Financial Globalization, Technological Innovation and Environmental Performance in Developing Countries

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Abstract

This study examines how financial development (FD) and technological innovation (TI) influence environmental performance in developing economies, using a balanced panel of 51 countries from 1995–2024. To account for cross-sectional dependence, unobserved heterogeneity, and heterogeneous long-run dynamics, the analysis applies Driscoll–Kraay pooled OLS, Driscoll–Kraay fixed effects, and the Augmented Mean Group (AMG) estimator, with additional estimates for lower-middle-income (26) and upper-middle-income (25) subsamples. The results indicate that the effects of FD and TI are not uniform across estimators or income groups. Financial development is generally weak in pooled and fixed-effects models but becomes positive in the full-sample AMG specification, suggesting that finance contributes to environmental performance only when long-run heterogeneity and common shocks are properly modelled. Technological innovation is positive in pooled and fixed-effects estimates for upper-middle-income countries and the full sample, yet loses robustness under AMG, implying that measured patenting does not consistently translate into greener outcomes across heterogeneous developing contexts. GDP is more consistently positive, especially in upper-middle-income economies, while the AMG common dynamic process is large and significant, highlighting the role of shared global trends such as climate policies and energy-price cycles. The findings underscore that greener development requires directing finance and innovation toward clean investment and eco-innovation, supported by strong institutions and targeted policy instruments.

Keywords: Financial Globalisation, Technological Innovation, and Environment, Driscoll–Kraay Pooled OLS, Driscoll–Kraay fixed effects, Augmented Mean Group.

Introduction

The concept of sustainable development has become the focus of global policy, especially following the adoption of the Sustainable Development Goals (SDGs) in 2015 (United Nations, 2015). The SDGs focus on the shared aim of achieving economic prosperity, social inclusion, and environmental protection, a goal that is particularly challenging for developing states. Such economies need to boost their development rates to reduce poverty and inequality while, at the same time, preserving ecosystems, improving environmental conditions, and playing their role in maintaining the climate (Sachs, 2016). Growing, however, is not the policy challenge; it is growing in a resilient, inclusive, and environmentally sustainable manner.

This issue is even more pressing, as environmental performance, as reflected in emissions intensity, energy mix, and overall ecological strain, has become a determinant of long-run welfare and productivity. Environmental degradation may compromise health outcomes, diminish labour productivity, increase the cost of adaptation, and undermine development gains

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(Anser et al., 2021; Chen et al., 2023). Yet, the channels through which developing countries can enhance the environment are debatable, especially in settings with institutional limitations, limited financial resources, and limited access to state-of-the-art technology.

Financial globalisation and technological innovation are two forces particularly important to the development of these pathways. Financial globalisation, characterised by increased cross-border capital flows, financial integration, and external funding facilities, can have both positive and negative effects on environmental outcomes. On the one hand, foreign finance will be able to provide more ecologically friendly infrastructure, enabling investment in renewable sources and the spread of ecologically efficient technologies through foreign direct investment and international financial networks. Conversely, when environmental laws are lax or incentives are inefficient, higher capital flows can drive consumption through pollution-intensive production processes, strengthen extractive growth, and increase ecological pressure. These opposing possibilities mean that the environmental impact of financial globalisation depends on how capital is distributed and regulated (Stiglitz et al., 2009).

In a similar way, technological innovation is centre stage. Innovation enhances productivity and competitiveness by establishing new processes, products, and organisational methods that cut costs and open markets (Awosusi et al., 2022; Usman and Hammar, 2021). Significantly, innovation may also improve environmental performance by enabling energy-efficient operations, reducing emissions per unit of production, and promoting cleaner change across industries. However, innovation is not necessarily becoming green. Without environmental policies and enabling institutions, the effects of technological change can also increase energy demand through scale effects, promote carbon-intensive growth, or trigger rebound effects that can offset efficiency gains. Therefore, the overall environmental impact of innovation would depend on its orientation (clean vs. dirty), its level of adoption, and regulatory and market conditions.

One aspect that has not been studied thoroughly is that financial globalisation and technological innovation might not be independent of each other. Financial globalisation has the potential to ease travel bans on financing research and development, enhance access to foreign technologies and increase the scale of commercialising the cleaner solutions. Meanwhile, the ability to innovate can make or break the process of sustainable upgrading of economies, as external capital can promote, invest in, or bind economies to a pollution-inducing pathway. Such interaction applies especially to developing countries, whose systems of innovation are usually weaker, domestic financial markets might be shallow, and environmental governance uneven (Acemoglu & Robinson, 2019).

Although there has been increasing attention to the relationship between the financial and innovation environments, the empirical literature remains incomplete in three significant respects. To begin with, most of the literature overemphasises developed economies, which have more developed financial systems and innovation ecosystems, with higher regulation implementation, and are not generalizable to developing environments. Second, the mixtures in evidence are frequently caused by differences in measurement (individual indicators versus more inclusive environmental performance), time coverage, and the treatment of heterogeneity and global shocks. Third, there is a scarcity of studies that specifically consider the synergistic impact of financial globalisation and technological innovation on long-term environmental outcomes, accounting for significant global shocks and policy changes.

This paper fills these gaps by analysing how financial globalisation and technological innovation can influence the environmental performance of 51 developing countries between 1995 and 2024 in a panel. It is a timeframe that reflects significant changes in world integration and sustainable governance, such as the growth of international finance and production, the Asian financial crisis (199798), the global financial crisis (200809), the post-2015 era of climate policy under the Paris Agreement, and the COVID-19 shock. Due to the focus on developing economies for almost 30 years, the analysis provides a more precise description of how external finance and innovation capacity are translated into environmental performance across different institutional and macroeconomic settings. The study contributes to the literature in three ways. First, it provides evidence on whether financial globalisation improves or worsens environmental performance in developing countries, where the direction of effects is theoretically ambiguous. Second, it evaluates the role of technological innovation as a direct driver of environmental performance and as a potential channel through which globalisation-related capital influences environmental outcomes. Third, by focusing on a long sample period that includes major crises and sustainability policy shifts, it offers policy-relevant insights into when external finance and innovation are likely to support cleaner development pathways.

Theoretical and Empirical Literature Review

This section describes the major theories related to finance, technological innovation, trade openness, economic growth, and environmental performance. These frameworks inform the analytical model of the study by explaining (i) how finance and innovation can be transmitted through channels to stimulate growth and openness and (ii) why the same forces can enhance or deteriorate the outcome of environmental processes based on institutions, incentives, and the organisation of production.

Financial Globalisation, Financial Development and Structural Change

Financial development determines capital allocation and risk management in economies. Theoretically, healthy financial systems take advantage of saving, lower transaction costs, enhance screening and monitoring borrowers, and diversify risks- hence increasing investment efficiency and promoting long-run growth (Schumpeter, 1911; McKinnon, 1973; Shaw, 1973; Levine, 2005). With the help of these processes, finance not only affects the degree of economic activity but also its structure, which areas grow, which technologies companies follow, and to what extent economies modernise.

Financial globalisation brings such channels to the domestic economies, connecting them with external capital, institutions, and technologies. Increased financial integration will ease the financing bottleneck and expand access to foreign direct investment and international credit, thereby accelerating industrial upgrading and export capacity expansion. This can increase trade openness by helping finance exports, meet working capital requirements, and invest in logistics and productive capacity. Nevertheless, cross-border finance may also increase volatility and lead to short-term, high-paying investments that are harmful to the environment under weak regulatory oversight.

In environmental terms, finance impacts emissions and resource pressures in at least three ways. First, a scale effect: the more output and energy consumption can be easily financed, the more pollution will occur unless the production becomes cleaner. Second, a composition effect: depending on comparative advantage and political preference, capital can either move towards cleaner services and sophisticated manufacturing or heavy industry and extraction. Third, a technique effect: finance can encourage the adoption of cleaner technologies and adherence to environmental standards when they exist. These avenues suggest that institutional quality, environmental regulation, and investment orientation are imperative in determining whether financial development and globalisation enhance environmental performance.

Technological Innovation and Development

Technological innovation is a core driver of long-run growth, as it increases productivity and introduces new products, processes, and organisational forms (Romer, 1990). Schumpeter's idea of creative destruction also underscores that innovation alters markets by substituting old technologies and business models with newer, more efficient ones (Schumpeter, 1942). These concepts drive one of the major requirements of development: the more innovative (or better able to adopt and adapt innovations) an economy is, the faster and brawnier its expansion.

Trade openness is also related to innovation. Competitiveness in international markets is determined by productivity, product quality, flexibility, and the ability to adapt to changing standards. The more innovative firms are more likely to enter export markets, participate in global value chains, and shift to the production of higher-value products. On the other hand, the inability to innovate can trap economies in specialisation based on low-value exports and resources, further increasing environmental pressures from land use, extraction, and fossil-driven energy consumption.

Depending on the direction of the innovation, it has environmental implications. Green innovation (renewables, energy efficiency, pollution control, circular production) has the potential to reduce emissions and waste, thereby improving environmental performance. Innovation, on the other hand, may boost energy demand by increasing energy use or through rebound effects, particularly when the growth rate exceeds the rate of efficiency improvement. In the developing world, these forces are defined by the limitations of skills, infrastructure, research and development systems, and institutions. Consequently, the gains from innovation tend to be skewed across sectors and geographies, and advanced clean technologies may spread slowly. Notably, countries need not be frontier innovators to benefit: the adoption, adaptation, and successful implementation of available technologies can yield significant productivity and environmental benefits if complementary systems (human capital, regulation, finance, and infrastructure) are in place.

Sustainability, Trade and Environmental Economics

Conventional growth models largely considered the degradation of the environment to be an externality. Environmental economics introduced the discussion of pollution, resource depletion and climate risk by showing the potential of unregulated market activities to have long-run social costs. Trade and globalization bring about other mechanisms which are making the growth environment relationship difficult. Openness may increase pressure on the environment through the scale effect (increased production), and a composition effect (specialization in pollution-intensive industries). Simultaneously, a technique effect of trade can lead to environmental performance improvement; because being exposed to global markets stimulates technology transfer, learning, and standards compliance, especially with respect to importing cleaner capital goods or being a part of a regulated value chain. The environmental outcome is also subject to whether the countries are to become pollution havens and dirty industries are lured in the country where there are comparatively loose environmental regulations (Copeland and Taylor, 2004). That is why the governance and regulatory capacity becomes particularly decisive in Global South.

More contemporary sustainability viewpoints claim that the relationship between growth and environmental performance can be mutually reinforcing in cases where economies transition to cleaner forms of energy, resource efficiency and innovative-based forms of upgrading (Porter and van der Linde, 1995). The implication of this research in this study is that, environmental performance is most likely to be improved when finance and innovation are matched with sustainability incentives: finance must invest in cleaner; and innovation must change production to lower emissions and higher efficiency.

Data and Methodology

Data Sources

This thesis relies exclusively on secondary, macro-level data drawn from internationally recognised repositories. All variables are measured at the country–year level, forming a panel of 51 developing economies observed over 1995–2024 (up to 30 annual observations per country). Using secondary sources offers three advantages. First, institutions such as the World Bank, International Monetary Fund (IMF), World Intellectual Property Organization (WIPO), and International Energy Agency (IEA) employ harmonised definitions and validation procedures, which improves cross-country and intertemporal comparability. Second, the public nature of these datasets strengthens transparency and replicability, which are core standards for credible empirical research (Goodman et al., 2016). Third, the long-time span supports an integrated examination of the finance–innovation–growth–environment nexus across major episodes, including global integration reforms and the post-2015 expansion of sustainability-oriented finance.

Empirical Design

To ensure comparability across outcomes, each empirical model follows a common two-way panel framework:

$$Y_{it} = \beta_0 + \beta_1 FD_{it} + \beta_2 TI_{it} + \gamma' X_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

where:

- Y_{it} is the development outcome of interest (e.g., log GDP per capita in Model 1; trade openness in Model 2; environmental performance in Model 3),
- FD_{it} and TI_{it} are the primary regressors (financial development and technological innovation),
- X_{it} is a vector of control variables appropriate to each model,
- μ_i captures country fixed effects (time-invariant heterogeneity such as geography, legal origins, and deep institutional traits),
- λ_t captures year fixed effects (global shocks and common trends),
- ε_{it} is the idiosyncratic error term.

This shared structure supports consistent interpretation of how finance and innovation relate to multiple development objectives. Conceptually, the three-model approach responds to a single policy question: Can financial and technological capacity support outward-oriented, growth-enhancing, and environmentally sustainable development in the Global South? Each model operationalises this question through a different, but complementary, outcome.

Environmental Performance Equation

Environmental performance is included because sustainable development requires balancing economic progress with ecological integrity. Financial systems and innovation ecosystems can enable cleaner technologies, more efficient production, and improved environmental management; however, they can also expand scale and industrial intensity if incentives and regulation are weak. Model 1 therefore evaluates whether financial development (FD) and technological innovation (TI) are associated with improved environmental outcomes, controlling for core structural factors.

The model also connects to the Environmental Kuznets Curve (EKC) hypothesis, which predicts that environmental degradation may rise at early stages of development but decline after income surpasses a threshold, reflecting cleaner technologies, stronger regulation, and changing preferences (Grossman & Krueger, 1995; Tamazian & Rao, 2010). To test EKC formally, income enters in both linear and squared form. Following is the baseline environmental model (two-way fixed effects)

$$\begin{aligned} EP_{it} = \beta_0 + \beta_1 FD_{it} + \beta_2 TI_{it} + \beta_3 \ln GDPpc_{it} + \beta_4 (\ln GDPpc_{it})^2 + \beta_5 TRAD_{it} \\ + \beta_6 INDUS_{it} + \beta_7 LBFR_{it} + \beta_8 GFCF_{it} + \mu_i + \lambda_t + \varepsilon_{it} \end{aligned}$$

The two-way fixed-effects specification identifies associations using within-country variation over time, net of time-invariant country characteristics and global year shocks. This is appropriate for macro panels where unobserved national traits (e.g., geography, baseline institutional structures, long-run resource endowments) are likely correlated with finance, innovation, and environmental outcomes. By including $TRAD$, $INDUS$, $LBFR$, and $GFCF$, the model further reduces omitted-variable bias stemming from structural and scale-related drivers of environmental performance.

Table 1: Environmental Performance Equation

Variable	Expected Sign	Justification (theory/evidence)
FD (Financial Development)	±	Access to finance can support green investments and cleaner technologies (positive) but may also enable environmentally intensive industrial expansion (negative) (Tamazian & Rao, 2010).
TI (Technological Innovation)	+	Innovation promotes the development and diffusion of cleaner technologies, enhancing environmental outcomes (Jaffe et al., 2002).
GDP (Economic Development)	±	Environmental Kuznets Curve (EKC) hypothesis suggests an inverted U-shaped relationship: pollution rises at early stages of growth, but declines as economies mature and adopt greener practices (Grossman & Krueger, 1995).
INDUS (Industrial Output)	−	Industrial activities are often associated with higher emissions and resource depletion, especially in countries lacking strict environmental regulations.
LBFR	−	Increased household consumption typically raises energy use and emissions, particularly if reliant on fossil-fuel-intensive goods and services.
GFCF (Gross Fixed Capital Formation)	±	Investment in physical capital can be either environmentally beneficial (e.g., green infrastructure) or damaging, depending on technology and sector composition.
TRAD (Trade Openness)	±	Trade can increase pollution through scale effects but may reduce it via technology transfer and specialization in cleaner sectors (Antweiler et al., 2001).
μ (Country Fixed Effects)		Controls of time-invariant factors (e.g., geography, legal systems) affecting baseline environmental performance.
λ (Time Fixed Effects)		Captures year-specific global events (e.g., climate accords, pandemics) that influence environmental indicators over time.

Results and Discussion

Descriptive Statistics

Table 2 reports summary statistics for the balanced panel of 51 developing economies (1995–2024). Trade openness averages 72.66% of GDP but varies substantially (13.75–278.74), reflecting large cross-country differences in external orientation. Technological innovation (TI) displays wide dispersion, consistent with uneven innovative capacity across countries and time. Financial development/globalisation (FD) also exhibits considerable variation, indicating heterogeneous financial conditions and integration. The logged scale variables (GDP, industrial output, and labour force) show comparable ranges, capturing differences in economic size across the sample. Overall, the descriptive statistics suggest meaningful cross-country heterogeneity and potential outliers in openness and finance measures that are addressed in robustness checks.

Table 2: Descriptive statistics of all developing countries

Variable	Mean	Std. Dev.	Min	Max
GDP	24.315	1.723	19.983	28.8
TR	72.657	33.464	13.753	278.741
GFCF	23.95	9.019	-2.909	76.782
FD	34.612	28.445	-43.36	158.505
TI	4.195	2.297	-.847	10.39
INDUS	23.02	1.819	18.577	27.47
LBFR	24.083	1.716	19.419	28.424

Source: Author's Estimations using Stata 19.

Correlation Analysis

Table 3Y reports pairwise correlations. Most associations among the key explanatory variables are modest, reducing concerns about collinearity between financial development/globalisation and technological innovation. However, GDP, industrial activity, and labour force are extremely highly correlated (ranging from 0.959 to 0.993), suggesting these variables largely capture common scale effects. To mitigate multicollinearity and ensure stable inference, the empirical specification avoids including multiple highly collinear scale variables simultaneously and/or replaces level measures with economically meaningful shares (e.g., industry value added as a percentage of GDP) and participation rates.

Table 3: Correlation analysis of all developing countries

	GDP	TRAD	RENC	GFCF	FD	TI	INDUS	LBFR
GDP	1							
TRAD	0.232	1						
RENC	0.051	0.016	1					
GFCF	-0.064	0.072	0.052	1				
FD	0.304	0.015	0.12	0.021	1			
TI	0.404	0.175	0.002	0.117	0.192	1		
INDUS	0.982	0.224	0.053	-0.009	0.291	0.399	1	
LBFR	0.993	0.218	0.081	-0.108	0.31	0.395	0.959	1

Source: Author's Estimations using Stata 19.

Results and Discussions of Panel Regression

Using the same threefold estimation strategy, Driscoll–Kraay–adjusted pooled OLS and fixed-effects models, along with the AMG estimator, the analysis captures both short-run dynamics and long-run heterogeneity across countries. By comparing results across the full sample and income-based subgroups, the subsection investigates whether financial depth and innovation capacity act as robust engines of growth or whether their impacts are conditional on structural and institutional development. Special attention is given to the stability and economic significance of the coefficients, ensuring that policy conclusions are grounded in both statistical rigour and developmental context.

Table 4: Impact of Financial Development and Technological Innovation on Environmental Performance

	Lower Middle-Income Countries			**Upper Middle-Income Countries**			**All countries**		
	Driscoll-Kraay Standard Errors-Pooled	Driscoll-Kraay Standard Errors-Fixed	Augmented Mean Group Estimator	Driscoll-Kraay Standard Errors-Pooled	Driscoll-Kraay Standard Errors-Fixed	Augmented Mean Group Estimator	Driscoll-Kraay Standard Errors-Pooled	Driscoll-Kraay Standard Errors-Fixed	Augmented Mean Group Estimator
FD	-0.001	0.002	0.003	0.01	0.001	0.001	-0.001	0.001	0.002
	-0.886	-0.096	-0.063	-0.183	-0.012	-0.525	-0.099	-0.234	-0.046
TI	-0.003	-0.001	-0.068	0.178	0.027	-0.005	0.02	0.003	-0.036
	-0.645	-0.457	-0.357	0	0	-0.485	-0.035	-0.007	-0.341
GDP	1.871	0.269	0.178	0.805	1.057	0.666	1.551	0.796	0.293
	0	-0.187	-0.415	0	0	0	0	0	-0.035
INDUS	-0.108	0.283	0.386	0.403	-0.267	0.034	-0.053	0.103	0.261
	-0.183	-0.006	-0.006	0	0	-0.737	-0.076	-0.097	-0.007
LBFR	-0.701	0.342	-0.092	-0.416	-0.21	-0.01	-0.515	-0.118	-0.002
	0	-0.01	-0.705	0	-0.009	-0.915	0	-0.05	-0.987
GFCF	0.012	-0.002	0.001	0.001	-0.001	0.001	0.011	-0.002	0.001
	-0.001	-0.284	-0.811	-0.857	-0.112	-0.662	0	-0.318	-0.734
TRAD	0.015	-0.114	0.063	0.0501	0.023	0.011	0.062	-0.002	0.055
	-0.785	-0.042	-0.043	-0.03	-0.686	-0.864	-0.211	-0.924	-0.157
CD			0.884			0.768			0.861
Process			-0.004			-0.001			-0.003
Cons.	-23.094	-17.42	-7.179	-16.307	-11.12	-13.369	-21.104	-15.314	-9.401
	0	0	-0.065	0	0	0	0	0	0
No. of Countries	26	26	26	25	25	25	51	51	51
R-square	0.384	0.857		0.431	0.81		0.462	0.817	
F-stat (p-value)	0	0		0	0		0	0	
Wald Chi2			113.4			196.87			125.43
(p-value)			0			0			0

Note: CDP is the Common Dynamic Process.

Table 4 reports the estimated effects of financial development (FD) and technological innovation (TI) on environmental performance for (i) lower-middle-income countries, (ii) upper-middle-income countries, and (iii) the full sample. Three complementary estimators are employed: Driscoll–Kraay pooled OLS, Driscoll–Kraay fixed effects (FE), and the Augmented Mean Group (AMG) estimator. The Driscoll–Kraay approach provides inference robust to cross-sectional dependence and serial correlation, while AMG additionally accounts for heterogeneous slopes and an unobserved common dynamic process (CDP).

Lower-middle-income countries

For lower-middle-income economies, FD is not statistically significant in pooled OLS ($\beta = -0.001$, $p = 0.886$) and is only weakly significant under FE and AMG ($\beta = 0.002$, $p = 0.096$; $\beta = 0.003$, $p = 0.063$). This indicates that, for this income group, deeper finance does not exhibit a robust, average association with environmental performance after accounting for cross-country differences and common shocks.

TI is negative across all three specifications ($\beta = -0.003, -0.001, -0.068$), but is statistically insignificant in all cases ($p = 0.645, 0.457, 0.357$). This suggests that measured innovation activity (proxied by patents) is not yet systematically aligned with improved environmental outcomes in lower-middle-income countries.

Among controls, GDP is strongly positive in pooled OLS ($\beta = 1.871$, $p < 0.01$) but becomes insignificant under FE and AMG ($p = 0.187$ and 0.415). This pattern implies that the positive GDP–environment relationship in this group is driven mainly by between-country differences rather than within-country changes over time. Industrial activity (INDUS) turns positive and statistically significant under FE and AMG ($\beta = 0.283$, $p = 0.006$; $\beta = 0.386$, $p = 0.006$), indicating that within-country industrial changes, conditional on the model, are associated with higher environmental performance. Trade openness (TRAD) is negative and significant in FE ($\beta = -0.114$, $p = 0.042$) but positive and significant in AMG ($\beta = 0.063$, $p = 0.043$), pointing to estimator-sensitive effects: short-run within-country movements in openness may coincide with weaker environmental outcomes, while longer-run heterogeneous dynamics may differ across countries. GFCF is positive and significant only in pooled OLS ($\beta = 0.012$, $p = 0.001$), but not in FE or AMG, suggesting the investment effect is not stable once country fixed effects and heterogeneous dynamics are incorporated.

Upper-middle-income countries

For upper-middle-income economies, FD is statistically significant only in the FE specification ($\beta = 0.001$, $p = 0.012$) and is insignificant in pooled OLS and AMG ($p = 0.183$ and 0.525). This indicates that within a given upper-middle-income country, increases in financial development are associated with modest improvements in environmental performance, but the relationship is not robust to alternative long-run heterogeneous modelling. TI is positive and highly significant in pooled OLS and FE ($\beta = 0.178$, $p < 0.01$; $\beta = 0.027$, $p < 0.01$) but becomes insignificant in AMG ($\beta = -0.005$, $p = 0.485$). This suggests that innovation is positively associated with environmental performance in the pooled and within-country FE settings, but the effect is not robust once cross-country heterogeneity and common dynamic factors are explicitly modelled.

GDP is positive and statistically significant in all three estimators ($\beta = 0.805$; 1.057; 0.666; all $p < 0.01$), providing consistent evidence that higher income levels in upper-middle-income countries are associated with improved environmental performance, consistent with upgrading effects and stronger capacity to adopt cleaner technologies and standards. Other controls are less stable: INDUS is positive in pooled OLS but negative in FE and insignificant in AMG, while TRAD is significant only in pooled OLS.

Full sample

In the full sample, FD remains insignificant in pooled OLS and FE ($p = 0.099$ and 0.234) but becomes positive and statistically significant under AMG ($\beta = 0.002$, $p = 0.046$). This suggests that, after accounting for heterogeneous dynamics and common factors, financial development exhibits a small but statistically significant association with environmental performance across developing countries on average.

TI is positive and significant in pooled OLS and FE ($\beta = 0.020$, $p = 0.035$; $\beta = 0.003$, $p = 0.007$), but negative and insignificant in AMG ($\beta = -0.036$, $p = 0.341$). Hence, the innovation–environment link is not robust to AMG's allowance for heterogeneous long-run responses and common shocks.

GDP is consistently positive and significant across pooled OLS and FE ($p < 0.01$) and remains significant in AMG ($\beta = 0.293$, $p = 0.035$), implying that, on average, higher income is associated with better environmental performance in the developing-country panel. INDUS becomes positive and statistically significant in AMG ($\beta = 0.261$, $p = 0.007$), while TRAD is not significant across estimators for the full sample, indicating no stable average effect of openness once heterogeneity and common shocks are considered.

The AMG results confirm the importance of common global dynamics: the CDP coefficient is large and statistically significant for lower-middle-income (0.884, $p = 0.004$), upper-middle-income (0.768, $p = 0.001$), and the full sample (0.861, $p = 0.003$). This provides strong evidence that environmental performance in developing countries is influenced by shared external forces, such as global commodity cycles, common technology trends, and international climate policy and finance, beyond country-specific fundamentals.

Conclusion

This paper has investigated the relationships among financial development (FD), technological innovation (TI), and environmental performance in developing economies, and has also examined three complementary estimators of these phenomena: Driscoll-Kraay pooled OLS, Driscoll-Kraay fixed effects estimation, and the Augmented Mean Group (AMG) estimation. The inferences made with the help of such estimators are stronger in terms of dealing with serial correlation and cross-sectional dependence (Driscoll-Kraay) and allowing the slope heterogeneity and unobserved common dynamics (AMG), particularly important in environmental and globalisation studies.

Three fundamental conclusions can be made. To begin with, the environmental impact of financial development is low and estimator-related. In the lower- and upper-middle-income subpanels, FD is not associated with environmental performance, with a steady, robust result. Under AMG, FD is statistically significant across the entire sample, indicating that better environmental outcomes can be supported by finance when heterogeneous long-run dynamics and global common factors are taken into account. Nevertheless, the weaknesses in the strong specifications suggest that financial deepening itself is not necessarily green: it is in its role of turning capital toward cleaner infrastructure, efficient production, and low-carbon technologies, rather than toward pollution-intensive processes, that financial systems can be directed.

Second, technological innovation has heterogeneous impacts across income groups and depends on the modelling strategy. TI has a positive relationship with environmental performance in the pooled and fixed-effects estimates for upper-middle-income economies (as well as in the entire sample), indicating that innovation capacity and adoption can help these nations upgrade production processes and enhance environmental performance. However, the relationship is less stable in the presence of AMG, indicating that the long-run average effect of innovation is no longer stable once cross-country heterogeneity and global common shocks are explicitly accounted for. In lower-middle-income countries, TI is neither significantly positive nor negative, which is consistent with the view that innovation activity in these environments may still be a case of catch-up industrialisation rather than green innovation.

Third, macroeconomic structure and global dynamics are powerful factors that influence the environmental performance. The positive income (GDP) correlation is most stable in the upper-middle-income category and throughout the panel, which supports the impression that developmental and upgrading can be combined with better environmental management. The industrial structure is also an issue. As several specifications show, changes in industrial activity are related to environmental performance, but more so for estimators and income groups. Above all, the AMG outcomes show that there is a big and significant common dynamic process between all the samples, i.e., common external forces, including the energy-price cycles by the world, international climate agreements, technology diffusion waves, and climate finance trends, which play a significant role in the formation of environmental performance in developing economies, in addition to country-specific forces.

These results have obvious policy implications. Financial deepening should not be an end in itself for developing countries aiming to progress towards a greener development pathway, but rather the means of directing the flow of finance into environmentally productive activities through mechanisms such as green credit policies, climate-risk reporting, sustainable finance taxonomies, and incentives to invest in renewable energy and energy efficiency. Similarly, innovation policies must not be limited to generic patenting or industrial growth; instead, direct innovation should be pursued, which entails supporting the diffusion of clean technology, environmental standards, and firm-level upgrading, especially in lower-middle-income countries, where innovation is not necessarily environmentally oriented. Lastly, the significance of the shared dynamic process suggests that international cooperation, technology transfer, and access to climate finance should be reinforced by domestic strategies to allow developing economies to coordinate growth with environmental performance in the face of global shocks and transitions.

Overall, the paper demonstrates that developing countries can increase their environmental performance, but such growth, finance, and innovation alone are insufficient. Future studies can further elaborate on this discussion by identifying the clean and dirty innovations, the nonlinear or threshold impacts of financial development and income, and testing whether institutional quality and environmental regulation modulate the finance-innovation-environment relationship across different developing economies.

Policy Implications

The results have definite policy implications for developing nations in an Endeavour to enhance environmental performance while maintaining growth.

First, the development of finance should be greened and not expanded indiscriminately: regulators and central banks need to implement sustainable finance taxonomies, disclose climate-related risks and stress tests, and incentivise (e.g. preferential refinance support, credit guarantees, and reduced risk weights) bank lending to renewable energy, energy efficiency, cleaner transport, and clean-up investments.

Second, because technological innovation has unequal and environmentally unfriendly effects, the innovation policy must be more directional. Supporting generic patenting should be replaced by targeted clean-technology diffusion, including granting R&D support, green public procurement, promoting standards and certification, and partnerships that help firms implement proven low-carbon technologies.

Third, due to the high existence of common world shocks and trends, governments must enhance resilience and access to global opportunities by enhancing the eligibility of climate finance, incorporating environmental standards in industrial and trade policies, and expanding the capacity of institutions in preparing and monitoring projects so that foreign capital and technology can be translated into additional green benefits.

All these measures indicate that better environmental outcomes can be achieved through coordinated finance and innovation, supported by coherent policy frameworks that incentivise cleaner production, enhance enforcement, and facilitate the transition to low-carbon development pathways.

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