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Fiscal Decentralization and Sustainable Development Linkage – The Role of Green Innovation

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ABSTRACT

Many studies have demonstrated that fiscal decentralization and green innovation are pathways to sustainable development in countries. The interaction of these two factors also affects sustainability. To explore the moderating effect of green innovation on the relationship between fiscal decentralization and sustainable development, this study applied Bayesian regression on a dataset of 33 countries for the period 2010-2022. The results suggest that green innovation not only reduces the negative impact of fiscal decentralization on sustainable development but also promotes sustainable development of countries with a probability of 100%. In addition, other economic variables such as economic growth and trade openness positively impact sustainability, while foreign direct investment and urbanization hinder the sustainability of studied countries.

1. INTRODUCTION

In the 21st century, sustainable development (SD) has become a goal for individual countries and a common task of the international community. To pursue sustainable development goals, countries have deployed many specific strategies and actions, such as developing a green economy, promoting green innovation, and applying innovative technologies to minimize environmental impacts. Many countries, such as China, EU countries, the US, etc., increase fiscal decentralization levels to promote SD. While previous documents have focused on the impact of fiscal decentralization (FD) on economic growth [1], the effect of FD on SD has not received attention. Decentralized local governments can play an essential role in many aspects of national SD, such as the economy and environment. FD enhances overall economic efficiency by assisting local governments in making the most of their informational advantages and initiatives. On the other hand, excessive FD may also result in economic inefficiencies and adverse effects, including intense rivalry among governments, distortion of public expenditure frameworks, and adverse effects on sustainable development.

Concepts and phrases like “green innovation”, “circular economy”, or “clean energy” are becoming more common at international conferences in reference to countries' commitments to and actions toward the Sustainable Development Goals (SDGs). Green innovation, sometimes called eco-innovation or sustainable innovation, is the process of creating and implementing new products, business models, technologies, and procedures to address environmental issues, lessen ecological footprints, and advance sustainability in various societal contexts. By lowering environmental impacts, boosting resilience to environmental stresses, or achieving more responsible and efficient use of natural resources, green innovation is defined by the European Commission as “any form of innovation that leads to or aims to achieve significant and demonstrable progress towards SD” [2]. Many studies have shown that green innovation is a pathway to SD for countries [3-5].

To investigate the role of green innovation on the linkage between FD and SD, this study used Bayesian regression on a dataset of 33 countries from 2010 - 2022. With the advantage of handling the disadvantages of small research samples and the defects of multivariate regression models, Bayesian regression is used in many studies. This study has made the following contributions: First, the study shows that green innovation not only reduces the negative impact of FD on SD but also promotes the SD of countries with a probability of 100%. In addition, other economic elements such as economic growth and trade openness help enhance sustainability, while FDI (Foreign direct investment) sources and urbanization will hinder the SD of countries.

The rest of the research is designed as follows: Section 2 reviews some empirical studies on the research topic. The dataset and methodology are presented in Section 3 - Methodology. Section 4 analyzes and discusses the research outcomes. Section 5 concludes and provides some policy suggestions.

2. LITERATURE REVIEW

2.1 Fiscal decentralization and sustainable development

Currently, for countries in general and developing countries in particular, economic development and ecological protection are two main goals to achieve SD. It has been widely demonstrated that FD significantly affects economic growth, but its ecological impact remains unclear [6]. Thus, a large number of empirical studies have been carried out to fill the research gap on the linkage between FD and environmental quality [6-11]. There are two primary categories for these studies. Konisky [7], Cheng et al. [11], Kuai et al. [6] are among the first group of researchers who found the positive influence of FD on the environment. According to Konisky [7], a high level of FD is necessary before ecological outcomes may be enhanced. Furthermore, Cheng et al. [11] contended that defining roles at various governmental levels is essential to successfully meet targets for low CO_2 emissions and fiscal spending geared toward energy efficiency. Using spatial econometric models, Kuai et al. [6] examined the correlation between FD and environmental quality in 30 Chinese provinces and cities between 1998 and 2016. The study's findings, which emphasized the importance of FD as this component is more successful in enhancing the environment, showed that revenue and spending decentralization positively affected environmental quality. Ji et al. [12] investigated the effects of FD on environmental sustainability in seven nations with high degrees of FD: Australia, Austria, Belgium, Canada, Germany, Spain, and Switzerland. Findings confirmed that FD improves the environment by lowering CO_2 emissions, according to the results of the CS-ARDL regression approach. Because decentralized administrative entities are more likely to monitor polluting enterprises, the authors advise nations to decentralize to improve environmental quality. Sun et al. [10] used data from OECD countries for the period 1990 – 2019 to study the impact of FD on environmental sustainability using the Method of the Moments Quantile Regression (MMQR). The regression results concluded that there is a positive connection between these two factors, or in other words, FD significantly contributes to the improvement of environmental quality in OECD countries. In addition, this study showed that FD improves environmental sustainability through renewable energy conversion and green capital. Also studying OECD countries, Safi et al. [13] focused only on the impact of FD on environmental sustainability in 7 advanced countries with FD during the period 1990 – 2918. The Spatial Durbin Model (SDM) outcomes suggested that FD increases carbon emissions in short terms. However, in long terms, FD reduces CO_2 emissions and is necessary to achieve the zero carbon emissions goal. Fang and Fang [14] examined the impact of FD on SD in G7 countries during the period 1995 – 2020, in which SD is considered from the perspective of environmental sustainability through the ecological footprint variable. The MMQR estimation results suggested that FD improves environmental quality at all quantiles. Udeagha and Muchapondwa [5] examined the impact of FD and ecological innovation on environmental sustainability in South Africa from 1960 to 2020. The results support the view that FD and green innovation increase the ecological sustainability.

In regards to the linkage of FD and environmental quality, the second group of research – which includes Millimet [15], Sigman [16], Fell and Kaffine [17], Yang et al. [18], Chen and Liu [8], Yang et al. [9]– are more pessimistic. According to Millimet [15], decentralized systems that give sub-state entities more authority and unfavorable local circumstances force nations to make concessions on environmental quality. Similarly, Sigman [16] discovered that rising FD causes environmental quality to decline due to free-riding behavior amongst jurisdictions. Fell and Kaffine [17] argued that decentralization approaches cannot assist in resolving environmental issues. Yang et al. [18] evaluated the effect of FD on CO_2 emissions in provinces of China between 2005 and 2016 using the SDM approach. The authors concluded that carbon emissions rose in the localities they analyzed as FD grew. This is explained by local governments' degree of financial autonomy, which is reflected in the FD process. Local governments will be more financially independent and less likely to change their policies in response to incentives from the federal government as the FD degree increases. Economic growth is the primary factor considered when assessing the work of public servants, particularly in China. Therefore, rather than managing environmental quality, local officials frequently invest available budget funds and resources in the local economy in order to be promoted.

2.2 Green innovation and sustainable development

In recent years, environmental degradation has become a global concern. To address this issue and achieve SD goals, green innovation has emerged as an important catalyst and an effective strategy many countries are adopting. Green innovation, in contrast to traditional innovation, seeks to minimize negative output effects, replace hazardous inputs, enhance resource efficiency, and improve environmental quality [19]. Green innovation helps to decrease environmental risks, pollution, and other negative effects of energy use without undermining economic efficiency [20]. Many scientists have drawn important conclusions about the linkage between green innovation and sustainability. Using different samples, methods, and techniques, these studies also have various results on the correlation between green innovation and environmental quality – one of the three pillars of SD in particular and the connection between green innovation and SD in general.

Brandão Santana et al. [21] studied the correlation between technological innovation and SD during the period 2000 – 2007 (for 8 BRICS countries) and 1996 – 2008 (for G7 countries). Using "investment in research and development" to represent "technological innovation," the study showed that innovation is important for the three pillars of SD in BRICS but only for social development in G7 countries. This finding suggests that the effects of technical innovation vary according to the degree of development of the nation or area being studied.

Applying panel data regression techniques to 71 countries in the world during the period 1992-2012, Du and Li [22] found evidence that green innovation improves environmental quality by promoting technological progress. However, the results are slightly different when considering each group of countries by income. Specifically, the regression results by each group of countries show that green innovation can only be effective for developed countries, while for developing countries, the effect is insignificant. This is explained by the fact that low-income countries often pay more attention to improving living standards, and therefore, green innovation will be less widely applied due to high costs. Another explanation is that technological functions are often closely related and complementary across sectors. Thus, green technologies can only be commonly adopted in high-income economies with additional support from other innovations. This result is consistent with Du et al. [3] but contrary to Chang et al. [23], who studied China – a developing country. Applying the SDM to data from 30 provinces, this study shows that green innovation can improve environmental quality when there is a moderating role of environmental regulations from the government. This result shows the importance of the state in issuing appropriate laws and regulations to achieve SD goals.

Using the number of environmental patents as a variable of green innovation, Többelmann and Wendler [24] explored the connection between green innovation and carbon emissions in 27 (EU) countries. The GMM regression results confirmed that green innovation contributes to lowering carbon emissions. The study also emphasized that only green innovation brings about this reduction effect. In contrast, innovation in general (measured by the total number of patents) is unrelated to emission reduction. Consistent with the results of Du and Li [22], Többelmann and Wendler [24] also argued that green innovation contributes more strongly to emission reduction in more developed economies than in less developed countries.

Unlike previous studies that often use CO_2 emissions to measure environmental quality or sustainability, Koseoglu et al. [25] used "ecological footprint" – a comprehensive environmental sustainability index. In the top 20 green innovation nations, the authors looked into the connection between ecological footprint and green innovation. The findings indicated that while urbanization has no statistically significant effect on environmental degradation, economic expansion is its primary cause. The ecological footprint is moderately affected by the use of renewable energy. More critically, the ecological footprint is statistically significantly impacted by environmental technologies. In particular, there will be a 0.129% reduction in the ecological footprint for every 1% growth in environmental technologies. The study's conclusions showed that encouraging nations to support green innovation can lead to economic growth and environmental protection.

Chien et al. [26] explored the impact of eco-innovation on SD in ASEAN countries, using greenhouse gas (GHG) emissions to measure SD. The results obtained from the ARDL model demonstrate that eco-innovation contributes to SD in the studied countries by reducing GHG emissions. The research also found that other factors contributing to SD are financial development, trade openness, green energy use, public governance, and industrialization. Recently, Chien [27] applied the ARDL model to analyze the impact of green innovation on SD in China. Using the Human Development Index as a variable for SD, the study confirmed the importance of green innovation for China's SD from 1991 to 2020. Moreover, findings implied that SD is also driven by green investment, research and development expenditure, and financial inclusion.

2.3 The role of green innovation in the linkage between fiscal decentralization and sustainable development

In addition to their independent effects on SD, green innovation and FD are closely related. According to the Public goods theory, public goods such as clean air or renewable energy are characterized by non-rivalry and non-excludability. They are often underprovided in a market-based system. Green innovaation focuses on developing technologies and policies to provide these public goods. At the same time, FD allows local governments to allocate financial resources to suitable projects, ensuring the optimal provision of public goods tailored to local needs. Public choice theory explains how individuals and organizations make public financial decisions, often prioritizing policies that benefit the community. FD enhances flexibility for local governments to implement green innovaation, enabling them to quickly respond to specific community needs, reduce policy failures at the central level, and increase public participation in environmental protection efforts. Thus, FD contributes to creating favorable conditions for green ennovation to promote SD.

Therefore, in addition to studies on the independent effects of FD and green innovation on SD, some studies have examined the indirect effects of green innovation on the relationship between FD and SD. The research results are still inconsistent. A typical example is Satrovic et al. [28], conducted in 9 countries in the EU with a data set from 1995 to 2018. Utilizing the MMQR model, the regression results confirmed that green innovation directly impacts reducing environmental degradation. At the same time, FD promotes environmental degradation in the studied countries.

Regarding indirect effects, green innovation reduces the negative relationship between FD and environmental degradation. These findings implied that EU member states should empower municipalities to reduce pollution through climate change mitigation technology innovation to strengthen SDG 12. In addition, Yi et al. [29] argued that FD drives green innovation at local levels, thus encouraging local levels to decentralize further to promote green innovation, contributing to sustainable growth.

Li and Xu [4] investigated the moderating role of green innovation on the connection between FD and SD of China's green economy by utilizing the interaction term between FD and green innovation. The study, which used information from thirty provinces, municipalities, and autonomous regions, discovered that FD hinders the growth of China's green economy and that green innovation exacerbates this detrimental effect.

Using the cross-provincial panel data of China from 2007 to 2017, Pan et al. [30] examined the connection between eco-efficiency and green innovation using the spatial Durbin model, with FD being considered a moderating component. The findings demonstrated that green innovation greatly enhanced environmental sustainability and eco-efficiency in the locations under study. FD, in particular, contributed positively to promoting this beneficial effect. These results suggest that China should support the cooperation between institutions and green innovation to increase eco-efficiency.

It can be seen that there are quite a few studies examining the impact of FD on SD within a country or a group of countries. However, these studies show conflicting conclusions. We found some research gaps as follows through a review of studies on this topic. First, many papers examine the impact of FD on SD using many different approaches, but the results found are not consistent. In addition, most studies on the impact of FD and green innovation on SD mainly focus on the aspect of environmental sustainability, using variables such as CO_2 emissions, GHG emissions, or ecological footprint to represent environmental sustainability.

Meanwhile, SD needs to be considered comprehensively, including three closely related pillars: social sustainability, environmental sustainability and economic sustainability. However, the review shows that there are very few studies that consider sustainability research from a comprehensive synthesis perspective of all three pillars. In addition, the studies reviewed above show that most previous studies mainly focus on the direct impact of FD and green innovation on SD. Empirical evidence on the moderating role of green innovation on the correlation between FD and SD is still very rare. Research on the moderating role of green innovation is important in proposing appropriate policy implications on FD and SD. Therefore, this study expects to fill the above gaps by using Bayesian regression to study the moderating role of green innovation on the linkage between FD and SD in 33 countries during the period 2010 – 2022. In this study, SD is approached using the United Nations Sustainable Development Goals Index (SGD Index) - an index measuring the performance of 17 SD indicators and related goals, covering many economic, social and environmental aspects, reflecting the integrated nature of SD.

3. METHODOLOGY

3.1 Research model and variables

Based on Hui and Martinez-Vazquez [1], Li and Xu [4], and Hoang et al. [31], this study suggests the model (1) of the impact of FD and green innovation on SD as follows:

$$SDGI_{i,t} = \beta_i + \beta_1 FD_{i,t} + \beta_2 GI_{i,t} + \beta_3 Z_{i,t} + \varepsilon_{i,t} \quad (1)$$

To examine the moderating role of green innovation in the linkage between FD and SD, the study uses the interaction variable FD×GI in the model (2):

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

where, i =1, 2, 3,…, N denotes the country and t = 1, 2, …, T is the year.

Dependent variable:

Sustainable Development (SDGI): To measure the SD of countries, this article uses the Sustainable Development Goals Index (SGD Index) calculated by the United Nations and published in the annual Sustainable Development Report. SDGI is also used in Oanh [32] and Dinh et al. [33].

Independent variable:

Fiscal decentralization (FD): Based on the studies of Yang et al. [18], Hui and Martinez-Vazquez [1], the paper uses the proportion of local expenditure in total government expenditure to measure the degree of FD of countries.

Green innovation (GI): This study uses the ratio of environmental technology patents to total technology patents (%) to represent green innovation. This variable is used in many previous papers such as Du et al. [3], Li and Xu [4], and Udeagha and Muchapondwa [5].

Control variables:

Based on Kuai et al. [6], Yang et al. [18], Yang et al. [9], and Hui and Martinez-Vazquez [1], we propose control variables as follows:

Economic growth (GDP): The Environmental Kuznets Curve (EKC) theory shows that economic growth has an impact on environmental quality – one of the three pillars of SD. Empirical studies by Kuai et al. [6], Chen and Liu [8], Yang et al. [9], Lingyan et al. [34], and Wang et al. [35] also confirm the impact of economic growth on SD.

Trade openness (TO): According to Grossman and Krueger [36], trade openness has both positive and negative impacts on environmental quality. Trade openness helps reduce conflicts between countries, thereby increasing the scale of production and possibly increasing CO_2 emissions into the environment. However, it is a factor that promotes technology transfer from advanced countries to developing ones. Countries importing technology can increase energy efficiency, reduce environmental degradation, and promote SD.

Foreign Direct Investment (FDI): FDI has both positive and negative impacts on SD [37, 38]. It helps reduce the burden on governments to invest in climate change mitigation projects and adopt greener business practices [37]. Multinational corporations engaging in FDI often transfer advanced technologies and management practices to the host country. This can facilitate innovation, skills development, and industrial upgrading, contributing to long-term sustainable development.

Government size (SIZE): Bodman [39] argues that fiscal decentralization is constrained by the fiscal capacity of the government. If FD reduces the size of the public sector and negatively affects the relationship between public sector size and SD, the estimated results will be biased. With the results found from the studies of Hui and Martinez-Vazquez [1] and Jin and Jakovljevic [40], the paper expects to find evidence of a positive impact of government size on SD.

Urbanization (URBAN): Urbanization is believed to lead to increased resource consumption, pollution, and habitat destruction, leading to environmental unsustainability [24]. However, as regional growth centers, urban areas have strong agglomeration effects and can benefit from scale effects in energy use, which can reduce CO_2 emissions [3].

All variables in the research models are detailed in Table 1.

Table 1. Variables description

Sign	Variable	Description	Source	Study
		Dependent variable		
SDGI	Sustainable Development	SDG Index	Sustainable Development Report	[29, 30]
		Independent variable		
FD	Fiscal decentralization	Local spending/total government spending ratio (%)	IMF, OECD	[1, 9, 17, 38]
GI	Green innovation	Environmental technology patents/ total technology patents ratio (%)	OECD	[3-5, 22]
		Control variable		
FDI	Foreign Direct Investment	Foreign direct investment, net inflows (% of GDP)	World Bank	[8, 9, 22]
GDP	Economic Growth	GDP per capita in terms of logarithm	World Bank	[6, 8, 9, 20, 32]

SIZE	Government size	Government revenue (% of GDP)	World Bank	[1, 37]
TO	Trade Openness	The sum of exports and imports of goods and services (% of GDP)	World Bank	[1, 4, 17, 20, 22, 37]
URBAN	Urbanization rate	Urban population (% of total population)	World Bank	[4, 8, 9, 17, 22]

3.2 Data and methodology

This paper takes a Bayesian statistical technique, in contrast to earlier research on FD and SD, which frequently used the frequency econometric method. To overcome the drawback of small sample sizes in studies, the Bayesian method combines research data with prior knowledge to calculate the posterior distribution. The outcomes are explained as the probability distribution of parameter values, regardless of sample size [41, 42]. The model parameters are supposed to be random in the Bayesian technique, while the observed data sample remains fixed. The observed sample and the parameter's prior distribution will be used to estimate the parameters' posterior distribution, which will then be used to interpret the findings. A data set's sampling distribution or statistical characteristics serve as a basis for the interpretation. That is to say, the distribution of the conditional parameter of the observed samples provides the basis for the response provided by Bayesian analysis. The three steps of Bayesian regression are as follows. First, we make an a priori assumption about the normally distributed coefficients, assuming each has a mean of zero. An a priori specification like this suggests that the coefficients from the Bayesian analysis are more likely to be near zero than nonzero. Most significantly, neither a positive nor negative bias is introduced into the Bayesian analysis outcomes of the research hypotheses by the study. Second, for the relevant likelihood functions of the coefficients, the study assumes normal distributions with parameters derived from equations (1) and (2). Finally, the study uses Gibbs Sampling and Markov Chain Monte Carlo (MCMC) techniques to estimate and simulate 12,500 times from the data in order to obtain the associated posterior distributions of the coefficients. The study will, as usual, eliminate the first 2,500 instances. In many different domains, the MCMC technique is widely employed to fit complex models [43].

The author conducts research from 2010 to 2022, including 33 countries. Thus, each country has only 13 observations. With such a small sample, the Bayesian approach is appropriate. Moreover, this approach does not take into account autocorrelation, heteroscedasticity, and endogeneity.

Because of the data limitation, specifically related to the FD variable, the study uses balanced panel data from 33 countries (Appendix 1) from 2010 to 2022.

4. RESULTS AND DISCUSSION

4.1 Descriptive statistics

The variables in the research model are described in Table 2. The Sustainable Development Goals Index (SDGI) for 33 nations between 2010 and 2022 had an average value of 4.32; Finland (2022) had the highest value at 4.46, and South Africa (2010) had the lowest. The fiscal decentralization (FD) average for the nations was 34.68%. Vietnam had the highest degree of decentralization of all, at a rate of 82.51%, in 2018. On the other hand, with a decentralization rate of just 3%, Turkey had the lowest level of FD in 2019. Between 2010 and 2022, the average green innovation rate for all countries was 12.46%; Denmark had the highest rate at 26.62%, while Columbia had the lowest at 5.04%.

Table 2. Descriptive statistics

Variable	Obs	Mean	Std. dev.	Min	Max
SDGI	429	4.322938	0.078472	4.09722	4.463152
FD	429	0.34677	0.159986	0.03	0.8251
GI	429	0.12463	0.037506	0.050411	0.266156
GDP	429	9.978465	0.996672	7.395115	11.59394
FDI	429	0.031594	0.090509	-0.40086	1.065735
URBAN	429	0.758622	0.135277	0.30417	0.98153
TO	429	0.791892	0.380984	0.233927	1.930922
SIZE	429	0.362329	0.113015	0.124613	0.638626

4.2 Results and discussion

Table 3 details the effects of FD and green innovation on SD in 33 countries from 2010 to 2022. Table 4 displays the probabilities of these effects. The model is deemed to comply with the standards, as evidenced by its average acceptance rate of 0.8254 and minimum efficiency (Avg efficiency: min) of 0.1806, surpassing the permissible level of 0.01. Furthermore, every parameter's Monte-Carlo Standard Error (MCSE) is very small. Flegal et al. [44] stated that the MCMC is more stable when its MCSE value is closer to 0. It is okay for the MCSE to be less than 6.5% of the standard deviation, and less than 5% is ideal. Therefore, findings in Table 3 indicate that the MCSE values meet the optimal level.

One of the most important tests of the Bayesian method is to test the convergence of the MCMC chain. To determine the convergence of the Bayesian simulation, this study uses graphical and visual convergence diagnosis, which is performed through the trace plot that tracks the regression values of the parameters over the simulations. Figure 1 shows that the regression coefficients in the trace plot fluctuate around the mean value, which means that the MCMC chain is stationary. The autocorrelation plot decreases rapidly after 20 lags, which reflects the agreement with the simulation density and the lag is within the effective limit. Balov [45] asserts that if the posterior distribution histogram and the probability density estimate histogram have a normal distribution shape, it can be concluded that the Bayesian inference is robust. Thus, all the simulations' graphs are satisfactory for the MCMC chain in the models to converge.

Findings in Table 3 and Table 4 indicate that FD negatively impacts sustainable development (SDGI) with 100% probability. This result is supported by the "race to the bottom" hypothesis in Tiebout's fiscal decentralization theory. As the degree of FD increases, the degree of independence in fiscal spending of local governments will increase. Local governments compete to attract investment, businesses, and citizens. This competition can lead to declining spending policies and standards as localities seek to minimize costs and maximize their attractiveness to taxpayers and businesses. Local governments may also reduce public spending on essential services such as education, health, infrastructure, and social welfare programs to reduce taxes or maintain a budget surplus. These cuts in public services can negatively affect the jurisdiction's quality of life, social welfare, and economic development. In addition, public choice theory suggests that decentralized fiscal systems can lead to rent-seeking behavior, in which local officials and interest groups lobby for preferential treatment or access to public funds. This can lead to inefficient resource allocation as funds may be directed towards projects of narrow benefit rather than promoting SD goals. This result is consistent with the findings of Millimet [15], Sigman [16], Fell and Kaffine [17], Yang et al. [18], Chen and Liu [8], and Yang et al. [9].

Table 3. The impacts of fiscal decentralization and green innovation on sustainable development

SDGI	Mean	Std. dev.	MCSE	Median	Equal-tailed [95% cred. interval]	
FD	-0.05566	0.013015	0.00013	-0.05571	-0.08122	-0.03005
GI	0.367548	0.053651	0.000537	0.367944	0.263524	0.471668
GDP	0.047588	0.003383	0.000034	0.047596	0.040985	0.054263
FDI	-0.00913	0.022092	0.000221	-0.00928	-0.05237	0.034212
URBAN	-0.07526	0.021804	0.000218	-0.0751	-0.11831	-0.0333
TO	0.039475	0.005601	0.000056	0.039494	0.028313	0.050567
SIZE	0.255586	0.024062	0.000241	0.255467	0.207711	0.301911
_cons	3.755089	0.023744	0.000242	3.755276	3.708853	3.801545
Avg acceptance rate	0.8101					
Avg efficiency: min	0.0669					

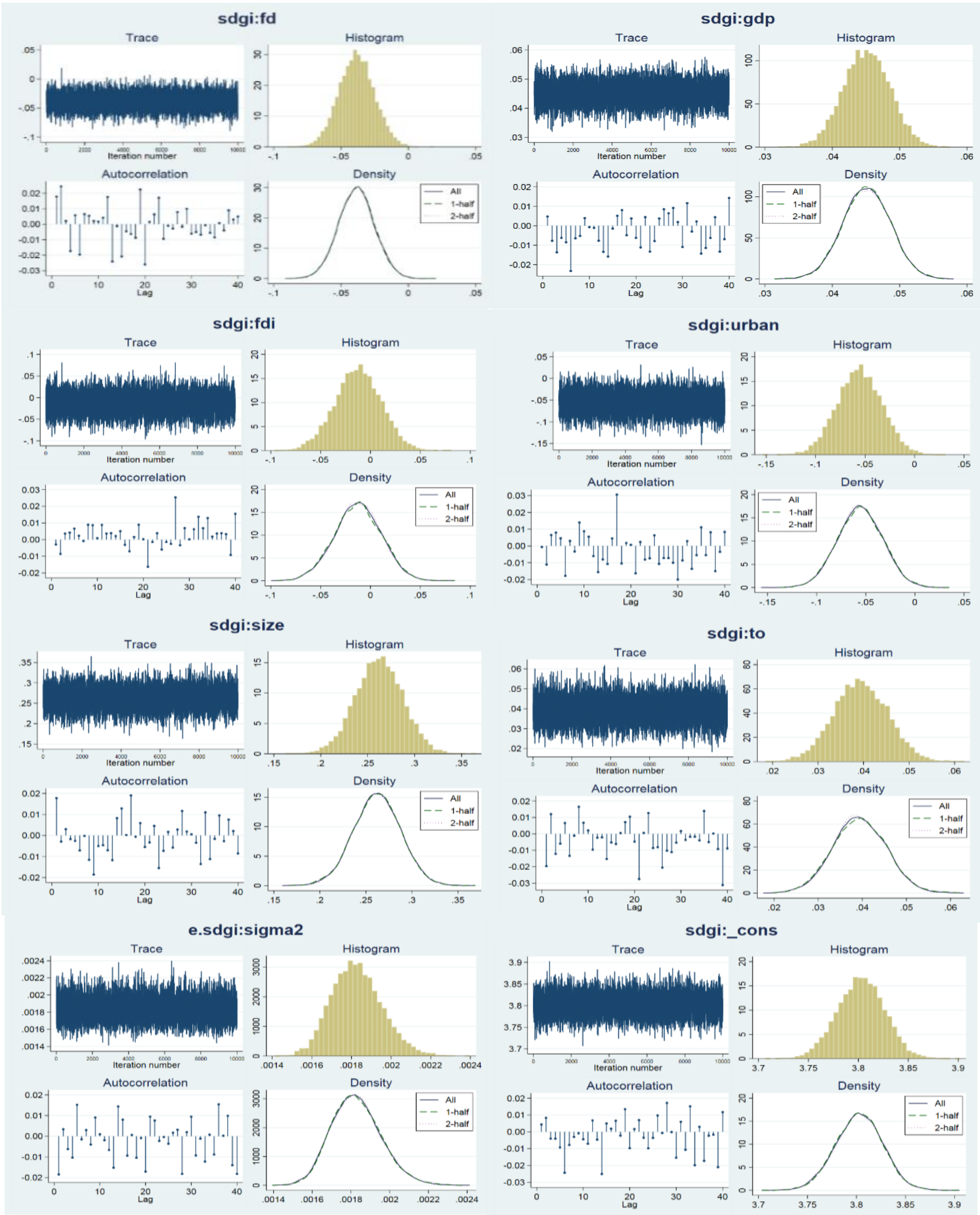

Figure 1. Convergence test results

In addition, the research results show that green innovation promotes SD in the studied countries with a probability of 100%. According to the classical growth theory of Solow and the Green Solow Model of Taylor and Brock (2004), green innovation represents a form of technological progress that focuses on developing environmentally sustainable solutions. By focusing more on research and development (R&D) to create cleaner technologies, improve energy efficiency, and reduce environmental impacts, economies can increase productivity and sustainable growth while minimizing negative environmental impacts. By promoting green innovation, economies can achieve higher productivity levels while promoting environmental sustainability and resilience. This outcome is also supported by the endogenous growth theory and the empirical results of Töbelmann and Wendler [24], Koseoglu et al. [25], and Chien et al. [26].

Table 4. Probabilities of model (1)

Variable	Mean	Std. Dev.	MCSE
Prob{SDGI:FD} < 0	1.0000	0.0000	0.0000
Prob{SDGI:GI} > 0	1.0000	0.0000	0.0000
Prob{SDGI:GDP} > 0	1.0000	0.0000	0.0000
Prob{SDGI:FDI} < 0	0.6595	0.4739	0.0047
Prob{SDGI:URBAN} < 0	0.9993	0.0265	0.0003
Prob{SDGI:TO} > 0	1.0000	0.0000	0.0000
Prob{SDGI:SIZE} > 0	1.0000	0.0000	0.0000

Findings also suggest that GDP growth positively impacts SD with a probability of 100%. This result aligns with the Environmental Kuznets Curve Theory as well as the empirical results of Kuai et al. [6], Chen and Liu [8], Yang et al. [9], Lingyan et al. [34], and Wang et al. [35]. Economic growth promotes innovation and technological progress, leading to the development of greener technologies and practices that reduce resource consumption, pollution, and environmental degradation; create employment opportunities, increase income and reduce poverty, contributing to improving living standards and social welfare; create the political will and institutional capacity needed to enact and enforce environmental regulations, standards, and policies to reduce environmental risks, protect natural resources and promote sustainable management practices.

Foreign direct investment reduces SD with a probability of 65.95%. This result supports the "pollution haven" proposition. FDI projects, especially in industries with high pollution levels or generating hazardous waste, can pose risks to human health and the environment. Pollution from industrial activities, including air pollution, water pollution, and hazardous waste disposal, can adversely impact local public health, affecting respiratory health, water quality, and food safety and undermining SD outcomes. This result is supported by Farooq et al. [46] and Nawaz et al. [47].

High levels of urbanization are also a factor that reduces SD, with a probability of 99.93%. Urbanization is believed to increase resource consumption, pollution, and habitat destruction, leading to environmental unsustainability [24].

Trade openness promotes SD with an absolute probability of 100%. Grossman and Krueger [36] argued that trade liberalization is a factor that helps encourage technology transfer from advanced, developed countries to underdeveloped, backward economies. From there, countries importing technology can increase energy efficiency, reduce environmental degradation, and promote SD. Du et al. [3] and Jin and Jakovljevic [40] also found similar results in their study.

The results also showed that government size positively affects SD with a probability of 100%. Larger government size allows for increased public investment in infrastructure, including transportation, energy, healthcare facilities, education, and social services. Well-planned and well-funded infrastructure projects can promote SD by improving access to essential services, increasing productivity, and supporting economic growth and social inclusion. Larger governments will have greater capacity and resources to implement environmental regulations, standards, and policies to protect natural resources, reduce pollution, and mitigate climate change. This result aligns with the empirical studies of Hui and Martinez-Vazquez [1] and Jin and Jakovljevic [40].

To investigate the role of green innovation in the linkage between FD and SD, the research used the interaction variable FDxGI. It continued to use Bayesian regression for analysis. The results of regression coefficients and impact probabilities are presented in Tables 5 and 6 below.

Table 5 shows that the coefficient of FDxGI is positive, implying that FD combined with green innovation reduces the negative impact of FD on SD and promotes the SD of countries. The probability of this impact is 100%. Countries should decentralize more fiscal spending to local governments towards green innovation activities to minimize environmental negative impacts and promote SD [28]. On the contrary, FD is a factor that supports green innovation at the local level, thus encouraging countries to decentralize further to promote green innovation, contributing to sustainable growth [29].

Table 5. Results of the moderating role of green innovation in the linkage between fiscal decentralization and sustainable development

SDGI	Mean	Std. dev.	MCSE	Median	Equal-tailed [95% cred. interval]	
FD	-0.13137	0.023382	0.000246	-0.13129	-0.17764	-0.08569
FDxGI	0.647916	0.133566	0.001371	0.645946	0.381094	0.908665
GDP	0.047938	0.003519	0.000035	0.047935	0.041051	0.054884
FDI	-0.01057	0.022609	0.000226	-0.01056	-0.05501	0.033776
URBAN	-0.07034	0.022189	0.000222	-0.07027	-0.11362	-0.02698
TO	0.039462	0.005719	0.000057	0.039501	0.028203	0.050532
SIZE	0.239918	0.025018	0.00025	0.239955	0.189963	0.288527
_cons	3.797009	0.023469	0.000235	3.796932	3.751295	3.842674
Avg. acceptance rate	0.8916					
Avg. efficiency: min	0.0604					

Table 6. Probabilities of model (2)

Variable	Mean	Std. Dev.	MCSE
Prob{SDGI:FD} < 0	1.0000	0.0000	0.0000
Prob{SDGI:FDxGI} > 0	1.0000	0.0000	0.0000
Prob{SDGI:GDP} > 0	1.0000	0.0000	0.0000
Prob{SDGI:FDI} < 0	0.6812	0.4660	0.0047
Prob{SDGI:URBAN} < 0	0.9994	0.0245	0.0002
Prob{SDGI:TO} > 0	1.0000	0.0000	0.0000
Prob{SDGI:SIZE} > 0	1.0000	0.0000	0.0000

Table 7. The impacts of fiscal decentralization and green innovation on sustainable development measured by HDI

HDI	Mean	Std. dev.	MCSE	Median	Equal-tailed [95% cred. interval]	
FD	-0.03989	0.00823	0.00008	-0.03987	-0.05610	-0.02377
GI	0.03455	0.03303	0.00033	0.03430	-0.02919	0.09971
GDP	0.07163	0.00204	0.00002	0.07165	0.06756	0.07562
FDI	-0.01344	0.01332	0.00013	-0.01337	-0.03916	0.01229
URBAN	0.04659	0.01329	0.00013	0.04655	0.02096	0.07285
TO	0.01990	0.00346	0.00004	0.01990	0.01312	0.02667
SIZE	0.04545	0.01469	0.00015	0.04545	0.01639	0.07440
_cons	0.08629	0.01517	0.00015	0.08616	0.05679	0.11597
Avg acceptance rate	0.9175					
Avg efficiency: min	0.1748					

Table 8. Results of the moderating role of green innovation in the linkage between fiscal decentralization and sustainable development (measured by HDI)

SDGI	Mean	Std. dev.	MCSE	Median	Equal-tailed [95% cred. interval]	
FD	-0.04327	0.01423	0.00014	-0.04305	-0.07082	-0.01580
FDxGI	0.03189	0.07971	0.00080	0.03048	-0.12550	0.19070
GDP	0.07146	0.00207	0.00002	0.07145	0.06745	0.07558
FDI	-0.01350	0.01335	0.00014	-0.01340	-0.03981	0.01248
URBAN	0.04791	0.01324	0.00014	0.04780	0.02198	0.07415
TO	0.01982	0.00343	0.00003	0.01980	0.01310	0.02655
SIZE	0.04498	0.01504	0.00015	0.04483	0.01579	0.07461
_cons	0.09138	0.01448	0.00015	0.09141	0.06304	0.12006
Avg. acceptance rate	0.8964					
Avg. efficiency: min	0.0629					

4.3 Robustness check

To test the robustness of the research models, the paper used the Human Development Index (HDI) variable to represent the level of sustainable development of countries. HDI is a composite statistical measure developed by the United Nations Development Program (UNDP) to assess and compare people's overall well-being and living standards in different countries. It combines many indicators of three main aspects of human development including health, education, and income. The findings are summarized in Table 7 and Table 8. It can be seen that the results do not change the direction of the impact of the independent variables on the dependent variable: FD negatively affects SD, green innovation promotes SD and weakens the negative impact of FD and SD. These outcomes prove that the models proposed in this study ensure robustness and reliable results.

5. CONCLUSION AND POLICY IMPLICATIONS

Applying Bayesian regression to data from 33 countries over the period 2010-2022, the study found that green innovation directly promotes SD and plays a moderating role in reducing the negative impact of FD on SD. Promoting decentralization of spending on green innovation activities and initiatives helps minimize negative environmental impacts and promote SD. In contrast, FD incentivizes local governments to promote green innovation, thereby encouraging countries to decentralize further to promote green innovation, contributing to SD. Factors such as economic growth, trade liberalization and government size also promote SD in countries. Therefore, to achieve SD goals, countries need to have solutions to balance FD with green innovation initiatives, such as strengthening local financial capacity through reasonable budget allocation, building a green financial support system, and improving financial management skills for local officials. In addition, countries need to build a supportive legal and policy framework by issuing policies to encourage green innovation, setting national sustainability standards, and strengthening supervision to ensure efficient use of resources. Countries need to increase trade liberalization because developing countries will transfer advanced technology from developed countries, thereby increasing energy efficiency, reducing pollution, and increasing environmental and economic sustainability. In addition, attracting FDI capital needs to be cautious; there needs to be a balance between financial and SD goals.

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NOMENCLATURE

FD	Fiscal Decentralization
FDI	Foreign direct investment
GHG	Greenhouse gas
MCMC	Markov Chain Monte Carlo
MCSE	Monte-Carlo Standard Error
MMQR	Method of the Moments Quantile Regression
SD	Sustainable Development
SDGs	Sustainable Development Goals
SDM	Spatial Durbin Model
SGD Index	Sustainable Development Goals Index

APPENDIX

Table A1. List of countries

Australia	Colombia	United Kingdom	Korea, Rep.	Portugal	United States
Belgium	Germany	Hungary	Mexico	Russian Federation	Vietnam
Canada	Denmark	Indonesia	Netherlands	Sweden	South Africa
Switzerland	Spain	Israel	Norway	Thailand	
Chile	Finland	Italy	Peru	Türkiye	
China	France	Japan	Poland	Ukraine	