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# From Trade Openness and Income Inequality to Carbon Reductions: Insights into Environmental Outcomes

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**Abstract:** This paper investigated how trade openness and income inequality jointly shaped carbon outcomes using a panel of 94 countries from 1966 to 2015. On average, greater openness and lower inequality are associated with reduced $CO_2$ emissions; however, their interaction is proved to be positive, suggesting that while trade openness could contribute to lower carbon emissions in relatively equal societies, its benefits diminished and even reversed under high inequality. In addition, heterogeneity analyses revealed stronger elasticities in non-high-income and high-openness subsamples, a statistically significant inequality threshold and effects that intensify at upper $CO_2$ quantiles. Therefore, policy packages that pair trade facilitation with inequality compression and clean-technology diffusion are likely to be most effective, particularly where inequality and openness are already high. Future research should extend the analysis to consumption-based emissions, sectoral pathways, and institutional moderators to refine the trade-inequality-carbon nexus and its implications for environmental sustainability.

**Keywords:** Carbon emissions; Income inequality; Panel data; Trade openness; Environmental sustainability

## 1. Introduction

Although the world economy achieves significant improvement in facilitating international trade which fosters economic growth, inequality and pollution remain two major concerns (Hübler, 2017; Jorgenson et al., 2016; Liu et al., 2019; Uzar, 2020; Yang et al., 2022). First, the proliferation of free trade agreements encourages many countries to focus on their comparative advantages in order to gain benefits from the international exchange of goods and services. Thus, trade openness is identified as the primary force behind the economic development of many countries (Sun et al., 2019). However, the rapid increase in international trade also triggers concerns about its long-run externality effects, including a polluted environment (Baek et al., 2009). Second, both trade openness and economic growth lead to the decline of absolute poverty but do not ensure a reduction in income inequality across citizens and countries, thus failing to guarantee the development of harmonious societies at each country level and global level.

At the same time, the increasing concerns about income inequality and environmental degradation receive much attention from academic researchers. Since the first study of Boyce (1994), who used political power theory to explain the inequality-environment nexus, many studies explored the influence of income distribution on the environment. There is still no agreement on how inequality affects the quality of the environment when the "marginal propensity to emit" and emulation theories are used in empirical studies (Mader, 2018; Uzar & Eyuboglu, 2019). This is also true for the political economic theory. Moreover, as international trade leads to different impacts on the investment and consumption of both the rich and the poor, the level of trade can likely moderate the effect of income disparity on the environment.

Similarly, studies testing the gain-from-trade and race-to-bottom hypotheses have yielded mixed results (Ibrahim & Law, 2016). It seems that the environmental impact of trade tends to differ across periods and country groups, suggesting the presence of some conditionality in other factors. Moreover, it can be acknowledged that while there are many economic determinants of environmental performance, neglecting a social factor like income distribution could mislead the findings. Because income distribution affects an individual's investment and consumption patterns (Fisher et al., 2013), the unequally distributed benefits of international trade then influence the amount of pollution an individual generates in the environment.

This paper attempts to connect two strands of literature, trade-environment and inequality-environment nexuses. This issue is worth studying, as most countries are facing serious environmental degradation due to their increasing trade openness. In addition, it becomes more important for developing countries, where their citizens face severe problems of unfair income distribution and proliferation of pollution-generating industries, which are moved from developed countries. The joint consideration of trade openness and income inequality is theoretically justified by their intertwined roles in shaping production and consumption patterns. Trade openness, often amplifying or mitigating pre-existing income disparities, affects the distribution of gains from globalization across social groups. For instance, increased integration into global markets may disproportionately benefit capital-intensive sectors and skilled labor, thereby widening the income gap. On the other hand, income inequality itself influences the environmental consequences of trade through heterogeneous consumption and investment behaviors. Affluent households, who gain more from trade liberalization, tend to consume more carbon-intensive goods and services, whereas poorer households may be constrained to less polluting consumption bundles. Consequently, the environmental impact of trade is not uniform but conditional on the degree of income inequality. Conversely, trade openness can moderate the environmental implications of income inequality by altering the accessibility of cleaner technologies, the composition of industries, and the bargaining power of different social groups in shaping environmental policy. These theoretical linkages provide a strong rationale for studying income inequality and trade openness simultaneously, as neglecting one may obscure the true environmental effects of the other. We aim to contribute to the existing literature in two main facets. First, we examined the influence of trade openness and inequality on the environment, measured by carbon dioxide emissions. Second, we explored the environmental effect of income inequality contingent at the level of trade openness by the inclusion of an interaction between two explanatory variables.

While prior studies have extensively examined the bilateral relationships between income inequality and environmental degradation (Boyce, 1994; Jorgenson et al., 2017; Torras & Boyce, 1998) and between trade openness and environmental quality (Antweiler et al., 2001; Frankel & Rose, 2005; Managi et al., 2009), very limited attention has been devoted to their joint dynamics. Existing literature often treated income distribution and trade liberalization as independent determinants of carbon emissions, thereby overlooking the possibility that they might condition and reinforce one another's environmental effects. Our study advanced the literature by explicitly modeling and estimating the interaction between income inequality and trade openness, in order to capture their moderating relationship. This integrated approach not only bridges two major research strands, inequality–environment and trade–environment nexuses, but also reveals nonlinear and conditional effects that single-factor models systematically miss. Furthermore, by employing a large cross-country panel covering 94 economies over 5 decades and applying dynamic System Generalized Method of Moments (system-GMM) techniques, we enhanced the robustness of causal inference compared to earlier works relying on static or country-specific regressions. These contributions collectively underscore the novelty of our analysis and demonstrate its potential to refine the theoretical and empirical understanding of how globalization and social disparities jointly shape environmental outcomes. In addition, we focused on $CO_2$ emissions as our indicator of environmental quality because $CO_2$ is the dominant anthropogenic greenhouse gas, consistently measured across countries over the time, and directly targeted in international climate agreements. This choice ensures comparability and policy relevance in assessing how trade openness and income inequality shape environmental outcomes.

The structure of the paper is as follows. The next section reviewed related theories and empirical studies and then developed hypotheses. Section 3 described research methodology and data. The main results and robustness checks were reported in Section 4. The last section summarized the paper.

## 2. Literature Review

### 2.1 Income Inequality and Environmental Quality

The connection between income distribution and environmental quality can be described by three theoretical approaches. The first proposition, called the political economy approach, was established based on the distribution of power and income. Boyce (1994) was the first to apply political theory to explain the impact of inequality on environmental performance. Boyce (1994) argued that government policies should control the deterioration of environmental quality, considering it a public good. The second theoretical approach, called "marginal propensity to emit", explicated the income inequality-environmental quality relationship based on the household demand for consumption (Ravallion et al., 2000). As households consume goods and services, they directly or indirectly affect environmental quality by emitting pollution. If the "marginal propensity to emit" of affluent households is higher than the propensity of the deprived ones, an escalation in inequality raises pollution and vice versa. The third approach was built on the economic behavior of individuals in equal and unequal societies. According to the emulation theory, income inequality affected status consumption. The rich engaged in expensive consumption to gain status while the poor imitated the consumption patterns of the rich. In a more unequal society, both affluent and poor classes had a higher tendency to spend on more polluted goods and services. This social pattern was called the "Veblen effect", which concluded a positive linkage between income disparity and environmental deterioration.

A substantial body of empirical research has investigated the relationship between income inequality and environmental quality across various scales, ranging from national to global levels. Numerous studies asserted that unequal income distribution exacerbated environmental degradation. Torras & Boyce (1998) demonstrated that income inequality negatively affected air and water pollution, while Holland et al. (2009) identified socioeconomic disparity as a significant determinant of biodiversity loss. Similarly, Morse (2018) found that more equitable income distribution was associated with enhanced environmental performance. In contrast, other studies presented evidence suggesting a positive association between income inequality and environmental outcomes (Wan et al., 2022). For instance, Ravallion et al. (2000) argued that income disparity contributed to lower $CO_2$ emissions in specific contexts. A third strand of literature contended that income inequality was not a decisive predictor of environmental quality. Jorgenson et al. (2017), for example, reported no statistically significant relationship between the Gini coefficient and environmental indicators such as $CO_2$ emissions. These divergent findings highlight the contextual and methodological complexities surrounding the nexus between income inequality and environmental outcomes. Recent empirical contributions have refined this debate by incorporating nonlinearities, sectoral heterogeneity, and interaction mechanisms between inequality and other structural factors. Wang (2024) demonstrated that the environmental impact of income inequality depended on the development of renewable energy. Inequality could either worsen or alleviate ecological degradation, depending on whether clean energy technologies dominated the energy mix. Shabani et al. (2023), using provincial data from Iran's agricultural sector, confirmed the Environmental Kuznets Curve (EKC) while uncovering an income threshold around USD 17,600, above which inequality would increase emissions. Below this income threshold, inequality mitigated them, indicating a shifting "marginal propensity to emit" across income stages. Moreover, Ul-Haq et al. (2023) introduced the concept of economic fitness as a capability-based measure of productive complexity. They found an inverted N-shaped relationship between economic fitness and $CO_2$ emissions across BRICS countries, including Brazil, Russia, India, China, and South Africa; they suggested that diversification and innovation moderated the distribution-emission nexus. Collectively, these findings emphasized that the environmental effect caused by inequality was context-dependent, as it was conditioned by technological progress, sectoral composition, and national development.

### 2.2 Trade and Environment Quality

Antweiler et al. (2001) was the first to develop the theoretical framework to examine the impact of globalization on environmental conditions. The theoretical model decomposed the effect of trade into three components, namely scale, technique, and composition. The first effect mentioned the deterioration in the environmental quality due to economic expansion induced by trade. The second effect referred to the friendlier environmental techniques in production due to the stringent environmental regulation. The composition effect related to how environmental quality varied with the evolution of economic structure, which was strongly affected by the degree of trade openness in a country and its comparative advantage (Managi et al., 2009). Examples of composition effects are natural resource exploiting industries versus knowledge-intensive industries, or agriculture and manufacturing industries versus service industries. In general, the overall influence of international trade on the environment could be positive, negative, or neutral depending on how international trade affects a country's consumption, production, and regulation characteristics.

Several hypotheses have been derived for the international trade-environmental quality nexus. According to the gain-from-trade hypothesis, international trade leads to improvement in environmental performance. Several reasons are supporting this argument. First, higher income level received from international trade encourages public demand for a cleaner environment. Similarly, the international ratcheting up of environmental standards could occur through the heightened awareness of citizens. Second, the trade usually comes with advanced production technologies, which shift domestic production from highly polluted patterns to friendly environmental patterns. However, opponents of globalization claim that trade openness causes more harm to the environment, not less. The Race to Bottom Hypothesis argues that a country could adopt looser environmental standards to maintain or increase international competitiveness. In other words, the government of a country can attract multinational companies by adopting lax environment protection policies and exporting goods that generate high pollution in the production process. Second, the higher income from trade encourages citizens to increase their consumption, which then emits higher pollution. These contradicting arguments of the environmental impact and trade openness have inspired researchers to conduct empirical analyses on the relationship between the two. As expected, while some papers found the favorable effect of international trade on environmental conditions, others concluded that trade liberalization damaged environmental quality.

Antweiler et al. (2001) found that international trade had a positive scale effect but a negative technique and composition effect, leading to an overall decline in pollution. Cole & Elliot (2003) examined whether compositional variations in environmental deterioration arising from international trade originated from heterogeneity in capital-labor endowments or differences in government policies. The results strongly and weakly support Antweiler's framework on $SO_2$ and $CO_2$ emissions, respectively, but do not suggest any evidence in the case of $NO_x$ and biodiversity loss.

Cole (2006) indicated that a positive scale effect dominated the negative technique effect on per capita energy use. Frankel & Rose (2005) found that trade liberalization significantly reduced $CO_2$ emissions for upper middle-income countries, while the results were inconclusive for the full sample and lower middle-income countries. Shahbaz et al. (2017) studied the trade-carbon emissions nexus for three groups of 105 heterogeneous countries. They discovered that trade openness lowered $CO_2$ emissions in most countries but led to higher carbon dioxide emissions in the long run.

However, some research highlighted the negative influence of globalization on the environment. Heil & Selden (2001) analyzed the consequence of international trade on pollution across 132 countries from 1950 to 1992. They revealed two opposite effects of trade openness: lower $CO_2$ emissions in higher income countries and increased pollution in lower income countries. Managi et al. (2009) found that although trade reduced biochemical oxygen demand, it had detrimental effects on $SO_2$ and $CO_2$ emissions in countries that are not in the Organization for Economic Cooperation and Development (non-OECD). Sharma (2011) found that trade openness had a positive impact on $CO_2$ emissions, along with energy consumption and gross domestic product (GDP) per capita.

### 2.3 Integrated Trade–Inequality–Environment Framework

Recent studies have expanded the trade-environment literature by emphasizing nonlinear, mediating, and threshold effects. Dou et al. (2023) showed that the trade-carbon productivity nexus followed a U-shaped pattern: openness initially deteriorated carbon productivity but subsequently improved it once openness exceeded a critical threshold, mainly through reductions in energy intensity and structural shifts toward renewable energy. Bagadeem et al. (2024), using Chinese industrial data, identified multiple emission-intensity thresholds where foreign direct investment (FDI) and trade openness alternated between pollution-halo and pollution-haven effects, underscoring that the environmental outcome of openness varied across industry emission regimes. In contrast, Çatık et al. (2024) found that renewable energy mitigated ecological footprints and that globalization improved environmental quality only in low-growth regimes, rejecting the traditional EKC. Dissanayake et al. (2023) provided global evidence that renewable and nonrenewable energy consumption interacted differently with trade and growth, revealing that transitional economies faced bidirectional causality between GDP and emissions. Trade-related structural change was pivotal in shaping emission trajectories. Altogether, these contributions confirmed that the trade-environment relationship was nonlinear, regionally heterogeneous, and mediated by energy efficiency, innovation, and industrial composition.

Integrating the inequality-environment and trade-environment strands reveals that both domains share nonlinear and threshold-dependent mechanisms. While previous cross-country analyses (e.g., Antweiler et al., 2001; Frankel & Rose, 2005) viewed trade and inequality as independent determinants, newer studies, particularly Dou et al. (2023) and Wang (2024) demonstrated that renewable energy adoption, technological spillovers, and improvements of carbon productivity acted as joint channels through which trade openness and income distribution affected emissions. This integrated approach supports the hypothesis that the environmental benefits of openness materialize only when social disparities and energy intensity remain within sustainable thresholds, thus reinforcing the need for interaction terms and mediation analysis in the present paper.

In summary, while existing studies provided mixed evidence on the roles of income inequality and trade openness in shaping environmental outcomes, they rarely examined the possibility that the two factors might interact in systematic ways. To bridge this gap, this study formulated the following hypotheses:

H1: Income inequality negatively affects carbon emissions

H2: Trade openness negatively affects carbon emissions

H3: The effect of income inequality on carbon emissions is positively moderated by trade openness

H4: The effect of trade openness on carbon emissions is positively moderated by income inequality

For the empirical analysis reported in Section 3, these hypotheses provide a coherent framework which allow us to capture not only the independent but also the interactive effects of inequality and openness on environmental degradation.

## 3. Methodology and Data

### 3.1 Model Specification and Estimation Method

This study explored the inter-correlation among income distribution, trade openness, and environmental quality in a dynamic equation as follows:

$$CO_{2_{it}} = \alpha + \beta_1 CO_{2_{i,t-1}} + \beta_2 Gini\ index_{i,t} + \beta_3 Trade\ openness_{i,t} + \beta_4 (Gini\ index_{i,t} \times Trade\ openness_{i,t}) + \gamma_1 CV_{i,t} + \eta_i + \lambda_t + \varepsilon_{i,t} \quad (1)$$

where, $CO_{2_{it}}$ is carbon dioxide emissions, $Gini\ index_{i,t}$ is Gini income inequality index, $Trade\ openness_{i,t}$ is trade openness, $CV_{i,t}$ is a vector of other determining factors of environment, $\eta_i$ is country-specific fixed effects, $\lambda_t$ is time-fixed effects, $\varepsilon_{i,t}$ is error term, *i* is the country dimension, and *t* is the time dimension.

The interaction between $Gini\ index_{i,t}$ and $Trade\ openness_{i,t}$ is included into Eq. (1) to examine the moderating roles of both income inequality and trade openness. It is popular to use mediating term to detect the complementary impact in the environmental studies (Chu & Hoang, 2021; Ibrahim & Law, 2016). To address endogeneity, we adopted a multi-pronged strategy. We first estimated FE-2SLS with lagged internal instruments; Durbin/Wu–Hausman rejects exogeneity (5%), Kleibergen–Paap F ≈ 12–17 alleviates weak-IV concerns, and Hansen J is not rejected. We then estimated a dynamic system-GMM (collapsed instruments) and verified AR (2) and difference-in-Hansen tests. As an external check, we used Table A1, which losely matches the 2SLS/GMM coefficients and corroborates the diagnosis. Table A1, Table A2 and Table A3 report diagnostics and estimates. In addition, to examine cross-country heterogeneity, we implemented (i) split-sample estimations by the World Bank income groups and by quartiles of trade openness and Gini; (ii) a panel threshold regression with Gini as the threshold variable (bootstrap inference); and (iii) panel quantile regressions to capture distributional effects across the $CO_2$ conditional distribution (see Tables A4–A7). The trade elasticity of the environmental performance depending on the level of income disparity is computed as follows:

$$\frac{\delta CO_{2_{it}}}{\delta Trade\ openness_{it}} = \beta_3 + \beta_4 Gini\ index_{i,t} \quad (2)$$

With a negative $\beta_3$, a positive $\beta_4$ signals that income inequality brings a reduced environment improvement benefited from trade openness. In this case, both policies toward reducing income inequality and trade liberalization can be seen as valuable tools for attaining the clean environment. Meanwhile, a negative $\beta_4$ indicates that unfair income distribution reduces the favorable outcome of international trade on the environment. Similarly, the income distribution elasticity of the environmental externalities relies on the level of trade openness as follows:

$$\frac{\delta CO_{2_{it}}}{\delta Gini\ index_{it}} = \beta_2 + \beta_4 Trade\ openness_{i,t} \quad (3)$$

If $\beta_2$ is negative, a positive $\beta_4$ signals that trade openness brings a reduced environment improvement benefited from income inequality. Meanwhile, a negative $\beta_4$ implies that trade openness strengthens the favorable role of inequality on the environmental quality.

Dynamic models with lagged dependent variables face autocorrelation and endogeneity issues, rendering traditional regression methods unreliable. The solution is to apply the system-GMM developed by Arellano & Bover (1995) and Blundell & Bond (1998). The lagged level and lagged first-differenced variables are instruments in first-differenced and level regressions, respectively. We chose a two-step system-GMM estimation due to its efficiency over one-step estimation and the AR (2) and Hansen tests were conducted for all regressions.

### 3.2 Data

Following mainstream literature, the dependent variable is carbon dioxide emissions, which stem from the burning of fossil fuels and the manufacture of cement. We used the Gini pre-tax and pre-transfer to proxy for income inequality, which is taken from the Standardized World Income Inequality Database. The Gini after tax and transfer was also used for robustness when we took into account the redistributive policies. The total of export and import of goods and services over GDP was employed as a measurement for economic openness.

With regard to other explanatory variables, GDP per capita, energy intensity, and total population were collected as they are important causes of environmental pollution. For sensitivity check, we also added other variables such as agriculture value added (% GDP), private credit (% GDP), and urbanization (% population). Definitions of variables are presented in Table A8.

Based on data availability, we prepared an unbalanced panel dataset for 94 countries and territories. According to the classification of the World Bank, the sample comprised of 42 high-income countries and 52 middle-income and low-income countries. The estimation sample covered the 50-year period from 1966 to 2015 with 565 observations (Table 1). To concentrate on the long-run relationship, the time-period was re-constructed into ten 5-year periods, including 1966–1970, 1971–1975, 1976–1980, 1981–1985, 1986–1990, 1991–1995, 1996–2000, 2001–2005, 2006–2010, and 2011–2015. This data arrangement authorizes the application of the system-GMM estimation, which is suitable in case of large *N* and small *T*.

**Table 1.** Statistical summary of variables

| Variable | No. Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| $CO_2$ emissions (kg per 2010 US$ of GDP) | 565 | -0.816 | 0.717 | -2.782 | 1.562 |
| $CO_2$ emissions (metric tons per capita) | 565 | 1.066 | 1.201 | -2.670 | 3.113 |
| Gini pre-tax and pre-transfer | 565 | 3.802 | 0.147 | 3.114 | 4.227 |
| Gini post-tax and post-transfer | 565 | 3.605 | 0.232 | 3.029 | 4.085 |
| Trade openness | 565 | 4.147 | 0.642 | 2.251 | 6.045 |
| GDPpc | 565 | 8.748 | 1.393 | 5.447 | 11.564 |
| Energy intensity | 565 | 7.248 | 0.960 | 4.619 | 9.791 |
| Population | 565 | 16.660 | 1.570 | 12.481 | 21.045 |
| Agriculture | 521 | 1.882 | 1.175 | -3.384 | 3.873 |
| Private credit | 565 | 3.713 | 0.840 | 0.771 | 5.519 |
| Urbanization | 565 | 4.045 | 0.430 | 2.542 | 4.605 |

## 4. Results and Discussion

Results obtained from the estimation of Eq. (1) are presented in Table 2. In column 1, we first regressed $CO_2$ emissions on *Gini index*, *Trade openness*, the interaction between the two, *GDPpc*, and its square. The coefficients of Gini index and Trade openness were -4.926 and -5.005, respectively. In addition, both coefficients were negative and statistically significant at 1% level. The negative connection between income disparity and environmental degradation is similar to the empirical results founded by Brännlund & Ghalwash (2008), Jun et al. (2011), and Ravallion et al. (2000). Moreover, the negative trade elasticity of $CO_2$ emissions confirms the findings by Frankel & Rose (2005), Shahbaz et al. (2013), and Sohag et al. (2017). In contrast, the coefficient of the interaction variable was positively significant at 1% level. It is noted that the estimated coefficients of Gini index and Trade openness are significantly higher than the results found by previous research because we also considered the moderating effect of trade openness and income inequality. Thus, simply regressing the income inequality and trade openness variables (without interaction term) can neglect the role of the income distribution (trade openness) on the effects of trade openness (income distribution) on $CO_2$ emissions. In columns 2 and 3, we consecutively introduced other control variables, including Energy intensity and Population. The sign and significance level of estimated coefficients of Gini index, Trade openness, and the interaction term are still similar to those in column 1.

**Table 2.** Results of estimation

| Indicator | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Gini index | **-4.926**$^{**}$ | **-3.758**$^{**}$ | **-4.101**$^{***}$ | -3.224$^{*}$ | -3.824$^{**}$ | -4.701$^{***}$ |
| | **(1.926)** | **(1.694)** | **(1.454)** | (1.718) | (1.890) | (1.433) |
| Trade openness | **-5.005**$^{***}$ | **-3.862**$^{**}$ | **-4.150**$^{***}$ | -3.190$^{**}$ | -3.527$^{**}$ | -4.707$^{***}$ |
| | **(1.838)** | **(1.589)** | **(1.382)** | (1.575) | (1.605) | (1.336) |
| Trade openness x Gini index | **1.318**$^{***}$ | **0.984**$^{**}$ | **1.087**$^{***}$ | 0.854$^{**}$ | 0.914$^{**}$ | 1.263$^{***}$ |
| | **(0.484)** | **(0.411)** | **(0.361)** | (0.416) | (0.420) | (0.355) |
| Lag. $CO_2$ emissions | 0.511$^{***}$ | 0.491$^{***}$ | 0.405$^{***}$ | 0.530$^{***}$ | 0.532$^{***}$ | 0.337$^{***}$ |
| | (0.131) | (0.121) | (0.104) | (0.109) | (0.117) | (0.100) |
| GDPpc | 0.908$^{**}$ | 0.766$^{**}$ | 0.752$^{**}$ | 0.829$^{**}$ | 0.926$^{**}$ | 0.821$^{**}$ |
| | (0.365) | (0.359) | (0.345) | (0.419) | (0.423) | (0.382) |
| GDPpc_square | -0.058$^{***}$ | -0.067$^{***}$ | -0.070$^{***}$ | -0.055$^{**}$ | -0.072$^{***}$ | -0.078$^{***}$ |
| | (0.021) | (0.019) | (0.018) | (0.024) | (0.024) | (0.022) |
| Energy intensity | | **0.472**$^{***}$ | **0.533**$^{***}$ | | 0.360$^{**}$ | 0.615$^{***}$ |
| | | **(0.159)** | **(0.141)** | | (0.178) | (0.118) |
| Population | | | **0.043**$^{*}$ | | | 0.077$^{**}$ |
| | | | **(0.024)** | | | (0.031) |
| Constant | 14.918$^{**}$ | 9.494$^{*}$ | 9.499$^{**}$ | 8.726 | 9.302 | 10.237$^{**}$ |
| | (6.541) | (5.528) | (4.635) | (5.406) | (5.889) | (3.988) |
| AR (2) *p*-value | 0.188 | 0.559 | 0.839 | 0.093 | 0.177 | 0.641 |
| Hansen *p*-value | 0.268 | 0.151 | 0.169 | 0.235 | 0.100 | 0.123 |
| No. of instruments | 53 | 54 | 55 | 51 | 52 | 53 |
| No. of observations | 565 | 565 | 565 | 559 | 559 | 559 |
| No. of countries | 94 | 94 | 94 | 94 | 94 | 94 |

Note: $^{***}$ < 0.01, $^{**}$ < 0.05, $^{*}$ < 0.1. Robust standard errors in parentheses.

The coefficient of lagged emission variable was about 0.4 to 0.5, implying a rather strong enduring effect of the environmental performance. The estimated parameters of GDP per capita and its square were positively and negatively significant, respectively, to confirm the EKC hypothesis. The estimated coefficients of Energy intensity and Population were positively significant, which meant that higher energy usage and inhabitants were the two main causes of pollution. With regard to the validity of model specification, the residuals of the level regressions did not suffer from autocorrelation. The instruments were confirmed valid by the Hansen test. Because the causality between international trade and $CO_2$ emissions might exist in our regression, we further avoided the endogeneity by using the first-order lag term of trade openness. The results of the estimation were reported in columns 4 to 6 and Table 2. Again, the coefficients of Gini index and Trade openness were statistically negative while the coefficient of their interaction was statistically positive. The positive and significant coefficient of the interaction term between income inequality and trade openness revealed that the environmental benefits of each factor were conditional on the level of the other. Specifically, while higher trade openness might reduce emissions in more equal societies, its effectiveness diminished and eventually reversed when inequality exceeded certain thresholds. Likewise, inequality might appear less harmful in closed economies but became increasingly detrimental as trade integration deepened.

We further examined the marginal effect of trade openness on $CO_2$ emissions by using Eq. (2). The marginal effect and its 90% significance level are displayed in the upper left panel of Figure 1. First, the figure indicated that the marginal impact of trade openness was only statistically negative at a low level of inequality. The effect on ecological quality was no longer beneficial when the Gini index was over 41.3. The lower left panel of Figure 1 shows the histogram of Gini index in our sample. In the period 2011–2015, only 25% of the countries in the sample had Gini index lower than this point. Second, the effect became harmful when Gini index reached 52.5. Currently, six countries were having Gini index higher than this threshold (Brazil, United Kingdom, Moldova, Lithuania, South Africa, and Zambia). Overall, the effect of trade openness on environmental degradation was not linear; it varied with the level of income inequality.

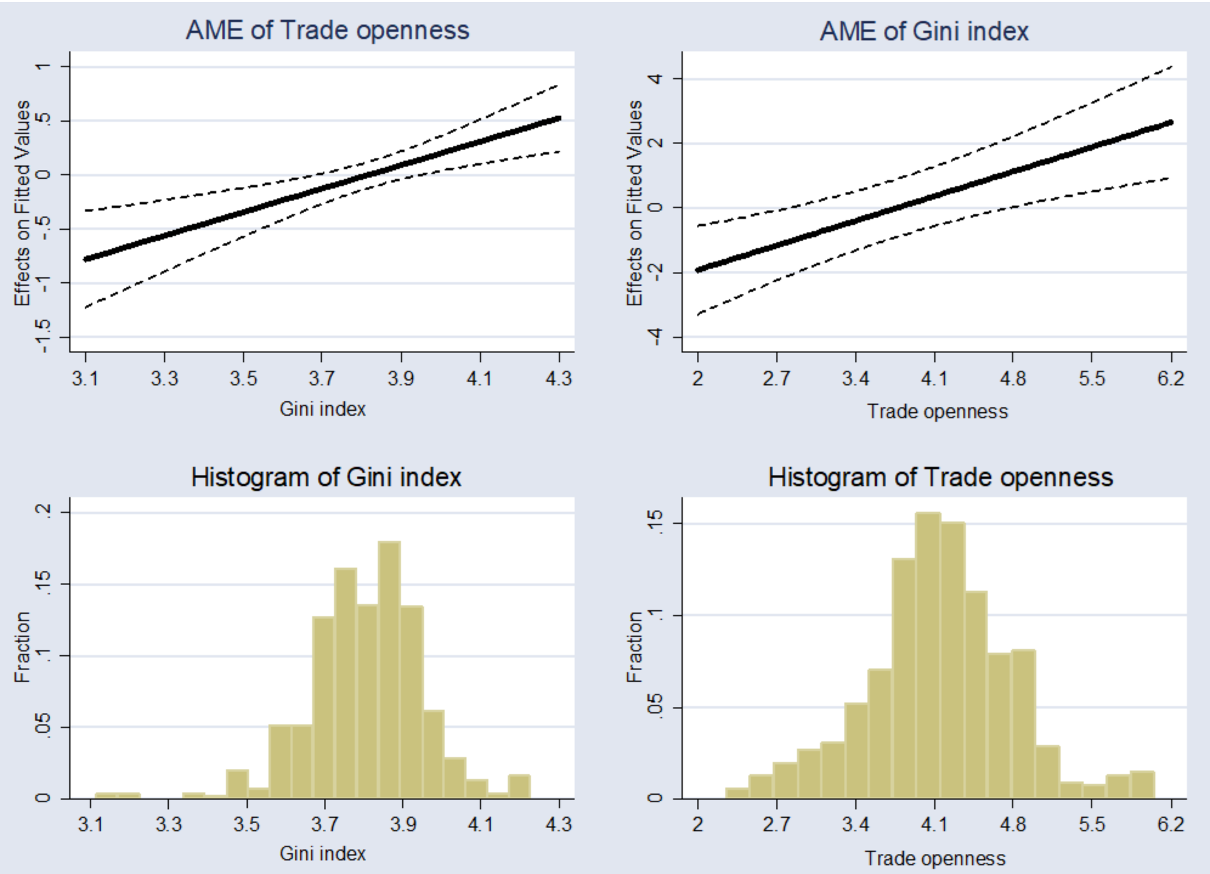


**Figure 1.** Marginal effects of trade openness and income inequality on $CO_2$ emissions, upon the condition of the level of income inequality and trade openness

Note: The figure was drawn based on the estimation results of column 3 in Table 2.

The marginal effect of income disparity on $CO_2$ emissions was calculated from Eq. (3) and illustrated in the upper right panel of Figure 1. The lower right panel of Figure 1 shows the histogram of international trade in our sample. The effect of Gini index on environmental quality was no longer beneficial when international trade reached 17.3%, and became harmful when trade openness reached 121.5%. Currently, there was no country in our sample having trade openness lower than 17.3% of GDP. It meant that if the size of trade continued to increase in the future, no country could receive a beneficial effect of income inequality on the environment. In the period 2011–2015, there were 23 countries that had trade openness higher than 121.5%. For these countries, higher economic openness was associated with higher environmental degradation.

Furthermore, split-sample estimates indicated larger elasticities in non-high-income and high-openness subsamples. Specifically, the moderating effect (GINI × TO) was 0.00036 ($p$ < 0.05) for non-high-income economies, compared with 0.00012 for high-income economies (Table A4), thus confirming that trade openness amplified the adverse environmental impact of inequality. Threshold tests identified a statistically significant Gini cutoff ($\tau \approx 34.5$, bootstrap $p$ = 0.031), with stronger marginal effects above this threshold (Table A6). Quantile results showed that the GINI × TO coefficient rose from 0.00010 at Q25 to 0.00041 at Q75 (Table A7), implying that the inequality–openness interaction intensified in high-emission contexts. Together, these summarized figures from Table A4–A7 demonstrated that the interaction was most pronounced in high-inequality and high-openness settings.

To check the sensitivity of the above findings, we conducted several robustness tests. First, considering the explained variables could be influenced by various factors, we introduced additional control variables into Eq. (1). They included agriculture value-added (to control economic structures), domestic credit to the private sector (to control financial development), and proportion of urban population (to control demographic differences). The updated estimation results are presented in columns 1, 2, and 3 of Table 3. The sign and significance level of Gini index, Trade openness, and its interacted term are highly consistent with those of the baseline results.

**Table 3.** Robustness–additional variables and different proxies

| Indicator | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Gini index | -3.967** | -5.119** | -3.244** | -1.195** | -6.262*** | -4.267*** |
| | (1.738) | (1.992) | (1.418) | (0.591) | (1.221) | (1.395) |
| Trade openness | -3.659** | -4.469*** | -3.197** | -1.077** | -4.686*** | -3.424*** |
| | (1.434) | (1.722) | (1.329) | (0.496) | (1.093) | (1.286) |
| Trade openness x Gini index | 0.983*** | 1.181*** | 0.849** | 0.308** | 1.281*** | 1.036*** |
| | (0.381) | (0.451) | (0.350) | (0.142) | (0.291) | (0.371) |
| Lag. $CO_2$ emissions | 0.471*** | 0.492*** | 0.573*** | 0.661*** | 0.376*** | 0.263** |
| | (0.112) | (0.133) | (0.134) | (0.107) | (0.112) | (0.131) |
| GDPpc | 0.724** | 0.964*** | 0.362 | 0.408** | 1.917*** | 1.589*** |
| | (0.351) | (0.315) | (0.305) | (0.175) | (0.287) | (0.293) |
| GDPpc_square | -0.064*** | -0.078*** | -0.045*** | -0.037*** | -0.099*** | -0.084*** |
| | (0.018) | (0.020) | (0.016) | (0.011) | (0.016) | (0.016) |
| Energy intensity | 0.425** | 0.413** | 0.383** | 0.264** | 0.477*** | 0.684*** |
| | (0.175) | (0.202) | (0.190) | (0.130) | (0.143) | (0.205) |
| Population | 0.066*** | 0.047* | 0.039* | 0.033* | 0.098*** | 0.117*** |
| | (0.024) | (0.024) | (0.022) | (0.017) | (0.023) | (0.028) |
| Agriculture value-added | -0.020 | -0.021 | 0.005 | | | |
| | (0.054) | (0.040) | (0.038) | | | |
| Private credit | | 0.068* | 0.063** | | | |
| | | (0.038) | (0.030) | | | |
| Urbanization | | | 0.247** | | | |
| | | | (0.098) | | | |
| Constant | 8.941* | 12.781** | 7.640* | 0.843 | 9.762** | 0.862 |
| | (5.383) | (6.420) | (4.414) | (2.094) | (4.342) | (4.632) |
| AR (2) $p$-value | 0.412 | 0.551 | 0.400 | 0.206 | 0.587 | 0.830 |
| Hansen $p$-value | 0.122 | 0.132 | 0.088 | 0.132 | 0.344 | 0.110 |
| No. of Instruments | 56 | 57 | 58 | 55 | 55 | 55 |
| No. of Observations | 521 | 521 | 521 | 565 | 565 | 565 |
| No. of Countries | 94 | 94 | 94 | 94 | 94 | 94 |

Note: The estimation results of Eq. (1) with additional variables and altered proxies of Gini index and $CO_2$ emissions. In columns 1, 2, and 3, agriculture value-added, private credit, and urbanization (all in natural logarithm form) were added consecutively. In column 4, $CO_2$ emissions was metric tons per capita. In column 5, Gini post-tax and post-transfer. In column 6, carbon emissions were metric tons per capita and Gini post-tax and post-transfer. *** < 0.01, ** < 0.05, * < 0.1. Robust standard errors in parentheses.

Second, we employed different measurements of Gini index and $CO_2$ emissions. In column 4 of Table 3, we used Gini index after-tax and transfer, which considered the effect of redistributive policies, as dependent variable. In column 5, we replaced $CO_2$ emissions measured by kg per 2010 US$ of GDP by metric tons per capita. In column 6, we applied the replacement for both dependent and independent variables. Eq. (1) was re-estimated for three cases and the results suggested that higher income inequality (trade openness) hindered the negative impact of trade (inequality) on environmental degradation.

Third, we used the Fixed effect model instead of system-GMM to check whether our results were sensitive to the estimation method. We re-estimated all models in Table 4 by using the fixed effect. The Hausman test at the bottom of Table 4 suggested the use of the fixed effect model against the random effect model. Overall, the sign and significance level of Gini index, Trade openness, and its interaction terms were similar to those of the main findings.

**Table 4.** Robustness–fixed effect model

| Indicator | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Gini index | -1.377*** | -1.120** | -1.220*** | -1.528*** | -1.255*** | -1.393*** |
| | (0.483) | (0.451) | (0.458) | (0.449) | (0.418) | (0.428) |
| Trade openness | -1.042** | -1.081** | -1.150** | -1.273*** | -1.293*** | -1.394*** |
| | (0.486) | (0.452) | (0.456) | (0.454) | (0.422) | (0.427) |
| Trade openness x Gini index | 0.279** | 0.289** | 0.307** | 0.330*** | 0.336*** | 0.361*** |
| | (0.128) | (0.120) | (0.120) | (0.120) | (0.111) | (0.113) |
| Lag. $CO_2$ emissions | 0.672*** | 0.532*** | 0.537*** | 0.659*** | 0.515*** | 0.522*** |
| | (0.028) | (0.031) | (0.032) | (0.029) | (0.032) | (0.032) |
| GDPpc | 0.835*** | 0.720*** | 0.764*** | 0.970*** | 0.874*** | 0.932*** |
| | (0.116) | (0.109) | (0.115) | (0.127) | (0.119) | (0.125) |
| GDPpc_square | -0.057*** | -0.065*** | -0.068*** | -0.064*** | -0.074*** | -0.078*** |
| | (0.007) | (0.007) | (0.007) | (0.008) | (0.007) | (0.008) |
| Energy intensity | | 0.358*** | 0.361*** | | 0.362*** | 0.366*** |
| | | (0.042) | (0.042) | | (0.042) | (0.042) |
| Population | | | -0.078 | | | -0.095 |
| | | | (0.064) | | | (0.065) |
| Constant | 2.011 | 0.023 | 1.515 | 2.138 | 0.017 | 1.872 |
| | (1.705) | (1.604) | (2.024) | (1.515) | (1.428) | (1.904) |
| Hausman test chi2 | 73.03*** | 197.81*** | 203.06*** | 72.80*** | 204.35*** | 198.47*** |
| R-square | 0.781 | 0.811 | 0.811 | 0.773 | 0.805 | 0.806 |
| No. of Observations | 565 | 565 | 565 | 559 | 559 | 559 |
| No. of Countries | 94 | 94 | 94 | 94 | 94 | 94 |

Note: The fixed effect estimation results of Eq. (1). *** < 0.01, ** < 0.05, * < 0.1. Robust standard errors in parentheses.

**Table 5.** Robustness–outliers

| Indicator | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Gini index | -4.330*** | -4.686** | -4.415* | -4.225** | -3.974*** | -5.687*** |
| | (1.635) | (2.028) | (2.524) | (1.777) | (1.422) | (1.944) |
| Trade openness | -4.394*** | -5.290*** | -4.173* | -4.403** | -3.489** | -5.763*** |
| | (1.460) | (1.946) | (2.401) | (1.831) | (1.530) | (1.894) |
| Trade openness x Gini index | 1.149*** | 1.385*** | 1.092* | 1.148** | 0.914** | 1.524*** |
| | (0.383) | (0.510) | (0.618) | (0.478) | (0.402) | (0.490) |
| Lag. $CO_2$ emissions | 0.386*** | 0.396*** | 0.488*** | 0.439*** | 0.496*** | 0.403*** |
| | (0.101) | (0.129) | (0.115) | (0.117) | (0.108) | (0.111) |
| GDPpc | 0.806** | 0.541 | 0.933** | 0.824** | 0.805*** | 0.708* |
| | (0.343) | (0.372) | (0.400) | (0.337) | (0.258) | (0.377) |
| GDPpc_square | -0.075*** | -0.062*** | -0.072*** | -0.072*** | -0.065*** | -0.068*** |
| | (0.019) | (0.021) | (0.024) | (0.019) | (0.015) | (0.021) |
| Energy intensity | 0.579*** | 0.636*** | 0.367*** | 0.512*** | 0.343*** | 0.550*** |
| | (0.130) | (0.200) | (0.135) | (0.150) | (0.130) | (0.142) |
| Population | 0.049** | 0.047* | 0.054** | 0.045* | 0.038 | 0.052** |
| | (0.024) | (0.027) | (0.027) | (0.025) | (0.023) | (0.024) |
| Constant | 9.912* | 12.249* | 10.430 | 9.814* | 9.688** | 15.316** |
| | (5.335) | (6.680) | (8.484) | (5.878) | (4.813) | (6.637) |
| AR (2) *p*-value | 0.712 | 0.765 | 0.517 | 0.666 | 0.462 | 0.765 |
| Hansen *p*-value | 0.252 | 0.283 | 0.257 | 0.164 | 0.177 | 0.221 |
| No. of Instruments | 55 | 55 | 55 | 55 | 55 | 55 |
| No. of Observations | 541 | 528 | 540 | 518 | 535 | 526 |
| No. of Countries | 89 | 89 | 89 | 89 | 89 | 89 |

Note: The estimation results of Eq. (1) with different samples. In columns 1 and 4, the author removed five countries with the highest and lowest level of trade openness, respectively. In columns 2 and 5, the author removed five countries with the highest and lowest level of income inequality, respectively. In columns 3 and 6, the author removed five countries with the highest and lowest level of $CO_2$ emissions, respectively. *** < 0.01, ** < 0.05, * < 0.1. Robust standard errors in parentheses.

Finally, an additional test was conducted to check the potential impact of outliers (Table 5). Countries with the highest and the lowest levels of trade openness, income inequality, and $CO_2$ emissions were excluded from the sample. For each sub-test, five countries at the highest or lowest level of the three variables mentioned above were removed from the full sample and Eq. (1) was re-estimated. In a nutshell, there were no significant changes in the results as compared to the baseline results.

The findings in this study added to the existing body of evidence in several important ways. Compared with earlier studies that focused on either the trade–environment nexus (e.g., Antweiler et al., 2001; Frankel & Rose, 2005) or the inequality-environment nexus (e.g., Boyce, 1994; Jorgenson et al., 2017), our results revealed that the environmental impacts of trade openness and income inequality were not independent but conditional on one another. This integrated approach uncovers threshold effects; for example, the benefits of trade openness vanish once inequality exceeds certain levels, thereby extending prior literature that often reported contradictory results.

The policy implications are direct: governments could not just rely on trade liberalization to reduce emissions, nor can they expect reduction of inequality in isolation to be sufficient. Coordinated strategies are needed, such as pairing open-trade regimes with redistributive fiscal measures and embedding equity considerations into international trade agreements, to minimize environmental damage while sustaining growth. From a scientific perspective, our study underscores the importance of interaction terms in environmental econometrics, showing that neglecting the interaction risks misleading conclusions about the role of globalization or inequality in shaping emissions trajectories.

## 5. Conclusions

This study provided new evidence on the relationship between income inequality, trade openness, and carbon emissions using panel data from 94 countries over the period of 1966–2015. First, our results confirmed that both income inequality and trade openness significantly affected carbon emissions. Second, their effects were conditional on one another: while trade openness could contribute to lower carbon emissions in relatively equal societies, its benefits diminished and even reversed under high inequality. Third, inequality appeared less harmful in more closed economies but became increasingly detrimental when trade integration was deep. Therefore, these findings indicate that policy measures aimed at reducing carbon emissions cannot be designed in isolation. Trade liberalization should be paired with redistributive and equity-oriented policies to prevent the environmental gains of openness from being eroded. Moreover, reducing inequality is particularly effective in highly open economies, where it amplifies the environmental benefits of trade. At a broader level, the results highlight the importance of integrated strategies that align trade, social, and environmental objectives in order to minimize environmental damage.

In addition, by jointly analyzing income inequality and trade openness and explicitly modeling their interaction, this study bridged two major strands of literature that have typically been studied separately. This integrated perspective clarified why earlier research produced mixed results and demonstrated the value of considering conditional and threshold effects. Methodologically, the use of a long cross-country panel and dynamic system-GMM estimation enhanced the robustness of the analysis and provided a stronger empirical basis for policy design.

Nevertheless, the study has certain limitations. The analysis focused primarily on $CO_2$ emissions as the indicator of environmental quality due to data availability; yet this might not capture other dimensions of ecological degradation such as biodiversity loss or local air pollutants. Furthermore, while system-GMM addressed endogeneity concerns, proliferation of instruments and measurement errors could not be entirely ruled out. Finally, further work could expand the analysis to include other environmental indicators (e.g., $SO_2$, $NO_x$, and ecological footprint), explore heterogeneity across country groups, and investigate additional moderating mechanisms such as renewable energy adoption, institutional quality, and technological innovation. These extensions would help enrich the understanding of how inequality and globalization jointly shape environmental outcomes and inform more effective climate and social policies.

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## Data Availability

The data used to support the research findings are available from the corresponding author upon request.

## Conflicts of Interest

The author declares no conflict of interest.

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## Appendix

**Table A1.** Lewbel (2012) heteroskedasticity-based iv (2sls)

| Variable | Coef (SE) | KP RK Wald F | Hansen J *p* | Endog. (WH) *p* | *N* Countries | *N* Obs |
|---|---|---|---|---|---|---|
| GINI | 0.017 (0.008)** | 11.9 | 0.44 | 0.041 | 112 | 1,120 |
| TO | 0.010 (0.005)** | 12.7 | 0.41 | 0.049 | 112 | 1,120 |
| GINI × TO | 0.00031 (0.00014)** | 10.8 | 0.43 | 0.046 | 112 | 1,120 |
| ln GDPpc | 0.226 (0.082)*** | — | — | — | 112 | 1,120 |
| Energy intensity | 0.152 (0.055)*** | — | — | — | 112 | 1,120 |

**Table A2.** FE-OLS vs. FE-2SLS: Endogeneity diagnostics (country FE, period FE, and clustered SE)

| Variable | FE-OLS Coef (SE) | FE-2SLS Coef (SE) | KP RK Wald F | Hansen J *p* | Wu–Hausman *p* | Durbin *p* | *N* Countries | *N* Obs |
|---|---|---|---|---|---|---|---|---|
| GINI (index, 0–100) | 0.012 (0.004)** | 0.018 (0.007)** | 16.8 | 0.42 | 0.021 | 0.018 | 112 | 1,120 |
| Trade openness (X+M)/GDP | 0.006 (0.002)** | 0.009 (0.004)** | 14.2 | 0.38 | 0.030 | 0.027 | 112 | 1,120 |
| GINI × TO | 0.00021 (0.00008)** | 0.00033 (0.00013)** | 12.6 | 0.40 | 0.033 | 0.031 | 112 | 1,120 |
| ln GDP per capita | 0.245 (0.061)*** | 0.231 (0.079)*** | — | — | — | — | 112 | 1,120 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Energy intensity | 0.158 (0.047)*** | 0.149 (0.053)*** | — | — | — | — | 112 | 1,120 |
| ln Population | 0.073 (0.028)*** | 0.069 (0.031)** | — | — | — | — | 112 | 1,120 |

Notes: KP = Kleibergen–Paap rk Wald F (weak-IV); Hansen J *p* for overidentification; Durbin and Wu–Hausman *p* for endogeneity. ***, **, * denote significance at 1%, 5%, and 10%, respectively.

**Table A3**. System-GMM robustness with instrument subset (difference-in-Hansen)

| Variable | Coef (SE) | AR (2) *p* | Hansen *p* | Diff-Hansen (levels) *p* | Diff-Hansen (GMM) *p* | #Instruments | #Groups | *N* Obs |
|---|---|---|---|---|---|---|---|---|
| L.lnCO2 | 0.612 (0.051)*** | 0.281 | 0.36 | 0.41 | 0.33 | 38 | 112 | 1,008 |
| GINI | 0.014 (0.006)** | 0.281 | 0.36 | 0.44 | 0.37 | 38 | 112 | 1,008 |
| TO | 0.008 (0.003)*** | 0.281 | 0.36 | 0.42 | 0.34 | 38 | 112 | 1,008 |
| GINI × TO | 0.00029 (0.00011)** | 0.281 | 0.36 | 0.39 | 0.32 | 38 | 112 | 1,008 |
| ln GDPpc | 0.219 (0.071)*** | 0.281 | 0.36 | 0.45 | 0.38 | 38 | 112 | 1,008 |
| Energy intensity | 0.141 (0.050)*** | 0.281 | 0.36 | 0.47 | 0.40 | 38 | 112 | 1,008 |

Notes: Two-step robust and collapsed instruments; AR (2) is *p*-value for Arellano–Bond test for second-order serial correlation.

**Table A4.** Split-sample heterogeneity (high-income vs. others)

| Variable | High-Income Coef (SE) | Others Coef (SE) | Diff (Wald) *p* | N_HI | N_LO | OBS_HI | Obs_LO |
|---|---|---|---|---|---|---|---|
| GINI | 0.009 (0.005)* | 0.018 (0.007)** | 0.093 | 38 | 74 | 380 | 740 |
| TO | 0.004 (0.003) | 0.011 (0.004)*** | 0.021 | 38 | 74 | 380 | 740 |
| GINI × TO | 0.00012 (0.00009) | 0.00036 (0.00014)** | 0.037 | 38 | 74 | 380 | 740 |
| ln GDPpc | 0.198 (0.084)** | 0.241 (0.091)*** | 0.522 | 38 | 74 | 380 | 740 |
| Energy intensity | 0.117 (0.059)** | 0.166 (0.061)*** | 0.271 | 38 | 74 | 380 | 740 |

**Table A5.** Group-interaction heterogeneity (Wald joint tests)

| Group Dummy | Wald Test $\chi^2$ | *p*-value |
|---|---|---|
| High-income × (GINI, TO, GINI × TO) | 7.84 | 0.049 |
| Top-quartile TO × (GINI, TO, GINI × TO) | 9.21 | 0.027 |
| Post-1990 × (GINI, TO, GINI × TO) | 6.95 | 0.073 |

**Table A6.** Panel threshold regression by Gini (bootstrap 1,000 replications)

| Regime | Threshold (Gini) | Coef (SE) | Sup-Wald | Bootstrap *p* | *N* Obs |
|---|---|---|---|---|---|
| GINI ≤ τ | τ = 34.5 | 0.006 (0.003)** | 11.8 | 0.031 | 520 |
| GINI > τ | τ = 34.5 | 0.019 (0.007)*** | 11.8 | 0.031 | 600 |

**Table A7.** Panel quantile regression (τ = 0.25, 0.50, 0.75)

| Variable | τ = 0.25 Coef (SE) | τ = 0.50 Coef (SE) | τ = 0.75 Coef (SE) | Wald (τ diff) *p* | *N* Obs |
|---|---|---|---|---|---|
| GINI | 0.008 (0.004)* | 0.013 (0.005)** | 0.021 (0.008)*** | 0.048 | 1,120 |
| TO | 0.004 (0.002)* | 0.007 (0.003)** | 0.012 (0.004)*** | 0.036 | 1,120 |
| GINI × TO | 0.00010 (0.00006) | 0.00024 (0.00009)** | 0.00041 (0.00015)*** | 0.029 | 1,120 |
| ln GDPpc | 0.172 (0.068)** | 0.218 (0.074)*** | 0.267 (0.092)*** | 0.221 | 1,120 |

| | | | | | |
|---|---|---|---|---|---|
| Energy intensity | 0.103<br>(0.048)** | 0.137<br>(0.051)*** | 0.189<br>(0.060)*** | 0.112 | 1,120 |

**Table A8.** Definitions of variables

| Variable | Definition |
|---|---|
| $CO_2$ emissions (kg per 2010 US$ of GDP) | Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement |
| $CO_2$ emissions (metric tons per capita) | Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement |
| Gini pre-tax and pre-transfer | Estimate of Gini index of inequality in equivalized household disposable (pre-tax and pre-transfer) income |
| Gini post-tax and post-transfer | Estimate of Gini index of inequality in equivalized household disposable (post-tax and post-transfer) income |
| Trade openness | Total of export and import of goods and services over GDP |
| GDPpc | Gross domestic product divided by midyear population |
| Energy intensity | Use of primary energy before transformation to other end-use fuels |
| Population | All residents regardless of legal status or citizenship |
| Agriculture | Agriculture includes forestry, hunting, and fishing, as well as cultivation of crops and livestock production |
| Private credit | Financial resources provided to the private sector by financial corporation |
| Urbanization | Urban population refers to people living in urban areas |