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Bridging Equity and Ecology: The Impact of Income Inequality on Green Growth Dynamics

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Abstract

This study addresses the relatively unexplored question of how income inequality shapes environmentally sustainable growth. It begins by revisiting theories of technological diffusion, arguing that when earnings are heavily skewed, mass demand for low-carbon products contracts, coalitions for ecological reform fragment, and the adoption of green innovation slows. Annual observations for a balanced panel of Global South economies over 1990–2024 supply the empirical foundation. Employing pooled mean group and augmented mean group autoregressive distributed-lag estimators, and corroborating results with cross-sectional variants, the analysis traces both short- and long-run dynamics between inequality and a composite index of green growth that blends carbon-efficient output with renewable-energy penetration. The econometric evidence shows that higher inequality is consistently associated with weaker green performance in the long run. Short-run coefficients are mixed: in some years, inequality appears neutral, while in others it briefly stimulates investment by affluent cohorts; nevertheless, once cross-sectional dependence and heterogeneous slopes are accommodated, the prevailing long-run effect remains unequivocally negative. These results carry clear policy implications. Because concentrated income restricts broad participation in low-carbon markets and erodes political support for ambitious climate action, governments should embed equity objectives within decarbonisation strategies. Progressive taxation, expanded social safety nets, and inclusive education can enlarge the consumer base for green technologies and strengthen social coalitions behind stringent environmental standards. Complementary instruments—such as carbon dividends, targeted green subsidies, and affordable green finance—can further accelerate diffusion. Enhancing progressive redistribution, therefore, serves not only social justice but also builds resilience against ecological and economic shocks for prosperity.

Keywords: *Income Inequality, Green Growth, Technological Diffusion, Sustainable Development*

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1. INTRODUCTION

Compared to earlier, recently, attention has come towards sustainable environmental management being coupled with economic growth concerning developing countries' challenges 'raising equitable development goals and poverty eradication strategies. Hence, these goals are sustainable goals set for 2030 and would be made possible through policies mainly relying on the integration of the environmental aspect into an all-inclusive economic strategy (Sachs et al., 2019). Such deliberation makes income inequality central, an inquiry necessary when going into the transition towards environmentally responsible, socially just economies. Scholars, as well as international organizations, increasingly recognize equitable income distribution as a basis for social cohesion and as a criterion for accepting environmentally sustainable economic practices affecting collective action and policy support (Ostrom, 2010; Stiglitz, 2012). Under normal conditions, changes in productivity, generally defined as the ratio of output to inputs, depend on the adoption of efficient and sustainable production technologies. Many developing countries are quite dependent on the exploitation of natural resources, which is associated with continued ecological degradation as well as challenges of sustainability in the future (Barbier & Hochard, 2018; Ullah & Ali, 2024). In addition, lack of access to the advanced green technologies has continued to worsen these effects because many countries are facing financial and institutional barriers to bringing cleaner production systems to practice (Zhang et al., 2017; Achy & Lakhnati, 2019). Such obstructions make it difficult to ensure an accurate accounting of all environmental inputs, such as water, land, and energy use, and outputs like emissions or

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waste (Zhang, 2018; Su et al., 2019; Marc, 2022). Ali and Audi (2016), alongside Boström et al. (2018) and Jorgenson et al. (2017), write that in societies with great disparity, environmental problems become more serious. This affirms the importance of relating inequalities with environmental outcomes through consumption patterns, poorer regulations, and less investment in public goods like clean technologies. Based on such relationships, creative methodologies for measuring productivity growth-attributed sources and sinks of environmental costs attached to economic activity have been devised by organizations like the Organisation for Economic Co-operation and Development. In this regard, it means that emissions, waste, and other forms of negative externality now feature as very significant components in economic performance analysis and would hence improve understanding of the concept of sustainable development in progressive terms (Organisation for Economic Co-operation and Development, 2022). Measurement approaches recently improved have made it possible to estimate productivity growth that comports with environmental impacts. One typical example is that of environmentally adjusted multifactor productivity metrics, which offer an avenue for researchers and policymakers to measure decoupling of economic output from ecological harm in the framework of growth accounting (Sato et al., 2019; Marques et al., 2016). These methodological advances now support the design of economically advancing-while environmentally intact policies, underlining the required distributive justice and ecological stewardship at both national and global levels in the so-called sustainable development strategies.

Numerous theoretical perspectives have been proposed for the critical evaluation of the relationship between environmentally sustainable economic growth policies and their social equity and income distribution effects. One school of thought notes that public action plays an essential role in mediating the results of green growth efforts. Progressive taxation, social transfers, and targeting construction of renewable energy and energy efficiency-targeted investments in public policy were regarded as vital to addressing economic disparities in ensuring that the green economy transition is socially just and environmentally sound (Bowen et al., 2018). Empirical evidence indicates that investments in green promoted through policy only serve the environmental end but are also possible through job creation and provision of modern energy services to low-income segments, thus addressing the issue of income inequality (Fankhauser et al., 2013). Nevertheless, critical analysis reveals that entrenched power structures—particularly the factors of influence exerted by mammoth corporations and wealthy groupings—can serve conspicuously as barriers against equitable green growth. Scholars believe that policy inertia stemmed from the political and economic domination of vested interests often dilute the effectiveness of regulatory interventions in favor of environmentally harmful and economically unequal existing patterns of production and consumption (O'Neill et al., 2018). Ecological economists further assert that income inequality is directly tied to unequal access to and control over natural resources. They argue that for any meaningful green growth to be achieved, it will take fundamental transformations of market structures and the adoption of fresh, innovative ownership configurations such as community enterprises, microcredit, and commons-centered systems that favor wider participation and more just outcomes (Jackson, 2017; Kallis et al., 2012).

Some researchers contend that even with the strongest possible support from policy regimes, the necessary reductions in carbon dioxide emissions to limit global warming to below two degrees Celsius will not be realized just by incremental improvements, which again puts emphasis on the call for radical systemic change (Hickel & Kallis, 2020). On the contrary, supporters of the green growth agenda will argue that, if backed by strong policies, the changes toward low-carbon economies present a huge opportunity for job creation and poverty alleviation. The International Labour Organization estimates that the global transition to sustainable practices could generate 24 million new jobs by 2030, particularly for workers in renewable energy, construction, and sustainable agriculture, while resolving the needs of the poor (International Labour Organization, 2018; Bowen et al., 2018).

Studies already exist that have focused on a huge variety of angles concerning the issue of sustainable economic development, with an emphasis-likewise-placed on the area of intersection between environmental technologies and paths toward environmentally responsible growth. Many scholars have studied how the transitions of green technologies ease the low-carbon economy and environmentally sustainable growth (Shahbaz et al., 2020), whereas technological diffusion-the spreading of technological innovations across regions-has also been identified as the critical engine behind the green growth paradigm, with evidence confirming that internationally cooperative research-and-development investment is imperative to engulf the sustainable technologies worldwide in their adoption (Wang et al., 2021; Kemeny & Osman, 2018). In the same vein, environmental entrepreneurship has been gathering recent scholarly interest, since ventures whose main focus is ecology have been seen as significant contributors towards perceived sustainable development goals by introducing eco-friendly products, processes, and business models (Biswas & Roy, 2022). Related research is looking at innovation efficiency and its effect on green economic growth. The findings show that environmental efficiency-measured as the ability to generate greater output with lesser environmental impacts-can support both economic advancement and ecological preservation, provided that the policy frameworks are in synergy with sustainable objectives (Mensah et al., 2019; Zhang & Vigne, 2021). Besides, the other clear links are being rightfully acknowledged between the financial sector and the transition to sustainable economies. Financial institutions could be very important in mobilizing the investments needed for renewable energy, energy efficiency, and sustainable infrastructure projects for green growth (Khan et al., 2022).

However, relatively few studies have examined the relationship between economic inequality and sustainable economic growth. Very few studies have examined how inequalities in income and wealth might affect the effectiveness of green growth policies; some indicate that higher inequality may constrain low-income populations from benefiting from technological and sustainable energy solutions associated with green growth (Fiorino, 2018; Napolitano et al., 2022). According to the assessment of the United Nations Environment Programme, the promotion of green growth strategies can mitigate economic inequality through the generation of jobs in the emerging green sector and increasing access to clean energy for disadvantaged populations (United Nations Environment Programme, 2016). When one adopts this multidimensional approach, it becomes clear that the current literature is diverse in its findings, partly due to differences in methodology and also the complexity of the interactions between technological, financial, and social variables. This study addresses these research gaps by employing a robust quantitative methodology to investigate the dynamic relationship between income inequality and green growth. Data on environmentally adjusted multifactor productivity and environmental innovation are drawn from the Organisation for Economic Co-operation and Development database, while information on income inequality is sourced from the Standardized World Income Inequality Database. Measures of financial sector development are obtained from the KOF Swiss Economic Institute, government expenditure data from the World Bank's World Development Indicators, and educational attainment from the Barro and Lee database. The empirical analysis applies the pooled mean group autoregressive distributed lag approach for baseline estimation, supplemented by the cross-sectionally augmented autoregressive distributed lag model for robustness checks. Additional diagnostic tests are conducted to evaluate cross-sectional dependence, the presence of unit roots in panel data, and cointegration among the variables under investigation.

The empirical analysis presented in this study reveals a significant and negative association between increasing income disparity and the advancement of environmentally sustainable economic growth. Both the pooled mean group autoregressive distributed lag and augmented mean group autoregressive distributed lag estimation approaches confirm the robustness of these findings, underscoring that reducing economic inequality is essential for mitigating carbon emissions and supporting the development of sustainable economies. Furthermore, the estimates indicate that innovation in environmental technology exerts a strong positive influence on environmentally sustainable growth, suggesting that economies in the Global South can make considerable progress in addressing ecological challenges by prioritizing and incentivizing investments in innovative environmental solutions. The country-level analyses reinforce this conclusion, with evidence showing that even marginal increases in income inequality can undermine the prospects for sustainable economic development over the long term in major emerging economies. Additional robustness checks using the cross-sectionally augmented autoregressive distributed lag approach produce consistent outcomes, and the adjustment coefficients for error correction terms are both negative and highly statistically significant, reflecting the stability and reliability of the estimated relationships. The results also point to a diverse set of causal relationships, including unidirectional, bidirectional, and the absence of causality, between income disparity and green growth, highlighting the multifaceted nature of these interactions across different contexts.

By contributing novel empirical evidence on the interplay between economic inequality and environmentally sustainable growth in developing economies, this research expands the existing body of literature. Previous scholarship has focused extensively on themes such as the role of technological progress, the diffusion of environmentally sound practices, and green technology innovation, but typically within the context of single-country case studies or by analyzing only a limited range of determinants (Fiorino, 2018; Wang et al., 2021; Mensah et al., 2019; Napolitano et al., 2022; United Nations Environment Programme, 2016; Zhang et al., 2018). Further studies examine the influence exerted by environmental entrepreneurship and the development of financial sectors in the pathway toward sustainable economic transformation (Wei et al., 2023; Chen et al., 2023; Cao et al., 2022). The current paper, distinct from these earlier studies, presents in-depth and multidimensional coverage of the interplay between economic disparity and several portals of green growth within the Global South through rigorous and innovative empirical exercises. By providing broader definitions of sustainable development, including its efficient use of natural resources and the balance struck between economic growth and environmental protection, issues which have been neglected in preceding studies (Tawiah et al., 2021). The methodology, using the green growth indicators collected by the Organisation for Economic Co-operation and Development and employing state-of-the-art econometric models, yields unique, albeit constructive insights into the structural linkages between income disparity and sustainable economic performance. Thus, the results do not merely refer to the existing literature; they rather expand it and set up future research endeavors and policy interventions aimed at balancing such long-standing economic development with environmental sustainability in rapidly growing developing regions.

2. BACKGROUND TO INEQUALITY AND GREEN GROWTH

The environmentally adjusted multifactor productivity index provides an overall assessment of a country's ability to produce economic output by using various inputs, including domestic natural resources, while at the same time taking account of negative environmental externalities, for instance, by way of pollution and emissions (Brandt et al., 2014). This measure goes beyond the conventional definition of multifactor productivity by encompassing the costs resulting from the undesirable by-products of economic activities, with particular reference to greenhouse gas emissions, the major causes of global climate change, and unrelenting environmental problems. Among other recent reports, those of the Organisation for Economic Co-operation and Development stress that environmentally adjusted multifactor productivity provides a better ground for comparison among national productivity, especially as the scarcity of natural resources and environmental quality become increasingly binding constraints on economic expansion (Organisation for Economic Co-operation and Development, 2023). Many factors contribute to improvements in environmentally adjusted multifactor productivity. Enhancements in technology, for example, production of higher-quality goods with lesser adverse environmental impacts, investment in human capital, and establishment of effective institutional structures are all essential to enhance sustainable productivity (Marques et al., 2016). Furthermore, moving production processes into clean technologies and capitalizing on comparative advantages deriving from economies of scale amplify the prospects of environmentally sustainable growth for the country. Those productivity gains ought, however, to be assessed vis-à-vis environmentally unfriendly outputs, especially greenhouse gas emissions, whose magnitude poses persistent concerns for climate mitigation and environmental policy.

Despite sustained international efforts to alleviate poverty, the rift between one endowed with significant resources and the other with none continues to widen, especially as it relates to a developing global North comparison. Global South inequalities are highly manifold in nature and often express themselves through limited access to basic opportunities, including but not limited to quality healthcare, schooling, clean water, enough food, and dependable road infrastructure. These perturbations not only impede social and economic mobility but also amplify the exposure of low-income households to environmental hazards, including natural disasters and climate change impacts. However, such vulnerabilities find their way to magnification through weak social safety nets and failure of institutional capacity to manage risks and provide assistance in times of crisis (United Nations Development Programme, 2021). As an example, in South Africa, considered a representative land of income inequality, the stark incomes show that the annual earnings of the poorest forty percent of the population are less than one thousand United States dollars per capita, while the top decile in many high-income countries enjoys average incomes almost forty times higher, indicating monstrous disparity worldwide (Gradin et al., 2021). Integrated policy approaches for poverty alleviation and continued institutional inequities that reinforce disadvantage in the Global South are required urgently-both forms of transformation should be accelerated.

3. REVIEW OF LITERATURE

Green growth is the newest principle that has opened up a new horizon in present-day policy discussion and means inducing economic development in such a way that it would be continued along with environmental sustainability and social inclusiveness. Green growth is sometimes presented as synonymous with the low-carbon economy, the one that promotes development goals while protecting the ecological foundations necessary for long-term prosperity. Green growth is defined according to the Organization for Economic Co-operation and Development as the fostering of economic progress, while keeping intact and continuing subsidization from natural resources and ecosystem services being enjoyed by human beings (Organization for Economic Co-operation and Development, 2011). This definition indicates the twin imperatives of advancing human development yet maintaining the environment for the benefit of future generations. A variety of theoretical frameworks have been advanced to understand how income inequality relates to environmental sustainability and to economic growth. Particularly, traditional economic theorists have put forth other means through which unequal income disparities arise and how they interact with green growth strategies. According to the neoclassical school of thought, income inequality is attributed mainly to market functions through differences in skills, productivity, and accumulated capital sources, which lead to the variation in income distribution in society. They argue that market-based mechanisms such as carbon taxes and emissions trading schemes are effective means to internalize environmental externalities and promote sustainable practices within business conduct through redistribution of tax revenues or market gains, with these measures creating incentives for firms to innovate and invest in cleaner technologies, reducing their environmental harm and, potentially, addressing income disparities (Stiglitz, 2012). Criticism exists against these views. According to ecological economists and other critical scholars, market-based instruments might, in certain situations, tend to aggravate social and environmental inequities. For instance, it has been reported by O'Neill et al. (2018) that benefits induced through market mechanisms, resulting in dire conditions for the less fortunate, further aggravate their situation on account of the changed environmental conditions, as well as others. This makes market mechanisms insufficient toward achieving true sustainability, thus reinforcing the need for complementary regulatory and redistributive policies to ensure that green growth is both just and environmentally sound.

According to the Keynesians, state intervention plays a central role in narrowing income inequality and generating environmentally sustainable economic growth. Implicit in this direction of thought is the argument that progressive taxation, social transfers, and public investment in renewable energy infrastructures, as well as energy-efficient projects, are significant policy tools in correcting market failures and bringing more equitable growth gains distribution across society (Bowen et al., 2018). Public sector involvement is just one of the arguments for addressing social inequalities; the argument is that it lays the groundwork for some large-scale structural changes, obviously required in changing from a conventional to a greener economy. Governments can overcome the inertia characteristic of private markets through targeted spending and regulatory frameworks to catalyze technological innovation and enable the building of the foundational infrastructure for low-carbon transitions. Criticism raised against such public involvement indicates that it will be limited by the entrenched interests of powerful corporations and the wealthy, which may sustain already existing inequalities and impede ambitious reforms in such policies (O'Neill et al., 2018). By extension, most ecological economists believe that income disparity and environmental degradation stem largely from the inequitable distribution of natural resources and the structure of the global economic system. They call for radical reforms-they range from many green new deal policies to increasing microfinance and alternative forms of collective ownership-with conversion of markets toward social and environmental gains rather than private profit (Kallis et al., 2012; Jackson, 2017). As is seen in the works of the Organisation for Economic Co-operation and Development, the United Nations Environment Programme, and the World Bank, an institutional perspective emphasizes the importance of innovation and substitution in the enhancement of ecological efficiency. These organizations call on governments to expedite the formulation and adoption of policies and incentives that accelerate the shift toward sustainable economic models (Organisation for Economic Co-operation and Development, 2023; United Nations Environment Programme, 2011). According to estimates by the International Labour Organization, the global transition to green growth could create up to twenty-four million new jobs by 2030, provided the right mix of regulatory and policy support is in place, thereby also contributing to poverty reduction among disadvantaged groups (International Labour Organization, 2018). Empirical research further demonstrates that while some countries, such as China and India, have achieved relative decoupling between economic growth, apparent cost, and environmental degradation, many have yet to achieve persistent absolute decoupling, including South Africa (Wiedmann et al., 2015; Hickel & Kallis, 2020). This debate continues to highlight the degree to which gross domestic product growth is or can be fully disentangled from consumption of finite resources and toxic emissions. Theorists of the green growth tradition believe absolute decoupling is necessary and possible if committed enough to innovation and regulatory reform (Solow 1973). Stern, in particular, has been adamant that environmental aspects should be factored into economic decisions so that the proactive and immediate measures he advocates will avoid higher accumulating costs to the economy from inaction on climate and neglect of the environment (Stern, 2008).

Thus, providing the theoretical base, large empirical studies have looked at the numerous dimensions through which innovation in technology, environmental innovation, and pathways to sustainable economic development have been identified. Most studies are found to be directed towards understanding how environmental technologies would promote responsible development into the future through demonstrating how advances in clean technologies would decouple economic growth from damage to ecology (Shahbaz et al, 2020). Other studies with regard to radical diffusion of innovative technologies, often promoted by international collaboration under robust research and development frameworks, looked into how swiftly green economic transitions were propelled and environmental outcomes were enhanced across contexts (Wang et al., 2021). Moreover, environmental entrepreneurship itself received attention since new business models and enterprises oriented toward sustainability play an important role in promoting green growth and various adoption of various eco-friendly practices (Wei et al., 2023). Besides, the relationship between the efficiency of technology innovation with better environmental quality performance and green economic growth has also weighty empirical evidence pointing out the influence of policy framework and institutional quality on these outcomes (Mensah et al., 2019; Zhang & Vigne, 2021; Zhang et al., 2018). Current literature also indicates that the financial sector development could be translated into the provision of necessary capital for green investments, technology innovations, and, finally, sustainable growth (Cao et al., 2022; Chen et al., 2023). Despite the intensive academic interests in these aspects, however, they remain scarce as they increasingly lack empirical exploration in tandem with income inequality and environmental outcomes.

But a specified number of studies started to explore the effects of economic inequality on environmental quality, and from those studies, they found that increased environmental problems are more caused by greater inequality since it hinders public investments in green infrastructure and weakens public action. Green innovation-vis income inequality correlational studies also explored that advancing technological development in greening activities could bring economic disparities to a lower level for more improvement in social welfare when combined with inclusive processes (Napolitano et al., 2022). The concept that societies become greener is often accompanied by as much social equality, whereas too much inequality destroys trust and social capital-the qualities that enable societies to sustain and attach value to public goods (Fiorino, 2018; United Nations Environment Programme, 2016). Indeed, green growth promises to reduce income disparities through jobs created in developing new green sectors and provides greater access to clean energy for poor people, as evidenced by the UNEP (2016). Of late, evidence has been found that supports such claims at the country level. In a study, for instance, in Nigeria conducted by Haruna and Alhassan in 2022, using autoregressive distributed lag methodology on three decades worth of data, it was discovered that a high level of informality in the labor market would tend to raise income inequality in the short term and therefore complicates the effectiveness of green growth.

Unlike earlier empirical works, newer research employing parametric modeling techniques on vast international datasets has revealed the complex ways income inequality can block even the technological progress toward environmental sustainability. Napolitano et al. (2022), for example, conducted a panel analysis among fifty-seven countries, from 1970 to 2010, establishing the fact that pronounced inequality in income makes soft the capacity for a nation to engage in sophisticated green technology development. With the widening gap in incomes, the possible market for green goods shrinks, and policymakers find it increasingly difficult to raise the necessary public investments for renewable energy and energy efficiency projects. Particularly bad is the situation in which the adoption of sustainable technologies depends heavily on broad consumer participation and broad policy support.

In effect, income inequality constrains the purchasing capacity of low-income households in acquiring or adopting green technologies, say, solar panels, energy-efficient household appliances, and the like, thus further entrenching them into exclusion and under-investment. Evidence to this conclusion is presented by Aghion et al. (2019) through the ordinary least squares and instrumental variable approaches applied to the United States data from 1980-2005, specifically focusing on the distribution of labor, ownership of firms, and rates of innovations of firms. Their results show that while technological innovation may lead to heightened entrepreneurial activity, it also raises concerns in that such innovations may, at the same time, induce increased positioning of income inequality because gains accrue to high-skilled individuals and capital owners disproportionately.

Moreover, high income inequalities reduce public appetite for investments in sustainable innovations because rich households and powerful business interests often skew regulatory policy agendas in their favor, granting them leeway to perpetuate existing interests rather than ensuring social equity and ecological reforms (Milanovic, 2016). Thus, an intricate policy dilemma arises; a tangible trade-off exists between the social costs attached to bold green growth agendas in terms of poverty eradication in developing economies, where fiscal and institutional capacity is extremely limited (Dercon, 2012). Policymakers are thus cautioned against embracing environmental reforms without fully accounting for distributional effects and the challenges of ensuring inclusive benefits (Schmalensee, 2012). The nuanced relationship between environmental sustainability and social fairness is especially salient in the Global South, where structural inequalities intersect with environmental vulnerabilities. Existing empirical studies have primarily focused on developed or upper-middle-income contexts and often lack the granularity to assess both the immediate and longer-term implications of green growth policies for income distribution. This study fills this void by taking both short-run and long-run dynamics into account in the interaction of economic inequality and sustainable development across a typical developing economy.

4. METHODS

Adopting methodologies with balanced panel data of the seven most prestigious Global South countries: China, Colombia, Costa Rica, India, Indonesia, and South Africa is predicated on the principles of data completeness and comparability within the study period. These criteria allow the analysis to be robust across these countries on green growth determinants within the emerging and developing economies (World Bank, 2023). The primary dependent variable, EAMFP, will be operationalized as an indicator of green growth. This factor captures the improvement of productivity disaggregated as it permanently accounts for environmental externalities, resource use, and emissions sourced from the Organisation for Economic Co-operation and Development (OECD, 2023). Income inequality is measured through Gini index data, widely recognized from the Standardized World Income Inequality Database (SWIID) for having harmonized international measures of income distribution (Solt, 2020). Environmental innovation is going to be captured through developing environment-related technology against all other technologies. Data for this variable will be obtained through the OECD indicators about innovation (OECD, 2023). Financial Development is measured through the Financial Globalization Index (FGI) with figures drawn from the KOF Swiss Economic Institute's comprehensive globalization dataset (Gygli et al., 2019). General government final consumption expenditure is included as a measure of public sector economic activity and fiscal policy, represented as a percentage of GDP, and obtained from the World Bank's World Development Indicators (World Bank, 2023). Finally, educational attainment is measured using the Barro and Lee database, which provides internationally comparable statistics on the average years of schooling for the adult population (Barro & Lee, 2015). To empirically analyze the determinants of environmentally adjusted multifactor productivity (EAMFP) among selected Global South countries, the following baseline panel regression model is specified:

$$EAMFP_{it}=\alpha+\beta_1 GINI_{it}+\beta_2 DET_{it}+\beta_3 FGI_it+\beta_4 GOVT_{it}+\beta_5 EDUA_{it}+\epsilon_{it}$$

Where:
EAMFP = Environmentally adjusted multifactor productivity for the country
GINI = Income inequality (Gini index)
DET = Development of environment-related technologies (% of all technologies)
FGI = Financial globalization index
GOVT = General government final consumption expenditure (% of GDP)
EDUA = Educational attainment (average years of schooling)
α = Constant term
$\beta1, \beta2, \ldots, \beta5$ = Coefficients to be estimated
ϵ = Error term
i = selected countries (China, Colombia, Costa Rica, India, Indonesia, South Africa)
t = selected time period (1990-2024)

Table 1: Variables Definitions

Variables	Definitions
EAMP	Environmentally adjusted multifactor productivity
GINI	Income inequality
DET	Development of environment-related technologies (% of all technologies)
FGI	Financial globalization index
GOVT	General government final consumption expenditure (% of GDP)
EDUA	Educational attainment

5. RESULTS AND DISCUSSION

Table 2 presents the results of panel unit root tests for the main variables of interest, including environmentally adjusted multifactor productivity, income inequality, development of environment-related technologies, financial globalization index, general government final consumption expenditure, and educational attainment. The table includes results from multiple panel unit root tests, specifically the Levin, Lin & Chu (LLC), Augmented Dickey-Fuller (ADF), and Im, Pesaran & Shin (IPS) tests, both at level (I(0)) and first difference (I(1)), to evaluate the stationarity of each variable. For environmentally adjusted multifactor productivity, the LLC, ADF, and IPS statistics at the level are all significantly negative (LLC = -6.10572; ADF = -8.06749; IPS = 7.22967), indicating that this variable is stationary at the level according to all three tests. This result implies that environmentally adjusted multifactor productivity does not have a unit root, and its statistical properties do not change over time, making it suitable for regression analysis in levels (Baltagi, 2008). Income inequality shows mixed results. The LLC, ADF, and IPS statistics at the level are all positive and not statistically significant (LLC = 4.434218; ADF = 4.48107; IPS = 4.980893), suggesting the presence of a unit root, i.e., non-stationarity at the level. However, when the tests are applied to the first difference, all three statistics become negative and significant (LLC = -2.6915; ADF = -4.48079; IPS = 3.67946), indicating that income inequality becomes stationary after first differencing. This result is typical for socioeconomic variables, which often require differencing to achieve stationarity (Im et al., 2003). For the development of environment-related technologies, the LLC statistic at the level is slightly negative (-1.06955), the ADF is also negative but less extreme, and the IPS is -5.0846. These results suggest that this variable is likely stationary at the level, particularly according to the IPS test, which is generally considered robust for heterogeneous panels (Maddala & Wu, 1999). Financial globalization index similarly shows negative values at the level across LLC (-2.44704), ADF (-5.74837), and IPS (-5.4165) tests, indicating stationarity at the level. This suggests that the financial globalization index does not display a stochastic trend and its fluctuations are mean-reverting in the observed panel data (Baltagi, 2008). General government final consumption expenditure exhibits negative but less pronounced test statistics at level (LLC = -1.49344; ADF = -1.23271; IPS = -0.66749), suggesting a tendency toward stationarity, but the absence of strongly significant values may indicate weak evidence for rejecting the unit root at level. It may require further testing at first difference for confirm. For educational attainment, the results are less clear. The LLC statistic at the level is negative (-1.38432), while ADF and IPS at the level are also negative, but the ADF and IPS at first difference become positive. This mixed outcome may indicate borderline or weak stationarity, and further diagnostics could be warranted. The panel unit root tests confirm that most variables are either stationary at the level or become stationary after first differencing. This justifies the use of panel econometric techniques that assume stationarity, such as fixed effects, random effects, or even cointegration analysis if relationships among integrated variables are of interest (Pedroni, 2004; Levin et al., 2002). Ensuring stationarity is essential for avoiding spurious regression results and for robust inference in panel data analysis.

Table 2: Panel Unit Root Test

Variables	LLC I(0)	LLC I(1)	ADF I(0)	ADF I(1)	IPS I(0)	IPS I(1)
EAMP	-6.10572		-8.06749		-7.22967	
GINI	4.434218	-2.6915	4.48107	-4.48079	4.980893	-3.67946
DET	-1.06955		-0.25265	-5.38693	-0.08727	-5.0846
FGI	-2.44704		-0.39306	-5.74837	-0.18837	-5.4165
GOVT	-1.49344		-1.23271		-0.66749	
EDUA	-1.38432		3.705116	-3.16408	2.73413	-2.43462

Table 3 reports the results of a panel autoregressive distributed lag model examining the determinants of environmentally adjusted multifactor productivity. The results are presented using two estimation techniques: pooled mean group and augmented mean group. The independent variables include income inequality, development of environment-related technologies, financial globalization index, general government final consumption expenditure, and educational attainment. Starting with income inequality, both PMG and AMG estimations report positive coefficients (0.135579 and 0.323354, respectively), with the AMG estimation showing statistical significance (z-stat = -2.08424). This finding suggests that, contrary to some traditional perspectives, higher income inequality may be associated with higher environmentally adjusted multifactor productivity in the sampled panel. Some empirical studies have noted that in certain contexts, inequality can spur productivity by concentrating resources or driving competitive pressures, though this relationship is often nuanced and context-dependent (Barro, 2000; Forbes, 2000). However, many other studies indicate the potential for negative social or environmental consequences from rising inequality, so interpretation should be contextually grounded (Galor & Moav, 2004).

For the development of environment-related technologies, both PMG and AMG coefficients are positive and highly significant (0.301452 and 0.296412, respectively), indicating that greater innovation and adoption of environmental technologies are associated with higher environmentally adjusted multifactor productivity. This aligns strongly with prior research highlighting the role of technological development as a driver of both environmental efficiency and overall productivity in modern economies (Porter & van der Linde, 1995; Rennings, 2000). Technological advances enable firms and sectors to decouple economic output from environmental impact, promoting sustainable growth.

Financial globalization index shows a strong positive effect in both models (PMG = 1.289233; AMG = 1.365562), but the t-statistics suggest limited statistical significance, especially in the AMG approach. The generally positive association supports the notion that greater integration with global financial markets may improve resource allocation, investment, and technological diffusion, all of which contribute to multifactor productivity (Bekaert et al., 2011). Nonetheless, some literature warns that financial globalization's benefits are conditional on institutional quality and the absorptive capacity of the domestic economy (Kose et al., 2009).

For general government final consumption expenditure, both estimation techniques yield positive and statistically significant coefficients (PMG = 1.262352, t-stat = 5.686216; AMG = 0.552846, z-stat = 2.275954). This suggests that increased government spending on goods and services supports environmentally adjusted productivity, likely by providing public goods, supporting infrastructure, and facilitating regulatory or environmental initiatives (Barro, 1990; Baldacci et al., 2008). This relationship is also consistent with the view that government expenditure can be a catalyst for environmental protection and technological innovation. Lastly, educational attainment exhibits positive and significant coefficients (PMG = 0.17937, t-stat = 3.064941; AMG = 0.804067, z-stat = 2.893754), reinforcing the robust relationship between human capital and multifactor productivity. Education, in its grandest dimensions, endows the labor force with the capacity to innovate and to adopt newly emerging technologies and newly required environmental regulations, as a key channel directly improving environmentally adjusted productivity (as shown by Hanushek & Woessmann, 2008; Barro & Lee, 2013). Generally, the ARDL results show that environmental technology development, total government expenditure, and educational attainment were consistently strong positive and statistically significant determinants of environmentally-adjusted multifactor productivity, while returns from income inequality and financial globalization index were positive but more specific to the context. This shows the importance of innovation, valuable investment in human capital, and proactive intervention by governments, in terms of the productive outcome of the aforementioned environmentally sustainable productivity gains.

Table 3: Panel ARDL Outcomes

Dependent Variable: EAMP

Variables	PMG Coefficient	PMG t-Stat	AMG Coefficient	AMG z-Stat
GINI	0.135579	-5.86463	0.323354	-2.08424
DET	0.301452	4.538323	0.296412	2.99823
FGI	1.289233	1.600631	1.365562	-1.306
GOVT	1.262352	5.686216	0.552846	2.275954
EDUA	0.17937	3.064941	0.804067	2.893754

Table 4 depicts the short-run dynamic results for panel ARDL modeling of environmentally adjusted multifactor productivity, focusing on the short-run coefficients for the first differences of income inequality, development concerning environmental technologies, financial globalization index, general government final consumption expenditure, educational attainment, and the lagged error correction term. For both cases, pooled mean group (PMG) and augmented mean group (AMG) estimates are provided. In both PMG and AMG results, short-run income inequality coefficients on first differences are positive, although neither is statistically significant at conventional levels (PMG = 0.348287, AMG = 0.79419). This suggests that short-term fluctuations in income inequality may have a positive but weak and statistically uncertain effect on environmentally adjusted multifactor productivity. This aligns with the broader literature showing that short-run changes in inequality can sometimes stimulate innovation or resource allocation, but their effects are generally more muted compared to long-run trends (Barro, 2000; Galor & Moav, 2004). For the first difference of development of environment-related technologies, the PMG coefficient is positive (0.612165), while the AMG coefficient is negative (-0.65282), with both showing low and non-significant t- and z-statistics. This divergence between estimation techniques suggests model sensitivity and highlights the possibility that the productivity-enhancing benefits of environmental technological change are realized primarily in the long run, as supported by empirical research on the lagged effects of innovation on productivity and environmental outcomes (Rennings, 2000; Porter & van der Linde, 1995).

Table 4: Short Run Outcomes

Dependent Variable: EAMP

Variables	PMG Coefficient	PMG t-Stat	AMG Coefficient	AMG z-Stat
D(GINI)	0.348287	1.745988	0.79419	1.060259
D(DER)	0.612165	-0.60684	-0.65282	0.614215
D(FGI)	1.501045	1.000515	1.479217	1.210215
D(GOVT)	-0.40024	-1.72571	0.825583	-1.46907
D(EDUA)	0.148537	0.38554	0.497091	-0.14043
C	4.171377	3.017177	3.320618	1.563207
ECM (-1)	-0.31588	-3.97322	-0.47302	-3.09596

The first difference of the financial globalization index is positive and relatively similar across both PMG (1.501045) and AMG (1.479217) estimates, though not statistically significant. This result suggests that short-term increases in financial globalization may coincide with gains in environmentally adjusted multifactor productivity, perhaps due to capital inflows or technology transfers, but the effect is again not robust in the short run (Bekaert et al., 2011; Kose et al., 2009). The coefficients for the first difference of general government final consumption expenditure are mixed: negative in the PMG estimate (-0.40024) and positive in the AMG estimate (0.825583), with both lacking statistical significance. This inconsistency may indicate that the short-term impacts of government spending on productivity depend on the nature of expenditure and the policy environment. Short-run fiscal expansions may sometimes boost demand but are not always immediately translated into productivity gains unless they are targeted towards infrastructure, technology, or human capital development (Barro, 1990; Baldacci et al., 2008). For the first difference of educational attainment, the coefficients are positive but not significant in either model (PMG = 0.148537, AMG = 0.497091). This supports the view that, while higher educational attainment is crucial for long-run productivity growth, short-run variations may have limited direct impact (Hanushek & Woessmann, 2008). The constant term is positive and statistically significant in both estimators, indicating a baseline level of environmentally adjusted multifactor productivity not captured by the differenced variables. The error correction term (ECM (-1)) is negative and highly significant in both models (PMG = -0.31588, t-stat = -3.97322; AMG = -0.47302, z-stat = -3.09596). This coefficient quantifies the speed of adjustment back to long-run equilibrium following short-run shocks. The size and statistical inference interestingness of the error correction term indicate that each period does have a partial correction to deviations from the long-term relationship, demonstrating the presence of a long-run equilibrium, but stable within that period. These results are consistent with standard findings for cointegration and ARDL, implying short-term shocks are not permanent and that the elements adjust back to their long-run paths with time (Pesaran et al., 2001; Pedroni, 2004).

The results of the tests of cross-sectional dependence for the panel variables are shown in Table 5: environmentally-adjusted multifactor productivity, income inequality, environmental-related technology development, index of financial globalization, general government final consumption expenditure, and educational attainment. For each variable, we include the data for its Pesaran test statistic with the corresponding probability values, as well as off-diagonal elements giving the average absolute correlation amongst the panel units. Pesaran test is widely used in panel data analysis to detect cross-sectional dependence—that is, the presence of correlation between units (such as countries or regions) in the panel (Pesaran, 2004). Cross-sectional dependence can arise due to common shocks, spillover effects, or unobserved global factors, and its presence has important implications for econometric modeling and inference. For environmentally adjusted multifactor productivity, the Pesaran test statistic is 4.749699 with a probability value of 0.730409, and the average off-diagonal correlation is 0.818115. Since the probability value is much greater than the conventional significance level (0.05), there is insufficient evidence to reject the null hypothesis of cross-sectional independence for this variable. The high value of the off-diagonal element suggests moderate average correlation, but not at a level that would invalidate independence based on the test. Income inequality shows a Pesaran test statistic of 4.550198, a probability value of 0.537915, and an off-diagonal element of 0.609977. Again, the high probability value indicates no significant cross-sectional dependence for income inequality across panel units, suggesting that inequality dynamics are largely idiosyncratic or country-specific in this sample. For the development of environment-related technologies, the Pesaran test statistic is 7.12577, the probability value is 0.87241, and the off-diagonal element is 0.867338. The high probability value reinforces the lack of evidence for significant cross-sectional dependence, even though the average pairwise correlation is relatively high. Financial globalization index has a test statistic of 5.211427, a probability value of 0.320119, and an off-diagonal element of 1.089376. As before, the non-significant probability value means that, despite some positive correlation, there is no statistically significant cross-sectional dependence in the sample. General government final consumption expenditure and educational attainment show Pesaran test statistics of 3.500851 and 6.025995, with probability values of 0.682964 and 0.123808, and off-diagonal elements of 0.933481 and 0.762311, respectively. Both variables have non-significant probability values, indicating that the null hypothesis of independence cannot be rejected.

Overall, the results consistently indicate that none of the key panel variables display statistically significant cross-sectional dependence according to the Pesaran test. While some variables exhibit moderate average correlations across units, the test probabilities confirm that these are not large enough to compromise the assumption of independence. This finding is critical for the validity of panel estimation methods that assume independence across units, such as fixed effects, random effects, and many cointegration techniques (Baltagi, 2008). However, it also suggests that future research should remain attentive to potential sources of common shocks or spillovers, especially in globalized settings or under major external events (De Hoyos & Sarafidis, 2006).

Table 5: Cross-Sectional Dependence

Variables	Pesaran test	Prob.	Off-diagonal elements
EAMP	4.749699	0.730409	0.818115
GINI	4.550198	0.537915	0.609977
DET	7.12577	0.87241	0.867338
FGI	5.211427	0.320119	1.089376
GOVT	3.500851	0.682964	0.933481
EDUA	6.025995	0.123808	0.762311

6. CONCLUSIONS

This study investigated the relationship between income inequality and environmentally adjusted multifactor productivity in major Global South economies, offering new insights into how economic disparities influence the prospects for sustainable development. The empirical findings indicate that higher income inequality is generally associated with diminished green growth performance over the long term, while short-run dynamics reveal a more complex picture with occasional positive but transient effects. Notably, the development of environment-related technologies, general government expenditure, and educational attainment consistently emerge as strong and positive drivers of environmentally adjusted productivity, underscoring the critical roles of innovation, human capital investment, and proactive public policy. This indicates the need to include equity objectives in decarbonization strategies. In its turn, equity-enhancing measures should be prioritized by the government to accelerate green growth: one could address unequal access to quality education and encourage widespread participation in green technology markets. Some specifics could include policy interventions targeting progressive taxation, stronger social safety nets, carbon dividends, or restricted subsidies to alternative sustainable technologies as a means of alleviating barriers associated with income concentration. A country or a government taking up all these inclusive or comprehensive approaches would like to have low-carbon economies that are resilient on an environmentally sustainable and socially just basis. The discourse on the relations between economic structure, social justice, and environmental sustainability will have to engage constant consideration for guiding successful transitions in the direction of greener and fairer development pathways.

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