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By Tang, Muhammad

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Entrepreneurship, Leadership, and Innovation as Catalysts for Green Economic Growth: Evidence from 85 Countries

Chor Foon Tang *[a] and Atif Muhammad[a]

[a] *Centre for Policy Research, Universiti Sains Malaysia, 11800 USM, Penang, MALAYSIA*

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This study attempts to empirically explore factors that influence green economic growth using unbalanced panel data from 2011 to 2020 across 85 countries. Unlike existing literature, our research takes a comprehensive approach by exploring various determinants of green economic growth, particularly the roles played by private enterprises (entrepreneurship), national leadership, technological innovations, and other factors in promoting green economic growth. We employ the dynamic panel system generalised method of moments (GMM) estimator to estimate the relationship between these factors and green economic growth. Our estimated findings show that countries with higher levels of technological innovation, national leadership quality, education, and renewable energy consumption are more likely to promote green economic growth. On the contrary, we find that entrepreneurship can be detrimental to green economic growth. This is primarily because private enterprises are likely to focus on profit, thus prioritising financial revenue over environmental issues. This situation highlights the need for targeted policies that align the activities of private enterprises with sustainable development goals (SDGs). To accelerate the transition toward green economy, policymakers should emphasise the importance of national leadership quality, education, technological advancement, and effective regulatory measures for private enterprises.

Keywords: Education, Entrepreneurship, Green growth, National leadership, Technological innovation

*Corresponding authors: tcfoon@usm.my / tcfoon@gmail.com

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1 Introduction

In recent decades, the discourse on sustainability has evolved significantly, emphasising the imperative of achieving green economic growth. Green growth is closely linked to a green economy, which aims to substantially reduce ecological scarcity and environmental dangers while promoting social equity and human well-being (United Nations, 2012). This shift toward a green economy is a global recognition of the need to harmonise economic development with environmental stewardship and resilience. Moreover, this concept has gained momentum in international policy circles as a catalyst for development by driving the transition of resources towards low-carbon and sustainable economic growth (Schmalensee, 2012).

By 2012, the United Nations (UN) strongly supported green economy initiatives, emphasising sustainable development and poverty reduction. The official declaration of the UN conference under the theme of "The Future We Want" listed green growth as one of several tools for sustainable development (United Nations, 2012). According to the Organisation for Economic Co-operation and Development (OECD), green growth promotes economic expansion while ensuring that natural resources and environmental services continue contributing to wealth (OECD, 2011b). Green growth prioritises investments and innovations to foster sustainable development and create new economic opportunities (Reilly, 2012). The focus is on low-cost methods to reduce environmental stress and protect the environment from surpassing critical thresholds. As such, the national green strategies to promote eco-friendly businesses, reallocate labour, capital, and technology towards environmentally friendly operations, and encourage eco-innovations are supported (OECD, 2011a; Kijek and Kasztelan, 2013).

However, the momentum towards a green economy faced setbacks at the Rio+20 Summit, where civil society labelled it "The New Enemy" with no clear direction for achieving it (Utting, 2012). Despite global efforts to push for sustainable development, progress varies across countries. For instance, Australia and Belgium rapidly adopt green growth, while Portugal and Turkey lag behind (OECD, 2020). Shahbaz et al. (2013) argued that economic expansion is the fundamental cause of environmental pollution. Chen et al. (2019) further asserts that rapid economic expansion drives urbanisation, attracting a large population and resulting in increased energy consumption and higher CO_2 emissions. Consequently, the transition to green growth faces a trade-off challenge: either sacrificing the environment for economic growth and development or vice versa, particularly during the developing stage (Liang et al., 2019; Yang and Song, 2019; Cai et al., 2018; Wu et al., 2018; Liu and Wang, 2017).

Motivated by these challenges, a large group of applied researchers attempted to contribute to the green economy literature by either exploring factors that could potentially uplift green growth or mitigate CO_2 emissions and ecological footprints (e.g., Ansari et al., 2022; Chu, 2022; Maiti, 2022; Li et al., 2022; Tawiah et al., 2021; Tang et al., 2021). Moreover, a strand of literature applied Solow's version of the green growth model to understand the behaviour of CO_2 emissions (e.g., Bassetti et al., 2024; Brock and Taylor, 2010). Instead of analysing green growth, a strand of literature cleverly focused on renewable energy and technological innovations as they believe these factors are a "double-edged sword" that promotes economic growth while mitigating environmental degradation (e.g. Elmassah, 2024; Lee and Tang, 2022; Chen et al., 2021). Although numerous studies have contributed to developing a green economy, little research has paid special attention to the role of leadership, entrepreneurship, and technological innovations in materialising a green economy.

In this study, we hypothesise that the core of the green economy transition is closely associated with leadership, entrepreneurship, and technological innovation. Each plays a pivotal role across various sectors and scales to drive sustainable practices and outcomes. National leaders, for example, must formulate policies, direct national progress, and restructure institutions to enable growth catalysts for efficient role performance (Zolcsák, 2015; Jones and Olken, 2005). As such, both leadership and entrepreneurship stand as cornerstones in advancing green economic growth by influencing innovation, organisation, community, and national strategies towards sustainability. Sarros and Santora (2001) highlighted that effective leadership qualities such as honesty, integrity, respect, and trust are crucial for establishing long-term credibility and fostering respect within sustainability efforts. Leaders who embody these qualities serve as role models, inspiring others to embrace environmental stewardship and adopt sustainable practices. Bennis and Goldsmith (2010) added that organisations require clear direction from their leaders to navigate the complexities of sustainability challenges. This clarity enables stakeholders to align their efforts and resources towards achieving environmental goals.

Furthermore, technological innovations in renewable energy, agriculture, and industrial processes are crucial in reducing carbon footprints and promoting sustainable development (Sagar and Chandra, 2004; Lal, 2011). Zhou et al. (2010) emphasised that technological innovation reduces greenhouse gas emissions and enhances overall energy efficiency across industries. Therefore, technological innovation plays a pivotal role in developing industrial evolution to address both production-based and demand-based emissions (Yao et al., 2018). Given these compelling arguments, we aim to enrich the green economy literature by critically investigating the impact of national leadership, entrepreneurship, and technological innovation on green economic performance. This study utilises an unbalanced panel dataset of 85 countries from 2011 to 2020. Additionally, the dynamic panel system generalised method of moments (GMM) estimator is used to estimate our green economic growth model. Since the progress of the green economy may vary across different stages of economic development, as hypothesised in the Environmental Kuznets Curve (EKC), we extend our analysis to developed and developing countries. This initiative enhances robustness and provides more insightful findings for policymaking.

The balance of this study will be organised as follows. The next section discusses the empirical model, data and econometric estimation strategies. Section 3 presents and discusses the findings of the present study. Finally, the conclusion and policy recommendations will be presented in Section 4.

2 Review of Past Studies

2.1 National leadership and green growth

Achieving green economic growth—targeting poverty alleviation, environmental preservation, and sustainable economic advancement—has become central to modern economic policies. The green economy framework addresses major global challenges such as climate change, resource depletion, and ecological degradation. Specifically, climate change introduces challenges like biodiversity loss, rising sea levels, and extreme weather patterns, highlighting the urgency of transitioning to green economies that mitigate greenhouse gas emissions and foster sustainable resource management (UNEP, 2011). Unlike traditional economic models, green growth advocates for efficient and sustainable resource use, minimising waste while innovating resource management to combat environmental degradation effectively.

National leadership plays a pivotal role in this transition. Effective leadership, which embodies integrity, accountability, and environmental responsibility, motivates societal and institutional shifts toward sustainable practices. Green and McCann (2011) note that leaders who prioritise environmental objectives can influence policies that support sustainable development goals (SDGs), align private sector incentives with ecological preservation, and promote societal values favouring sustainability. By embodying these principles, national leaders inspire both public and private sectors to integrate resilience into their development strategies, fostering an environment where investments, governance, and cooperation enhance green growth prospects.

Furthermore, good governance—characterised by transparency, democracy, and accountability—supports the green growth agenda by tackling environmental concerns directly. Democratic systems empower citizens to participate in policy formulation and encourage leaders to pursue environmentally responsible actions (Parker et al., 2015). Participatory governance allows a broader engagement of stakeholders, creating inclusive green policies that adapt to diverse environmental and economic needs (Saul and Seidel, 2011). Leaders modelling these democratic principles reinforce institutions and attract investment by fostering a trustworthy environment for sustainable economic activities, improving resilience against environmental and economic shocks.

Research further suggests that strong national leadership encourages cooperation among politicians, educators, and environmental advocacy groups to promote green economic objectives. Collaboration ensures that policymaking aligns with ecological sustainability and builds on the strengths of diverse stakeholders. Alam et al. (2013) highlight that stakeholder engagement and transparent, inclusive policy processes are essential for effective green growth strategies. By fostering public awareness and addressing stakeholder concerns, national leadership can enhance policy efficacy and mobilise resources for sustainable growth.

However, a lack of sound leadership often leads to challenges such as corruption, inefficient governance, and political instability, which undermine green economic goals. Corrupt practices and inadequate transparency dilute environmental regulations, hindering green progress and exacerbating ecological degradation. Therefore, promoting accountability and transparency is critical for green governance, as highlighted by studies emphasising the role of institutional quality in environmental sustainability (Tang et al., 2021). Strong leadership, anchored in democratic principles and institutional accountability, can effectively mitigate environmental risks while advancing economic resilience.

2.2 Technological innovation and green growth

Besides national leadership, our review of past studies shows that technological innovation is a cornerstone for green economic growth by providing tools to enhance resource efficiency and reduce environmental impact (Sohag et al., 2019; Popp, 2012). Technological advances facilitate "decoupling" economic expansion from environmental degradation by reducing dependency on fossil energy resources and minimising pollution. Clean technologies, such as renewable energy systems and waste-reducing industrial processes, help decrease carbon emissions while sustaining productivity (Danish et al., 2020). Shafik and Bandyopadhyay (1992) highlight that technological progress is vital in improving environmental quality through emissions reduction and resource conservation.

Moreover, technological innovation improves energy efficiency and supports the transition to renewable energy sources, a critical element in meeting global climate targets while sustaining economic growth. Investments in green technologies enable countries to reduce their carbon footprints and bolster productivity. Emerging green energy technologies, for instance, reshape energy markets and facilitate sustainable economic structures, particularly in sectors with high environmental impact (Ibrahim and Ajide, 2021; Chen et al., 2021). Studies show that integrating advanced, eco-friendly technologies promotes green growth and enhances competitiveness by lowering energy costs and resource dependence (Ji et al., 2021; Perez, 2016).

Furthermore, Nosheen et al. (2021) find that technological innovations in Eastern and Western Europe significantly enhance green growth by boosting production efficiency and reducing emissions. Similarly, Lin et al. (2024) report that in China, advancements in green technologies and economic complexity are central to the nation's sustainable economic transition. Such findings underscore the value of technological innovation in achieving green growth goals, as it offers tools to mitigate environmental challenges while facilitating economic progress.

2.3 Entrepreneurship and green growth

Entrepreneurship can also drive green economic growth by encouraging sustainable business practices and developing eco-friendly products and services (Youssef et al., 2018). Entrepreneurship aligns economic objectives with environmental priorities through innovation, job creation, and revenue generation. By adopting sustainable practices, entrepreneurs can introduce solutions that reduce environmental footprints, benefiting the economy and community welfare (Khezri and Muhamad, 2023). For example, Shepherd and Patzelt (2011) argue that entrepreneurial activity plays a crucial role in supporting environmental sustainability. Specifically, this can help preserve ecosystems, mitigate the effects of climate change, reduce environmental degradation and deforestation, enhance agricultural practices and water supply systems, and safeguard biodiversity. Reinforcing this perspective, evidence from developed countries reveals a more nuanced relationship between entrepreneurship and environmental outcomes. As nations progress toward higher levels of economic development, this relationship tends to shift. In particular, this often follows an inverted U-shaped pattern, whereby entrepreneurial activity initially contributes to environmental harm but eventually begins to reduce it as economies mature. This dynamic suggests that increased entrepreneurial activity does not inherently lead to greater environmental degradation. Rather, its environmental impact is shaped by the broader context of economic development and institutional maturity.

However, the environmental impact of entrepreneurship is complex. Although entrepreneurship can promote sustainable innovation, some past studies indicate that, without robust regulatory frameworks, it may contribute to environmental degradation, particularly in developing countries. Many start-ups face pressures to prioritise profit, leading to unsustainable practices and resource wastage (Philip et al., 2022; Venecio and Pinto, 2020). This tendency is particularly noticeable in countries with weaker institutional support, where start-ups may lack incentives to adopt sustainable practices, posing challenges to green growth (Omri and Afi, 2020; Omri, 2018). Therefore, a supportive regulatory environment is essential to align entrepreneurial activities with green economic goals, ensuring that entrepreneurship contributes positively to sustainability rather than undermining it.

Moreover, past empirical findings suggest that the relationship between entrepreneurship and environmental impact varies by economic context. For example, studies such as those by Riti et al. (2015) and Cohen and Winn (2007) reveal that entrepreneurial activities in some sectors may lead to environmental degradation, especially when profit motives outweigh sustainability concerns. Venecio and Pinto (2020) further illustrate that, in both developed and developing countries, non-innovative entrepreneurship can hinder Sustainable Development Goals (SDGs), especially in areas concerning social equity and environmental protection. These findings suggest the need for policies that incentivise sustainable entrepreneurship, enabling start-ups to contribute positively to green growth objectives. In contrast, earlier research highlights cases where green entrepreneurship positively influences environmental sustainability. Karabetyan and Sart (2024) demonstrate that entrepreneurial activities, education, and renewable energy usage can reduce ecological footprints in G20 economies. Similarly, Saqib and Usman (2023) find that green entrepreneurship, supported by technological innovation, has reduced carbon emissions over the long term in high-emission countries like the United States and China. These examples show that when aligned with green objectives, entrepreneurship can significantly drive sustainable economic practices. Achieving sustainable economic growth and meeting COP28 commitments, green finance operates both as an institutional model and as a structural part of the financial system (Zhang et al., 2022). By directing capital toward green projects, this drives exogenous green economic growth. These investments bring multiple benefits, helping create jobs, improve welfare, support green technologies, and reduce air pollution-related deaths (Xu et al., 2023).

According to Woode (2024), green finance enables growth by redistributing capital to key sectors such as renewable energy, green buildings, corporate governance, and community development. Importantly, green finance encourages funding for low-energy, low-emission firms while limiting investment in polluting industries. This shift helps improve environmental performance and supports a cleaner economic structure (Lee and Lee, 2022). To support this transition, various tools are used, including green credits, bonds, loans, equity, grants, de-risking instruments, carbon finance, and green insurance (Praveen et al., 2025). These instruments build a strong financial foundation for green development. Evidence shows that green finance boosts green productivity. Zhang (2021) finds that it reduces emissions and promotes cleaner production. The study highlights the role of green credit in supporting both innovation and environmental outcomes. Similarly, Zhou et al. (2020) show that green finance creates a balance between economic growth and environmental protection. Yoshino et al. (2021) add that it improves access to capital for green innovation, which raises energy efficiency and expands green industries (Sun et al., 2022). These outcomes support the Porter Hypothesis, which argues that well-designed environmental regulations promote innovation and improve efficiency (Porter and Linde, 1995). Still, the design of regulations matters. As Jiang et al. (2024) point out, weak policies can delay green progress, while overly strict ones may hurt industrial performance. Therefore, collaboration is essential. Policymakers and businesses must work together to assess the impact of green loans and subsidies. Liu et al. (2023) argue that such subsidies lower capital costs and increase firms' motivation to innovate sustainably.

In summary, although past research has advanced the modelling of green economic growth, most studies have overlooked the critical roles of national leadership and entrepreneurship. It is essential to highlight that progress toward a green economy is significantly hindered without visionary national leadership to shape green policies and encourage private enterprises to innovate environmentally sustainable technologies and products. This gap calls for empirical research critically examining how national leadership, entrepreneurship, and technological innovation can drive green economic growth. Such an approach is essential to accelerate the worldwide transition toward sustainable economic growth.

3 Methodology

3.1 Empirical model

The primary goal of the present study is to explore the role of entrepreneurship, leadership quality, and technological innovation in explaining green economic growth. The neoclassical Solow growth model is used as the basic framework to construct the following double-log green economic growth model:

$$\text{lnGRECON}_{it} = \beta_0 + \beta_1 \,\text{lnTECH}_{it} + \beta_2 \,\text{lnENT}_{it} + \beta_3 \,\text{lnLEAD}_{it} + \theta \,\text{CV}_{it} + \varepsilon_{it} \tag{1}$$

where ln denotes the natural logarithm, ε_{it} is the residual term, and lnGRECON_{it} represents green economic growth measured as the ratio of gross domestic product (GDP) to total greenhouse gas (GHG) emissions. The variables lnTECH_{it}, lnENT_{it}, and lnLEAD_{it} denote technological innovation, entrepreneurship, and national leadership indicators, respectively, and constitute the three key explanatory variables of the present study.

Furthermore, following the neoclassical Solow growth theory and its empirical augmentations (e.g., Mankiw et al., 1992), the stock of real physical capital[1] (lnCAP_{it}), human capital (lnHC_{it}), financial development (lnFD_{it}), renewable energy consumption (lnRE_{it}), and $\ln(\text{n} + \text{g} + \delta)_{it}$ are included as control variables (lnCV_{it}), where n denotes the population growth rate, g represents the average growth rate of per capita real output, and δ is the rate of depreciation.[2]

3.2 Data and summary of statistics

This study utilises the unbalanced panel dataset spanning 85 countries from 2011 to 2020 (see Table 1). These datasets are collected from various reliable databases. Precisely, we extract datasets such as real GDP, total greenhouse gas emissions, growth rate of total population, renewable energy consumption, and gross fixed capital formation datasets from the World Development Indicators (WDI). The human capital variable in this study is measured by the education index collected from the United Nations Development Programme (UNDP). We obtain the financial development index and global innovation index from the International Monetary Fund (IMF) and the World Intellectual Property Organisation (WIPO), respectively.

Furthermore, the entrepreneurship variable is measured by the share of total private enterprises (businesses) to the total population. These datasets are collected from the World Bank's entrepreneurship database. Finally, the national leadership quality index is constructed using the weighted average entropy method. We follow Tang and Lim (2024) and Tang and Salisu (2023, 2021) to combine four different institutions and governance indicators, namely (a) control of corruption, (b) political stability, (c) government effectiveness, and (d) voice and accountability. These datasets are extracted from the Worldwide Governance Indicators (WGI). The descriptive statistics and unit of measurement of each variable are summarised in Table 2.

[1] The perpetual inventory method (PIM) is used to construct the capital stock variable from gross fixed investment (I_{it}). Accordingly, the capital stock variable is defined as $\text{CAP}_{it} = I_{it} + (1 - \delta)\text{CAP}_{it-1}$. Following de la Fuente and Doménech (2000), the initial value of the capital stock (CAP_{it-1}) is approximated as $\text{CAP}_{it-1} \approx I_0/(I_g + \delta)$, where I_0 denotes the initial level of investment, I_G represents the long-run average growth rate of gross fixed investment, and δ is the depreciation rate. According to the worksheet of the World Bank report by Ghosh and Kraay (2000), a reasonable depreciation rate ranges from approximately 4 to 8 per cent. Accordingly, an average value of 6 per cent is adopted as the depreciation rate, consistent with Law and Habibullah (2006) in computing the capital stock.

[2] Our calculations show that the average growth rate of per capita real output is approximately 1.3 per cent, and Law and Habibullah (2006) suggest a depreciation rate of 6 per cent. Accordingly, we apply $g = 0.01$ and $\delta = 0.06$ to construct $(n + g + \delta)$. Given that $g + \delta$ are constant, $(n + g + \delta)$ is commonly referred to as population growth.

Table 1: List of countries under review

No.	Countries	No.	Countries	No.	Countries	No.	Countries
1.	Albania	23.	Denmark	45.	Luxembourg	67.	Senegal
2.	Algeria	24.	Egypt	46.	Madagascar	68.	Serbia
3.	Argentina	25.	El Salvador	47.	Malaysia	69.	Singapore
4.	Armenia	26.	Estonia	48.	Mauritius	70.	Slovak Republic
5.	Australia	27.	Ethiopia	49.	Mexico	71.	Slovenia
6.	Austria	28.	Finland	50.	Moldova	72.	South Korea
7.	Azerbaijan	29.	France	51.	Mongolia	73.	Spain
8.	Belarus	30.	Georgia	52.	Namibia	74.	Sweden
9.	Belgium	31.	Germany	53.	Nepal	75.	Switzerland
10.	Bolivia	32.	Greece	54.	New Zealand	76.	Tajikistan
11.	Botswana	33.	Hungary	55.	Norway	77.	Tanzania
12.	Bulgaria	34.	Iceland	56.	Oman	78.	Thailand
13.	Cambodia	35.	India	57.	Pakistan	79.	Togo
14.	Cameroon	36.	Ireland	58.	Panama	80.	Tunisia
15.	Canada	37.	Israel	59.	Peru	81.	Uganda
16.	Chile	38.	Italy	60.	Philippines	82.	Ukraine
17.	China	39.	Jamaica	61.	Poland	83.	United Arab Emirates
18.	Colombia	40.	Japan	62.	Portugal	84.	United Kingdom
19.	Costa Rica	41.	Jordan	63.	Romania	85.	Uruguay
20.	Croatia	42.	Kazakhstan	64.	Russia		
21.	Cyprus	43.	Latvia	65.	Rwanda		
22.	Czechia	44.	Lithuania	66.	Saudi Arabia		

Table 2: Summary of descriptive statistics

Variables	Unit of measurement	Mean	SD	Min	Max
Green economy ($\ln\text{GRECON}_{it}$)	GDP to greenhouse gases (US$)	14.332	0.845	12.348	16.626
Innovation ($\ln\text{TECH}_{it}$)	Innovation index (0 to 100)	3.658	0.291	2.868	4.225
Entrepreneurship ($\ln\text{ENT}_{it}$)	% of population	3.224	1.505	–1.712	5.786
Leadership ($\ln\text{LEAD}_{it}$)	Leadership index (0 to 100)	4.044	0.430	2.438	4.594
Capital stock ($\ln\text{CAP}_{it}$)	Per capita real capital stock (US$)	9.943	1.650	6.238	18.275
Human capital ($\ln\text{HC}_{it}$)	Education index (0 to 100)	4.293	0.238	3.414	4.563
Renewable energy ($\ln\text{RE}_{it}$)	% of total energy consumption	2.604	1.581	–4.605	4.538
Financial development ($\ln\text{FD}_{it}$)	Fin. dev. index (0 to 100)	3.609	0.626	2.058	4.592
$\ln(\text{n}+\text{g}+\delta)_{it}$	% of population growth	–2.552	0.142	–3.049	–1.672

3.3 Dynamic panel generalised method of moments (GMM) estimator

Given that the structure of our panel data is large in cross-sectional (N) and small in time-series (T), the dynamic panel GMM estimator was chosen to estimate our green economic growth model. The approach of GMM was fundamentally presented by Holtz-Eakin et al. (1988). Then, Arellano and Bond (1991), Arellano and Bover (1995), and Blundell and Bond (1998) further extended the estimator for panel data analysis. The benefit of the GMM estimator lies in its ability to mitigate endogeneity constraints. Since this approach has been widely discussed in the existing literature, we briefly highlight the rationale of the dynamic panel GMM estimation employed in this study.

Equation (2) below presents the dynamic green growth model, in which lnGRECON_{it} depends on a set of explanatory variables, lnZ_{it} (e.g., technological innovation, entrepreneurship, national leadership, and the control variables), as well as the country-specific effect (γ_i).

$$\text{lnGRECON}_{it} = \beta_0 + \delta_1 \text{lnGRECON}_{it-1} + \phi\, \text{lnZ}_{it} + \varepsilon_{it} + \gamma_i \tag{2}$$

The model is likely subject to unobserved heterogeneity and endogeneity in the presence of country-specific effects and lagged dependent variable(s). As such, the standard OLS estimator tends to produce biased estimation results. To address these issues, we take the first differencing approach to eliminate the country-specific effect and the transformed model can be written as below:

$$\Delta\text{lnGRECON}_{it} = \beta_0 + \delta_1 \Delta\text{lnGRECON}_{it-1} + \theta \Delta\text{lnZ}_{it} + \Delta\varepsilon_{it} \tag{3}$$

Equation (3) is the First Difference GMM (FD-GMM) model. To address endogeneity, Arellano and Bond (1991) suggested the use of lagged-level variables as the instrument variables (IVs) with the following moment conditions:

$$E[(\text{lnGRECON}_{it-s})\,(\Delta\varepsilon_{it})] = 0 \quad \text{for } s \geq 2;\ t = 3, \ldots, T \tag{4}$$
$$E[(\text{lnZ}_{it-s})\,(\Delta\varepsilon_{it})] = 0 \quad \text{for } s \geq 2;\ t = 3, \ldots, T \tag{5}$$

However, the FD-GMM estimator is inefficient if the variables are persistent or subject to a unit root. To improve the efficiency, Arellano and Bover (1995) and Blundell and Bond (1998) suggested the system panel GMM estimator with additional moment conditions listed below:

$$E[(\Delta\text{lnGRECON}_{it-s})\,(\gamma_i + \varepsilon_{it})] = 0 \quad \text{for } s = 1 \tag{6}$$
$$E[(\Delta\text{lnZ}_{it-s})\,(\gamma_i + \varepsilon_{it})] = 0 \quad \text{for } s = 1 \tag{7}$$

To ensure the application of the GMM method is suitable. It is necessary to check the instrument's validity, and the model must be free from the second order of autocorrelation. As such, Hansen (1982) J-test can be used to evaluate the validity of the instrumental variables. Then, the autocorrelation test introduced by Arellano and Bond

(1991) will be applied to ensure that the model is free from the second-order autocorrelation.

4 Empirical Results and Discussions

The econometric literature widely acknowledges that the application of the Ordinary Least Squares (OLS) method to a dynamic panel model tends to yield overestimated results. In contrast, the Fixed Effect (FE) method will likely produce underestimated outcomes (Nickell, 1981). Consequently, the dynamic panel GMM estimator, introduced by Arellano and Bond (1991), has become a popular method in applied research literature to address this issue. In this study, we will implement the dynamic panel GMM methods to estimate the impact of national leadership quality, entrepreneurship, and technological innovations on green economic growth. Despite the dynamic panel GMM estimator commonly used in the empirical literature, choosing between the First Difference GMM (FD-GMM) and the System GMM (SYS-GMM) estimators remains a significant challenge. To address this, we follow the estimation strategy of Tang et al. (2021), as illustrated in Figure 1.

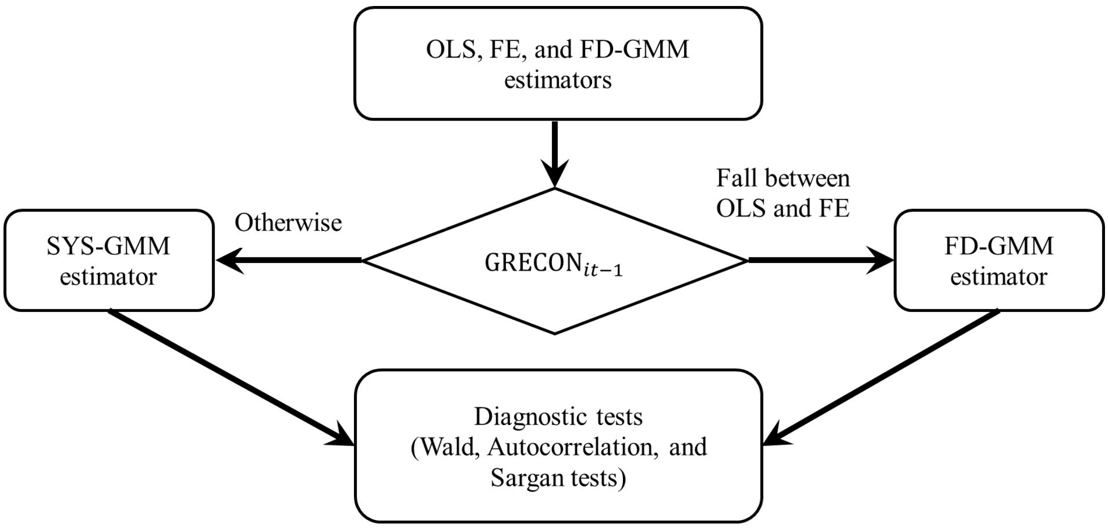

Figure 1: Summary of the dynamic panel GMM estimator selection procedure
Source: Modified from Tang et al. (2021)

As shown in Figure 1, we begin by estimating the dynamic green economic growth model using three different estimators, namely OLS, FE, and FD-GMM. The FD-GMM estimator is selected if the estimated coefficient of the lagged dependent variable (GRECON_{it-1}) falls within the bounds of the OLS and FE estimations. Otherwise, the SYS-GMM estimator is preferred. The preliminary estimation results obtained from the OLS, FE, and FD-GMM approaches are reported in Table 3.

Table 3: Estimation results of OLS, FE, and FD-GMM

Variables	**OLS**	**FE**	**FD-GMM**
Green economy ($\ln GRECON_{it}$)	0.9808***	0.6537***	0.6278***
	(0.0046)	(0.0296)	(0.0948)
Innovation ($\ln TECH_{it}$)	0.0510***	0.0176	0.2082**
	(0.0170)	(0.0403)	(0.0860)
Entrepreneurship ($\ln ENT_{it}$)	0.0010	0.0322**	0.1748**
	(0.0022)	(0.0157)	(0.0826)
Leadership ($\ln LEAD_{it}$)	0.0271**	–0.0003	0.0420
	(0.0107)	(0.0350)	(0.0892)
Control variables:			
Capital stock ($\ln CAP_{it}$)	–0.0002	0.0465***	0.0089
	(0.0023)	(0.0177)	(0.0367)
Human capital ($\ln HC_{it}$)	–0.0013	–0.2308	–0.7876
	(0.0188)	(0.1279)	(0.5954)
$\ln(n + g + \delta)_{it}$	0.0308	0.1375***	0.1505
	(0.0187)	(0.0435)	(0.1775)
Renewable energy ($\ln RE_{it}$)	0.0058***	0.0614***	0.1327***
	(0.0017)	(0.0115)	(0.0353)
Financial development ($\ln FD_{it}$)	–0.0043	–0.0728**	0.0506
	(0.0066)	(0.0340)	(0.1033)
Constant	0.0874	5.7914***	–
	(0.0733)	(0.7038)	
Diagnostic tests			
Wald test	16623.28***	150.57***	1567.68***
	[0.000]	[0.000]	[0.000]
AR(1) test	–	–	–4.18***
			[0.000]
AR(2) test	–	–	0.34
			[0.734]
Sargan-Hansen test	–	–	59.48
			[0.458]

Note: *** $p < 0.01$ and ** $p < 0.05$. Parentheses ( ) and brackets [ ] indicate standard errors and p-values, respectively. AR represents autocorrelation; OLS is Pooled Ordinary Least Squares; FE is Fixed Effects; FD-GMM is First-Difference Generalised Method of Moments.

As expected, we find that the estimated coefficient for GRECON_{it-1} obtained from the OLS estimator is substantially larger than that from the FE estimation (i.e., 0.9808 versus 0.6537). However, the FD-GMM estimation results indicate that the estimated coefficient for GRECON_{it-1} is 0.6278, which is lower than the FE estimate. Given that the FD-GMM estimate falls outside the bounds of the OLS and FE estimations, we conclude that the estimation results produced by the FD-GMM estimator are less efficient than those of the SYS-GMM estimator. Accordingly, we proceed with a full-sample analysis using the SYS-GMM estimator in the subsequent subsection.

4.1 Full-sample estimation of dynamic panel GMM analysis

We have estimated three green economic growth models using the one-step SYS-GMM estimator, and the results are presented in Table 4. To validate these results, we first focus on the diagnostic tests. The Sargan-Hansen tests are not statistically significant at the 10 per cent level across all three growth models. Following Roodman (2009) rule of thumb, the number of instrumental variables (IVs = 69) used in this study is less than the number of groups (N = 85). These two diagnostic indicators suggest that the instrumental variables used in this study to address the endogeneity problem are valid and not oversized. Moreover, the Arellano-Bond test for autocorrelation indicates that our dynamic green growth models are reasonable, as they only exhibit first-order autocorrelation, AR (1) and are free from second-order autocorrelation, AR(2). As such, we can discuss the estimated impacts on green economic growth with these validations.

Among the six control variables included in the models, we find that renewable energy and human capital consistently show positive and significant impacts across all models at the 1 per cent level. These findings suggest that countries with higher levels of human capital development (or education) and renewable energy consumption are typically more effective in promoting economic growth and mitigating environmental degradation simultaneously. This empirical finding aligns with Tang et al. (2021), who found that human capital and renewable energy robustly reduce environmental degradation in 114 countries. However, our study reveals that the impact of human capital on green growth is more substantive than that of renewable energy. A one per cent increase in renewable energy consumption will increase green growth by approximately 0.025 to 0.0286 per cent. Similarly, increased human capital will boost growth by nearly 0.2520 to 0.4040 per cent.

Furthermore, our findings in Table 4 indicate that technological innovation, entrepreneurship, and national leadership quality are three key factors influencing green economic growth. Their effects on green growth are robust across all models. More specifically, the impacts of technological innovation and national leadership on green growth are consistently positive and statistically significant at the 5 per cent level or better. A one per cent increase in technological innovation and national leadership quality will improve green economic growth by approximately 0.1078 per cent and 0.1263 per cent, respectively. Thus, our findings suggest that promoting quality national leadership and technological innovation, mainly on green or environmentally friendly technologies, can effectively accelerate the transition towards a green economy.

Table 4: Results of system GMM estimation

Variables	**Model 1**	**Model 2**	**Model 3**
Green economy (lnGRECON_{it})	0.9058***	0.9115***	0.9256***
	(0.0211)	(0.0213)	(0.0212)
Innovation (lnTECH_{it})	0.1339***	0.1110***	0.0785**
	(0.0347)	(0.0364)	(0.0374)
Entrepreneurship (lnENT_{it})	–	–0.0241**	–0.0424***
		(0.0108)	(0.0128)
Leadership (lnLEAD_{it})	–	–	0.1263***
			(0.0478)
Control variables:			
Capital stock (lnCAP_{it})	–0.0020	–0.0015	–0.0135
	(0.0071)	(0.0071)	(0.0081)
Human capital (lnHC_{it})	0.2520***	0.3787***	0.3754***
	(0.0868)	(0.1041)	(0.0958)
$\ln(\text{n} + \text{g} + \delta)_{it}$	0.1088	0.1419	0.0814
	(0.1015)	(0.1029)	(0.0993)
Renewable energy (lnRE_{it})	0.0250***	0.0286***	0.0265***
	(0.0069)	(0.0071)	(0.0069)
Financial development (lnFD_{it})	–0.0018	0.0141	–0.0216
	(0.0184)	(0.0198)	(0.0231)
Constant	0.0369	–0.4143	–0.8350***
	(0.2112)	(0.2932)	(0.3249)
Diagnostic tests			
Wald test	15436.84***	15328.22***	16528.19***
	[0.000]	[0.000]	[0.000]
AR(1) test	–8.02***	–8.00***	–7.97***
	[0.000]	[0.000]	[0.000]
AR(2) test	0.25	0.25	0.43
	[0.802]	[0.801]	[0.666]
Sargan-Hansen test	69.79	64.31	65.35
	[0.159]	[0.265]	[0.493]
Pesaran CD test	1.236	1.267	0.641
	[0.217]	[0.205]	[0.521]
Time dummies	Yes	Yes	Yes
$\text{N} \times \text{T}$	678	678	678
N	85	85	85
No. of Instruments	69	69	82

Note: *** $p < 0.01$ and ** $p < 0.05$. Parentheses ( ) and brackets [ ] denote standard errors and p-values, respectively. AR denotes autocorrelation, while CD represents cross-sectional dependence.

Contrary to our initial expectations, we find that enhancing private enterprises (or entrepreneurship) may hinder the process towards green economic growth. Specifically, a one per cent increase in entrepreneurship decreases green growth by approximately 0.0241 to 0.0424 per cent. This adverse effect on the green economy may be attributed to the profit-oriented nature of private enterprises, which may prioritise financial revenue over environmental concerns. Therefore, our findings of a negative relationship between entrepreneurship and green economic growth align with (Dhahri et al., 2021; Venâncio and Pinto, 2020).

4.2 Sub-sample estimation of dynamic panel GMM analysis

In the preceding sub-section, we investigated the full-sample green economic growth model. We have extended our analysis by dividing the sample into developed and developing countries to ensure robustness and better policy recommendations. The outcomes of this analysis are detailed in Table 5. Our dynamic green growth models have successfully passed several diagnostic tests, notably the Sargan-Hansen and Arellano-Bond tests for autocorrelations. Furthermore, the Wald test results are highly significant, and the size of the instrumental variables is relatively smaller than the size of N. Given these results, we can proceed to discuss the key findings of our study.

Our sub-sample analysis corroborates the full-sample findings, confirming that technological innovation plays a robust and pivotal role in stimulating green economic growth in both developed and developing countries. Specifically, a 1 per cent increase in technological innovation is associated with an average rise in green economic growth of approximately 0.1999 per cent in developing countries and 0.4961 per cent in developed countries. However, the findings of national leadership and entrepreneurship appear less robust and vary across different stages of economic development.

Notably, we observe marked disparities in the effects of entrepreneurship and national leadership between developed and developing countries. Our results suggest that national leadership quality significantly promotes green economic growth, but this effect is observed exclusively in developing countries. Specifically, a 1 per cent increase in national leadership quality is associated with an approximate 0.1883 per cent increase in green economic growth, holding other factors constant. Conversely, in developed countries, entrepreneurship exerts a significant adverse effect on green growth. More precisely, a 1 per cent increase in entrepreneurship corresponds to a 0.0491 per cent decline in green economic growth, implying that, in more advanced economies, entrepreneurial activity may be driven more by profit-seeking motives than by environmental concerns, thus limiting its contribution to green economic progress.

Table 5: Results of system GMM estimation by country group

Variables	**Developing**	**Developed**
Green economy ($\ln\text{GRECON}_{it}$)	0.8482***	0.7560***
	(0.0411)	(0.1096)
Innovation ($\ln\text{TECH}_{it}$)	0.1999**	0.4961***
	(0.0799)	(0.1570)
Entrepreneurship ($\ln\text{ENT}_{it}$)	−0.0150	−0.0491***
	(0.0193)	(0.0132)
Leadership ($\ln\text{LEAD}_{it}$)	0.1883**	−0.1233
	(0.0763)	(0.2159)
Control variables:		
Capital stock ($\ln\text{CAP}_{it}$)	−0.0012	0.3325***
	(0.0109)	(0.1054)
Human capital ($\ln\text{HC}_{it}$)	0.4413***	−2.3157***
	(0.1676)	(0.6415)
$\ln(\text{n} + \text{g} + \delta)_{it}$	0.4445***	0.2549
	(0.1524)	(0.1575)
Renewable energy ($\ln\text{RE}_{it}$)	0.0368**	0.0910***
	(0.0188)	(0.0266)
Financial development ($\ln\text{FD}_{it}$)	−0.0602	−0.4170***
	(0.0373)	(0.1083)
Constant	0.1381	11.2496***
	(0.8564)	(3.3338)
Diagnostic tests		
Wald test	1102.20***	4693.33***
	[0.000]	[0.000]
AR(1) test	−5.04***	−2.07**
	[0.000]	[0.039]
AR(2) test	0.52	−1.42
	[0.605]	[0.154]
Sargan-Hansen test	16.17	15.00
	[0.932]	[0.525]
Pesaran CD test	−0.830	1.043
	[0.407]	[0.297]
Time dummies	Yes	Yes
N × T	345	333
N	44	41
No. of Instruments	38	29

Note: *** $p < 0.01$ and ** $p < 0.05$. Parentheses ( ) and brackets [ ] denote standard errors and p-values, respectively. AR denotes autocorrelation, while CD represents cross-sectional dependence.

5 Conclusion and Policy Recommendations

The present study attempts to enrich the existing literature by investigating the pivotal roles of technological innovation, entrepreneurship and national leadership in propelling green economic growth. The dynamic system GMM estimator is used to achieve the research objectives. The estimation results reveal that technological innovation and national leadership consistently stimulate green economic growth. Conversely, private entrepreneurship appears to negatively impact green economic growth, primarily due to the tendency of private enterprises to prioritise financial returns over environmental protection. This observation remains consistent even in the sub-sample findings.

These empirical findings provide the foundation for policymaking that balances economic growth and environmental quality. First, governments should prioritise investments in the development and innovation of green technology to spur sustainable economic growth. Our findings indicate that technological innovation accelerates the transition to green growth. This can be accomplished through measures such as research and development subsidies, tax incentives, and targeted investments in the renewable energy sector. Concurrently, cultivating human capital is essential to sustain ongoing technical advancements, whether in eco-friendly products or renewable energy capacity.

Second, as entrepreneurship is found to jeopardise green economic growth, governments must bolster their institutional capacity and governance to ensure that entrepreneurs and private firms integrate environmentally sustainable practices into their operations. This approach will effectively supervise and regulate private firms, preventing them from causing persistent environmental degradation in pursuing private financial gain. Advancing environmental sustainability, policymakers should enforce clear and consistent environmental regulations to reduce CO_2 emissions. Strengthening such policies can help curb carbon-intensive activities and build a solid framework for climate governance. In turn, this creates the right conditions for expanding green finance and achieving long-term sustainability goals, such as those outlined in the COP28 agenda. Additionally, governments can foster green innovation by promoting financial instruments like green bonds, sustainability-linked loans, and mandatory environmental, social, and governance (ESG) reporting (Praveen et al., 2025). These tools not only support low-carbon technologies but also help resource-dependent economies transition toward greener growth paths.

Third, given that national leadership has been found to promote green economic growth effectively, it is essential to demonstrate good governance initiatives. A key element is developing a competent, accountable, and transparent administrative framework that respects the rule of law and is free from administrative burdens and corruption. Moreover, we suggest policymakers strengthen the connection between national leadership, technological innovation, and green entrepreneurship. This can be achieved by creating a conducive environment that encourages green innovation and aligns the goals of private enterprises with environmental preservation. As a result, the speed of transition towards a green economy can be expedited, which in turn leads to sustainable development.

Despite offering essential insights, this study has a few limitations that suggest directions for future research. First, the analysis covers the period from 2011 to 2020, which may not reflect recent developments in leadership, entrepreneurship, and technological innovation. Second, although these three factors are central to our model, other relevant drivers, such as trade openness, FDI, urbanisation, and natural resource rents, were not included and deserve further exploration in future studies. Lastly, the use of a linear model may overlook potential non-linear dynamics. Thus, future studies may employ non-linear approaches to uncover deeper relationships and provide more robust policy implications.

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