterior probability of 98.73%. Grossman & Krueger (1991) argue that trade liberalization facilitates the transfer of advanced technologies from developed to developing economies, thereby improving energy efficiency, reducing environmental degradation, and fostering sustainable development. These findings are corroborated by Du et al. (2019) and Jin and Jakovljevic (2023), who similarly identify positive effects of trade openness on sustainability.

Finally, the study confirms that government size plays a crucial role in promoting sustainable development, with a posterior probability of 100%. Larger governments can support broad-based public investments and infrastructure development, contributing to inclusive and sustainable growth. These findings are consistent with the empirical evidence provided by Hui and Martinez-Vazquez (2021), and Jin and Jakovljevic (2023).

The study proceeds to estimate the impact of revenue decentralization, green innovation, and geopolitical risk on sustainable development. The regression results and corresponding posterior probabilities are presented in Table 3 below:

Table 3. Bayesian regression results for the impact of revenue decentralization, green innovation, and geopolitical risk on sustainable development in developed countries

SDGI	Mean	Std. Dev.	MCSE	Equal-tailed		Posterior probability		
				[95% cred. interval]		Mean	Std. Dev.	MCSE
RD	0.03551	0.01946	0.00020	-0,00248	0,07304	0.9349	0. 2467	0.0025
GI	0.39964	0.06829	0.00069	0,26571	0,53241	1.0000	0.0000	0.0000
GPR	-0.00217	0.00477	0.00005	-0,01141	0,00722	0.7574	0.4357	0.0044
GDP	0.01830	0.00798	0.00008	0,00259	0,03390	0.9882	0.1080	0.0011
FDI	-0.04079	0.02838	0.00028	-0,09688	0,01374	0.9280	0.2585	0.0026
URBAN	-0.07707	0.02986	0.00030	-0,13624	-0,01833	0.9923	0.0874	0.0009
TO	0.02248	0.00717	0.00007	0,00832	0,03653	0.9873	0.1120	0.0011
SIZE	0.24422	0.03077	0.00030	0,18395	0,30443	1.0000	0.0000	0.0000
_cons	4.05781	0.07560	0.00076	3,91118	4,20789			
Avg acceptance rate		0.8169	Avg efficiency: min		0.0612			

The results in Table 3 indicate that revenue decentralization contributes positively to sustainable development in developed countries, with a posterior probability of 93.49%. When local governments are granted greater autonomy in revenue collection, they are incentivized to explore innovative solutions to broaden their revenue base, such as improving the local business environment, attracting investment, and promoting the development of key economic sectors. These activities not only stimulate local economic growth but also generate employment and enhance the standard of living, thereby reducing dependence on central government transfers.

Furthermore, decentralized authorities are better positioned to formulate and implement resource management and environmental protection policies that are tailored to their unique natural and developmental conditions. Measures such as environmental taxes, green subsidies, or incentives for eco-friendly projects serve as effective tools to encourage sustainable development and mitigate environmental degradation. These initiatives can reduce vulnerability to natural disasters and enhance long-term sustainability. These findings are consistent with those of Ji et al. (2021), Lingyan et al. (2022), and Fang and Fang (2023).

Similar to the results obtained with expenditure decentralization, the regression results using revenue decentralization also show that green innovation, economic growth, trade liberalization, and government size have a positive impact on sustainable development. In contrast, geopolitical risk, foreign direct investment (FDI), and urbanization are found to hinder sustainable development.

The analysis continues with a similar Bayesian regression for a group of 12 emerging economies. The results and posterior probabilities for the effects of expenditure decentralization, green innovation, and geopolitical risk on sustainable development in these countries are presented in Table 4 below:

Table 4. Bayesian regression results for the impact of expenditure decentralization, green innovation, and geopolitical risk on sustainable development in emerging economies

SDGI	Mean	Std. Dev.	MCSE	Equal-tailed		Posterior probability		
				[95% cred. interval]		Mean	Std. Dev.	MCSE
ED	-0.07809	0.02928	0.00028	-0,13513	-0,02074	0.9957	0.0654	0.0007
GI	0.24152	0.10234	0.00102	0,03725	0,44224	0.9905	0.0970	0.0010
GPR	0.02114	0.00893	0.00009	0,00373	0,03874	0.9910	0.0945	0.0009
GDP	0.04330	0.00836	0.00008	0,02695	0,05972	1.0000	0.0000	0.0000
FDI	0.01179	0.03457	0.00035	-0,05665	0,07973	0.6336	0.4818	0.0048
URBAN	-0.02810	0.04863	0.00049	-0,12446	0,06611	0.7181	0.4500	0.0045
TO	0.06370	0.01575	0.00016	0,03234	0,09468	1.0000	0.0000	0.0000
SIZE	0.23872	0.05680	0.00057	0,12814	0,35014	1.0000	0.0000	0.0000
_cons	3.76757	0.07693	0.00077	3,61916	3,91985			
Avg acceptance rate		0.8308	Avg efficiency: min		0.0706			

The research findings for emerging economies from 2010 to 2022 demonstrate a distinct pattern compared to developed countries. Expenditure decentralization was found to hinder sustainable development (SD), with a posterior probability of 99.57%. This result supports the "race to the bottom" hypothesis in fiscal decentralization theory originally proposed by Tiebout, where increased local fiscal autonomy leads to competitive behaviors among jurisdictions aiming to attract investment and residents. Such competition may result in deteriorating policy standards and reduced public service quality (Millimet, 2003; Batterbury & Fernando, 2006; Sigman, 2014; Fell & Kaffine, 2014; Yang et al., 2020; Chen & Liu, 2020; Yang et al., 2021).

In addition, revenue decentralization was also found to negatively affect SD, with an even higher posterior probability of 99.98%. This finding aligns with Oates' (1972) fiscal federalism model, which suggests that revenue decentralization can widen the gap between richer and poorer regions, weakening overall national sustainability. Local governments in less developed areas may struggle to raise adequate funds, potentially neglecting long-term investments in environmental protection, education, or healthcare. Moreover, the pursuit of short-term revenue generation may incentivize harmful competitive practices, such as lowering environmental and social standards to attract businesses.

Table 5. Bayesian regression results on the impact of revenue decentralization, green innovation, and geopolitical risk on sustainable development in emerging economies

SDGI	Mean	Std. Dev.	MCSE	Equal-tailed		Posterior probability		
				[95% cred. interval]		Mean	Std. Dev.	MCSE
RD	-0.01828	0.03454	0.00035	-0.04776	0.07700	0.9998	0.4584	0.0047
GI	0.29824	0.10347	0.00102	0.09473	0.50372	0.9986	0.0374	0.0004
GPR	0.01638	0.00966	0.00010	-0.00240	0.03556	0.9572	0.2024	0.0020
GDP	0.04370	0.00863	0.00009	0.02662	0.06038	1.0000	0.0000	0.0000
FDI	0.01055	0.03524	0.00034	-0.05879	0.07997	0.6163	0.4863	0.0049
URBAN	0.06215	0.04835	0.00048	-0.03142	0.15757	0.9026	0.2965	0.0030
TO	0.09132	0.01408	0.00014	0.06358	0.11920	1.0000	0.0000	0.0000
SIZE	0.23497	0.05893	0.00059	0.11935	0.35243	1.0000	0.0000	0.0000
_cons	3.64250	0.07751	0.00078	3.49071	3.79213			
Avg acceptance rate		0.8215	Avg efficiency: min		0.0383			

On a more positive note, the study finds that green innovation, economic growth, trade openness and government size significantly and positively influence SD in emerging economies, similar to the effects observed in developed countries. Notably, FDI emerges as a key driver of SD in emerging markets, with posterior probabilities exceeding 60% across both expenditure and revenue decentralization models. FDI contributes to sustainability by easing fiscal burdens and facilitating climate mitigation efforts through advanced technologies and greener practices (Voica et al., 2015). Multinational corporations also help enhance innovation and industrial upgrading, contributing to long-term sustainable development. These results echo earlier studies by Töbelmann and Wendler (2020), Chen and Liu (2020), and Yang et al. (2021).

Lastly, the study highlights the heightened sensitivity of emerging economies to geopolitical risk (GPR). While GPR negatively affects SD in both developed and emerging economies, its impact is more severe in the latter, with posterior probabilities reaching 99.1% (expenditure model) and 95.72% (revenue model). Geopolitical tensions tend to suppress economic growth and investment in emerging markets due to increased investor uncertainty. Paradoxically, the reduction in economic activity may temporarily improve environmental quality by lowering national energy consumption. These insights are consistent with the findings of Nawaz et al. (2023), Husnain et al. (2022), Anser et al. (2021), and Zhao et al. (2021).

5. Conclusion and policy implications

Using Bayesian regression on a panel dataset of 31 countries over the 2010–2022 period, this study reveals significant differences in how fiscal decentralization (FD), green innovation (GI), and geopolitical risk (GPR) influence sustainable development (SD) across developed and emerging economies. In developed countries, FD serves as a catalyst for SD, whereas in emerging economies, it tends to exert a detrimental effect. Conversely, while GPR negatively affects SD in developed economies, it appears to foster SD in emerging countries. Green innovation consistently contributes positively to SD across both groups. In addition, the study provides empirical support for the positive impacts of economic growth, trade liberalization, and government size on sustainable development.

Accordingly, developed countries should focus on enhancing fiscal decentralization by increasing the financial autonomy of local governments and fostering green innovation through tax incentives and support for environmentally friendly technological research. Formulating sustainable trade policies and closely monitoring FDI inflows are essential to ensure that economic development does not compromise environmental integrity. Reducing geopolitical risks by diversifying energy sources and strengthening international cooperation is also critical for maintaining economic stability. Furthermore, rational urban planning and investment in green infrastructure are key to managing the pace of urbanization and ensuring long-term sustainability.

In contrast, emerging economies need to strengthen coordination mechanisms between central and local governments to avoid resource misallocation and ensure cohesive implementation of SD policies. These countries should promote green innovation by supporting research and the adoption of eco-friendly technologies while channeling FDI into sustainable sectors such as renewable energy and clean production. Expanding international trade under green standards can facilitate economic growth without compromising environmental goals. Managing geopolitical risks through economic cooperation, supply chain diversification, and investment in strategic infrastructure can further enhance resilience and sustainability. Additionally, governments in emerging markets should play a more active role in development coordination by expanding public sector size and improving opersational efficiency, thereby ensuring effective public investment in infrastructure, education, and environmental protection.

In addition to its theoretical and practical contributions, the dissertation still has certain limitations. Due to data constraints, the analysis of the impact of FD, GI and GPR on SD was limited to 31 countries. Therefore, future studies could expand the scope to include more countries in order to obtain more generalizable results.

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