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Re-examining the link between economic inequality and environmental performance:A perspective based on the moderating effects of biodiversity

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Abstract: Inequality in economic distribution and environmental deterioration are two important issues facing the world today, and the relationship that exists between them is not yet clear. In what specific ways does economic inequality impact on the environment? Do redistributive instruments to combat income inequality cause environmental problems? Does the current state of the environment also have an impact on economic inequality? Answering these questions has important implications for the development of economic and environmental policies in countries around the world. This paper examines the relationship between the environment and income distribution by collecting panel data from 156 countries or regions around the world over the period 2006-2018. Furthermore, we examine the changes in the marginal utility of economic inequality on climate under different biodiversity scenarios by adding biodiversity as a moderating variable. The results show that, in the fixed-effects model, economic inequality has a positive effect on environmental performance in general, and that economic inequality will mainly affect the sub part of ecosystem vitality, with the most significant effect on climate change. Biodiversity has a moderating effect on economic inequality, with the most significant non-linear moderating effect.

Keywords: income inequality; environmental performance; panel regression; moderating effect

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1. Introduction

Environmental deterioration and economic inequality are major issues human society is facing today, and the United Nations adopted the *2030 Agenda for Sustainable Development* [1] in 2015, incorporating both of them into the 17 Sustainable Development Goals (SDGs). On the one hand, efforts to reduce the inequality of income distribution, narrow the income gap between social classes, reduce global environmental pollution and protect the earth's ecology to cope with environmental deterioration have become challenges that all countries in the world need to tackle together [2,3]. On the other hand, there is a strong link between inequality in income distribution and environmental performance [4]. The environmental performance is further influenced by the differences in resource allocation in government policies for different social classes or regions of the population economy [5]. At the same time, there are also different marginal effects of groups on the environment under different income conditions [6,7]. Due to these complex linkages, the mechanism and scope of these two effects are currently unclear.

Policymakers often need to consider the relationship between social stability, economic development and environmental protection. In most cases, this is a policy trade-off [8]. It is difficult for countries to reconcile multiple objectives in short-term development, while trade-offs must be made in long-term plans accordingly [9]. Therefore, understanding the relationship between economic inequality and environmental performance and analysing the intrinsic link between the two is important in policy making.

2. Literature Review

There has been much discussion of the current theoretical framework of environmental and income distribution inequality. For example, Yulin Liu et al. examined the impact of income inequality on household carbon emissions in China and concluded that the effect was positive: households in counties with higher income inequality emitted more [10].

However, the theoretical results on the general environmental aspects of the world are ambiguous for the moment. A variety of different environment-inequality Kuznets hypotheses have been proposed. The earliest view comes from Boyce's political perspective [11,12], which argues that the unequal distribution of wealth gives a small number of people access to vast resources that will influence their political influence. This further secures their profitable activities in polluting the environment, while the majority of the less wealthy bear the consequences of environmental pollution. Thus, the unequal distribution of wealth will influence environmental performance through national politics. The theory lies in that countries with a balanced income distribution tend to be more democratic, and that popular decision making results in more environmental policies that are in the public interest, which in turn improves environmental performance. This view has also been empirically supported by many scholars who argue that a given degree of democracy will play an enhanced role in the relationship between income inequality and environmental performance [13,14]. The existence of a direct, positive relationship between economic growth and CO2 emissions has also been recently confirmed by scholars using the environmental Kuznets curve as a tool [15]. Some studies found that the impact of income inequality and financial instability on CO2 emissions in the context of fossil fuel energy, economic development, industrialization and trade openness, showing that income inequality and industrialization significantly reduced environmental degradation, while fossil fuels, trade openness and economic growth reduced environmental quality [16].What's more, there are also scholars found that income has a positive effect on energy consumption per capita [17].

Nevertheless, there are a number of problems with the discussion of the relationship through political channels, as evidenced by the following: (I) There is also a clear pro-environmental behaviour of the wealthy [18]. (II) There is not necessarily a strong link between high incomes and profitable ways of destroying the environment [19]. (III) The relationship between income inequality and the degree of democracy is also open to further discussion [20]. (IV) Elements of democracy are positively correlated with the environment in high-income countries [21]. On the other hand, the marginal propensity to emit (MPE) theory has also been applied to the link between inequality and the environment [22], which can explain the link between inequality and emissions, as marginal propensity to emit is often associated with income. On a large number of empirical results, the relationship is negative for income and MPE [23,24], but there is a segment of the population whose emissions may be zero due to lack of access to modern energy sources such as electricity [25,26]. This relationship has also been examined from the perspective of consumption, where it has been argued that economic inequality will exacerbate comparative consumption within the class and, coupled with the Van Buren effect, will lead to an increase in total consumption and further damage the environment [27]. In order to maintain the same living conditions as the climbing classes, the average income group increases its working hours and generates more consumption that is detrimental to the environment [28–30].

A number of empirical studies have been generated to test the above theoretical framework and to quantify the association between unequal economic distribution and the environment by using different empirical models. Table A in the Appendix summarizes the empirical studies on this topic in recent years, including the relationships tested, the main methods and data used and the results of the empirical studies.As can be seen from Table A, current research on this topic has mostly explored the correlation between economic inequality and carbon emissions, which are only a small part of the environmental impact of climate change. To the best of our knowledge, no scholar has explored the relationship between comprehensive environmental indicators and indicators of economic inequality. This paper will use the Economic Inequality Index and the Environmental Performance Index (EPI) for analysis in an attempt to understand which specific aspects of the environment economic inequality will be associated with. Further, regressions using biodiversity as a moderating variable were conducted to explore the non-linear performance of these two composite indicators.

3. Data Description

This paper uses an unbalanced panel of data for 156 countries or territories for the period 2006-2018, with the main indicators being the Standardized Income Inequality Index (SEIID) and the Environmental Performance Index (EPI). One of the standardized income inequality measures is from The Standardized World Income Inequality Database (SWIID) [31], which is used mainly because SWIID standardizes inequality indices, making them comparable across countries, and because the database provides sufficient international data and has been widely used in a number of studies [32,33]. The EPI Index from the Yale Center for Environmental Law & Policy provides a measure of global sustainable development based on data and contains environmental data from 180 countries published from 2006 to date. The database is published every two years and has been widely accepted by scholars [34,35]. Further, taking into account the influence of politics and the degree of internationalisation on economic inequality and the environment as mentioned in previous studies, this paper includes a freedom house index to control for democracy [14,20] and international trade tax values to control for internationalisation. The economic and environmental indicators, including international trade tax values, GDP and forest cover, are taken from the World Development Indicators (WDI). To explore the specific impact of economic inequality on different aspects of the environment, the EPI index is also decomposed. As the EPI index has undergone several iterations and there are differences in the criteria used to calculate it, only some of the sub-indicators of the EPI that are more consistent in their calculation methods are selected to assess their impact on economic inequality. Table 1 shows the descriptive statistics of the data used in the paper, and Figures 1 and 2 show the distribution of the EPI index and the SWII inequality index, respectively.

Table 1. Data Summary

Statistic	N	Mean	St. Dev.	Min	Max
Environmental performance index	758	62.618	15.355	20.810	95.500
Gini index household disposable	758	38.360	8.232	23	66
Gini index household market	758	45.950	6.426	22.100	69.600
Total Freedom House	744	6.094	3.589	2.000	14.000
GDP annual growth	691	4.024	3.654	-17.669	34.466
The Share of 10% Highest income	404	29.123	6.420	20.100	51.300
The Share of 10% Lowest income	404	2.582	0.937	0.600	4.500
Global trade tax	430	6.760	8.137	-0.057	48.132
Life expectancy at birth	692	71.566	8.925	43.853	83.602
Forest area (% of land area)	649	30.680	21.162	0.000	98.506
Redistribution	758	7.590	7.537	-5.300	24.800
GDP (in Log)	690	24.986	1.998	19.122	30.339
Forest Area (in Log)	651	10.762	2.136	1.253	15.435
Foreign direct investment (in Log)	131	22.495	1.937	15.710	25.720

Statistic	N	Mean	St. Dev.	Min	Max
Population (in Log)	693	16.268	1.556	9.777	21.044
CO2 Emission (in Log)	652	10.052	2.067	4.733	16.147
Environmental Health Score	734	68.015	24.907	0.000	100.000
Biodiversity Score	758	57.595	27.881	0.000	100.000
Ecosystem Vitality Score	599	57.542	17.293	5.820	95.090
Climate Score	551	60.009	19.584	0.380	99.800
Water and Sanitation Score	596	61.817	27.144	0.000	100.000
Climate and Energy Score	630	63.183	26.457	0.000	100.000

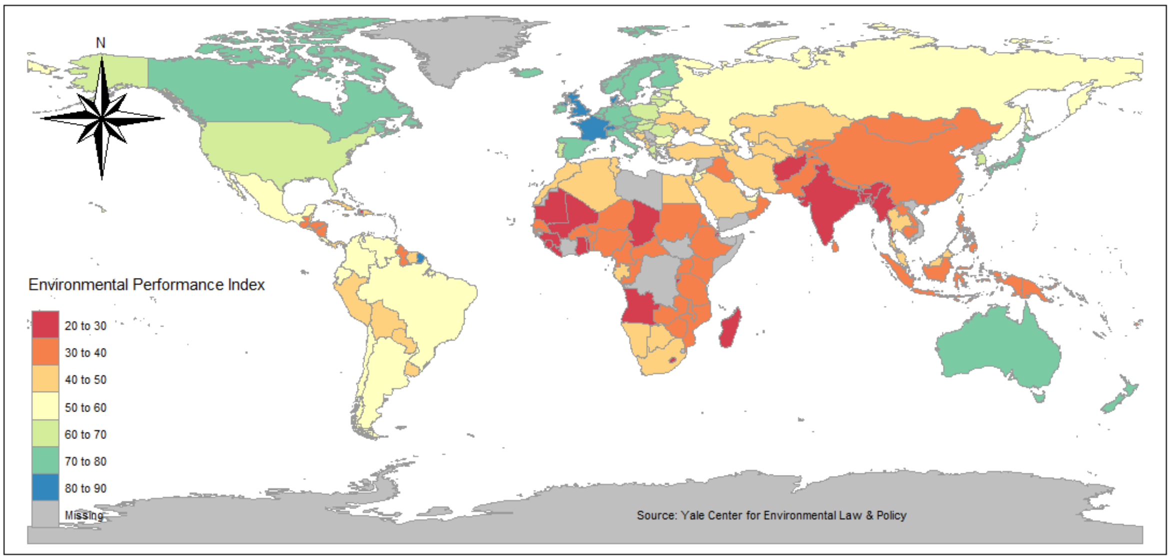


Figure 1. Environmental Performance Index

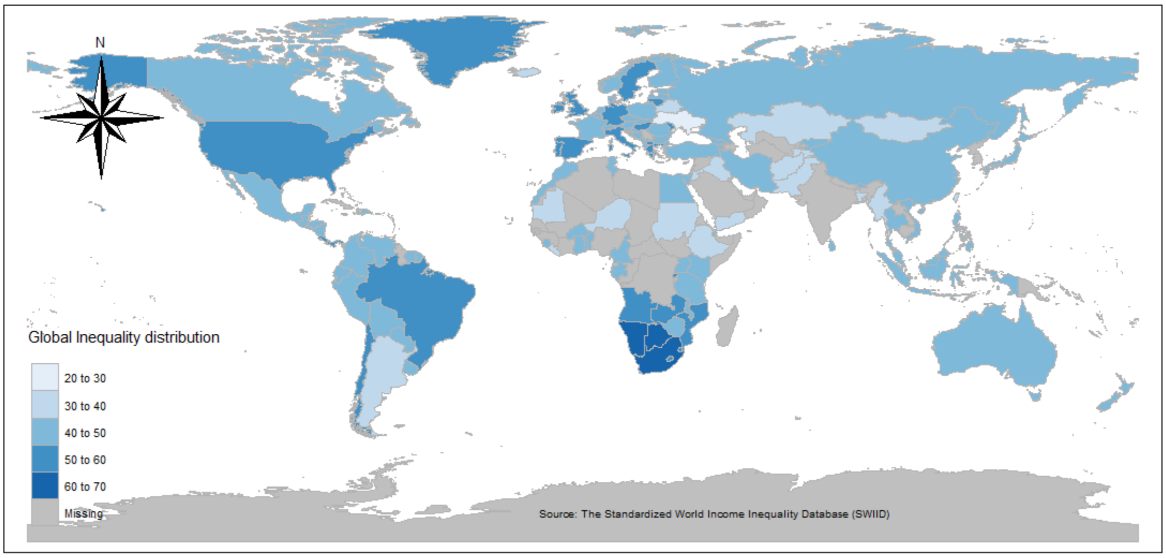


Figure 2. Global Inequality Distribution

4. Method

4.1. Benchmark: Overall EPI and Income Inequality

This paper uses panel data regression to test the relationship between economic inequality and environmental performance. The model setup is divided into two parts. The first part uses a fixed effects model to regress the standardized Gini index on the EPI index, gradually adding control variables to identify the impact of the standardized Gini index on environmental performance. The second part dismantles the EPI and retains the control variables from the first part to understand the specific effects of inequality on various aspects of environmental performance. The first stage EPI explanatory model assumptions are as follows:

$$EPI_{it} = \alpha_i + GINI\beta_1 + \sum Z\beta + u_{it} + \delta_{it} \quad (1)$$

of which α_i are individual effects that do not change over time, *GINI* is the standardised GINI index from the SWIID database, Z represented for the purpose of explaining *GINI* Control variables for accession, u_{it} is the model residual without individual effects, $\hat{\mathrm{I}}_{it}$ is a time fixed effect that does not vary with the individual, β is the parameter to be estimated.

In Stage 2, the EPI indicators are divided into two main sections, environmental health and ecosystem vitality, according to the way they are calculated, and the impact of the inequality index on the sub-projects is further examined. In general, environmental health includes indices for the assessment of the air and water environment and the condition of heavy metals, while ecosystem viability includes indices for the assessment of biodiversity, forest systems, fishing, climate change and energy, air pollution, water resources and agriculture. In the EPI indices from 2006 to the present, the calculations have undergone many modifications and some of the calculated indices have been changed in version changes, and aggregating them into complete time series data is not recommended. In order to avoid the problem of exponential differences due to the calculation method, regressions were also performed using the EPI ranking as a proxy for the indicators. The model assumptions for Stage 2 are as follows:

$$Subitem_{\ it} = \alpha_i + GINI\beta_1 + \sum Z\beta + u_{it} + \delta_{it} \quad (2)$$

The regression terms are consistent with Stage 1, but for the explained variables the sub-scores of the EPI index are used as estimated variables. An overview of the selection of variables for the above-mentioned models is given in Table 2.

Table 2. Regression Variables

Variables	Type	Explanation
Stage 1		
Environmental performance index	Dependent variable	Global Environmental performance index (2006-2018)
Gini index household market	Core independent variable	Estimate of Gini index of inequality in equivalized (square root scale) household market income
Total Freedom House	Control variable	Democracy may be a latent confounder that plays an important role in the nexus [13,14,20]

Variables	Type	Explanation
GDP annual growth	Control variable	
Global trade tax	Control variable	Level of Globalization has a two-way effect on income inequality and environment [36]
Life expectancy at birth	Control variable	
Forest area (% of land area)	Control variable	
Redistribution	Control variable	The difference between Gini index household market and Gini index household disposable
GDP (in Log)	Control variable	
Forest Area (in Log)	Control variable	
Foreign direct investment (in Log)	Control variable	Together with the Global trade tax as a Proxy variable of globalization level
Population (in Log)	Control variable	
CO2 Emission (in Log)	Control and dependent variable	Re-examine the relationship between Carbon emissions and income inequality
Stage 2		
Environmental Health Score	Dependent variable	Sub part of EPI
Ecosystem Vitality Score	Dependent variable	Sub part of EPI
Biodiversity Score	Dependent variable	Sub part of Ecosystem Vitality
Climate Score	Dependent variable	Sub part of Ecosystem Vitality
Climate and Energy Score	Dependent variable	Sub part of Ecosystem Vitality
Water and Sanitation Score	Dependent variable	Sub part of Environmental Health

4.2. Moderating effect of Biodiversity

Since economic inequality is significant for climate change, in order to examine the specific relationship between economic inequality and the environment, this paper adds the exogenous variable 'Biodiversity and Habitat' to the original regression equation (Table 5 Stage 2-2 Regression) to form an interaction term with economic inequality for further analysis. 'Biodiversity and Habitat' is used as a moderating variable to investigate whether the relationship between economic inequality and climate is influenced by 'Biodiversity and Habitat' in the region, i.e. whether the moderating effect of 'Biodiversity and Habitat' is significant.This paper uses three regressions to explore the patterns and methods of the moderation effect, with the main difference being the difference in the construction of the interaction terms. The main model setup for the interaction term regressions in the unbalanced panel data is as follows:

$$Climate_{it} = \beta_0 + \beta_1 GINI_{it} + \beta_2 biodiversity_{it} + \sum Z\beta + u_{it} + \delta_{it} + \alpha_i \quad (3)$$

$$\begin{aligned} Climate_{it} &= \beta_0 + \beta_1 GINI_{it} + \beta_2 biodiversity_{it} + \beta_3 GINI_{it} \times biodiversity_{it} \\ &+ \sum Z\beta + u_{it} + \delta_{it} + \alpha_i \end{aligned} \tag{4}$$

$$\begin{aligned} Climate_{it} &= \beta_0 + \beta_1 GINI_{it} + \beta_2 biodiversity_{it} + \beta_3 GINI_{it} \times biodiversity_{it} \\ &+ \beta_4 GINI_{it} \times biodiversity^2_{\mathrm{it}} + \sum Z\beta + u_{it} + \delta_{it} + \alpha_i \end{aligned} \tag{5}$$

$$\begin{aligned} Climate_{it} &= \beta_0 + \beta_1 GINI_{it} + \beta_2 biodiversity_{it} + \beta_3 GINI_{it} \times biodiversity_{it} \\ &+ \beta_4 GINI^2_{it} \times biodiversity_{it} + \sum Z\beta + u_{it} + \delta_{it} + \alpha_i \end{aligned} \tag{6}$$

Where $Climate_{it}$ is the dependent variable, $GINI_{it}$ significantly influences $Climate_{it}$ as the independent variable, and the relationship between Y and X is influenced by a third variable, $biodiversity_{it}$, which is said to act as the moderating variable (Moderator).

Since the sample data are unbalanced panel data, the following adjustments are made: (1) Use the INTERFLEX command in Stata to draw graphs to visualise the marginal effect of economic inequality on climate for different values of biodiversity under ordinary least squares regression [37]. (2) The original ordinary least squares regression is then changed to a panel data regression. (3) Robust standard error regression is used to prevent interference from heteroskedasticity problems. (4) The main focus is on the significance of the coefficients for the interaction term and the explanatory power of the $Climate_{it}$ interaction term, keeping the control variables as in the previous section. (5) To exclude the effects of multicollinearity, each interaction term is centralised in this paper.

5. Result

5.1. Overall EPI and Income Inequality

R was used to estimate the stage 1 model. In order to ensure the credibility of the model, carbon emissions were also used as an explained variable at this stage and the estimation of this variable yielded similar results as in the previous study. It is noteworthy that in this paper's model, inequality is more strongly correlated with the EPI than with carbon emissions. The two indicators show an inverse variation. This means that there are many other aspects of the environmental impact of economic inequality that need to be explored besides carbon emissions.

In terms of the stage 1 overall, the empirical results of this paper suggest that economic inequality has a positive effect on global environmental performance, which refutes the hypothesis that economic inequality brings about political inequality and thus lax environmental policies. At the same time, this is further supported by the weak significance of the degree of democracy and environment index.

On the other hand, however, the model with carbon emissions as the explanatory variable supports the inferred relationship of economic inequality-political power-environment. The coefficients of the (5) regressions in Table 3 are highly significant, but the significance shifts to the democracy index and other control variables when (6) and (7) regressions are added to the democracy index. This result is consistent with previous research [14].

Among the results in this section, the mixed-effects model reported in the appendix shows different estimation results from the fixed-effects model below, a similar situation to that found in other authors' studies [38], which may be explained by the relatively short panel structure (Small T with Large N). However, given the potentially serious autocorrelation issues in mixed-effects models and the large variation within countries, the analysis in this paper focuses on the results of fixed effects models.

Table 3. Stage 1 Regression

VARIABLES	(1) EPI without Control Variables	(2) EPI with Control Variables	(4) EPI with Control Variables	(5) CO2emis without Control Variables	(6) CO2emis with Control Variables	(7) CO2emis with Control Variables
Gini _ mkt	0.789***	0.944***	0.819**	-0.0478***	0.00141	-0.00254
	(0.251)	(0.354)	(0.329)	(0.0147)	(0.0101)	(0.00919)
log GDP		-2.363	-5.599		1.293***	1.257***
		(4.839)	(4.900)		(0.148)	(0.150)
log Forest area		12.38*	15.54**		-0.577***	-0.501**
		(7.385)	(6.776)		(0.219)	(0.203)
log Population		0.288	-8.005		0.452*	0.335
		(12.77)	(11.23)		(0.254)	(0.248)
log Global trade tax		-0.171	-0.0726		0.0307**	0.0322**
		(0.698)	(0.682)		(0.0126)	(0.0130)
Fh _ total		0.748	0.777		-0.0438***	-0.0441***
		(0.615)	(0.622)		(0.0141)	(0.0141)
Life expan			1.037***			0.0175**
			(0.334)			(0.00681)
Redistribution			-0.935			0.0181
			(0.923)			(0.0217)
2008.year	7.357***	8.466***	8.372***	0.0672***	-0.0525***	-0.0589***
	(0.567)	(0.830)	(0.819)	(0.0145)	(0.0192)	(0.0187)
2010.year	-5.846***	-5.430***	-5.841***	0.111***	-0.0761***	-0.0916***
	(0.779)	(1.178)	(1.149)	(0.0224)	(0.0258)	(0.0261)
2012.year	-13.85***	-11.38***	-12.26***	0.144***	-0.133***	-0.158***
	(0.870)	(1.267)	(1.321)	(0.0298)	(0.0294)	(0.0289)
2014.year	-12.32***	-12.33***	-13.57***	0.178***	-0.180***	-0.214***
	(0.819)	(1.661)	(1.752)	(0.0382)	(0.0357)	(0.0352)
2016.year	5.011***	6.080***	4.673**	0.158***	-0.233***	-0.271***
	(0.731)	(1.823)	(1.834)	(0.0393)	(0.0429)	(0.0434)
2018.year	-7.265***					
	(0.897)					
Constant	29.97**	-62.04	58.41	12.15***	-22.98***	-22.18***
	(11.59)	(244.2)	(220.2)	(0.685)	(4.964)	(4.845)
Individual Effect	YES	YES	YES	YES	YES	YES
Time Fixed Effect	YES	YES	YES	YES	YES	YES
Fixed Effect Model	YES	YES	YES	YES	YES	YES
Observations	758	390	389	652	390	389
R-squared	0.679	0.681	0.689	0.195	0.670	0.678
Number of ID	156	97	96	142	97	96

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5.2. Sub-Item and Income Inequality

This section further extends the results of the previous section by bringing in different sub-projects for regression under the condition that the total effect is significant, and then exploring the lower sub-projects when the primary sub-project is significant. The structural update of the EPI index over many years is taken into account. In this paper, only subprojects that are relatively consistent with the data source and the way they have been calculated over the last fifteen years have been artificially selected, and since the EPI index had not yet been divided into Ecosystem subprojects in 2006, the 2006 sample has been excluded from this paper.

The results show that the overall coefficient for 'Environment Health' is insignificant and the overall coefficient for 'Ecosystem Vitality' is significant for the two main sub-items, while the core explanatory variable of interest for 'Ecosystem Vitality', the 'standardized Gini coefficient', is also significant for Ecosystem Vitality. A strong and significant relationship is also shown, as in Table 4.

Table 4. Stage 2-1 Regression

VARIABLES	(1) Ecosystem Vitality	(2) Environmental Health
Gini _ mkt	1.892**	0.371
	(0.921)	(0.547)
log GDP	-26.18**	0.941
	(12.65)	(7.643)
log Forest area	41.75**	-14.30
	(19.30)	(12.72)
log Population	-26.98	40.55
	(31.95)	(24.74)
log Global trade tax	1.402	-0.311
	(1.335)	(0.757)
Fh _ total	0.903	-0.901
	(1.162)	(1.223)
Life expan	-0.567	1.727**
	(0.755)	(0.790)
Redistribution	-0.787	0.673
	(3.679)	(1.272)
2008.year		7.873***
		(1.404)
2010.year	-10.27***	-8.754***
	(1.608)	(1.565)
2012.year	-18.21***	-15.71***
	(2.802)	(4.495)
2014.year	-16.77***	-9.658***
	(2.748)	(2.762)
2016.year	7.089**	-2.282
	(3.188)	(3.364)
Constant	663.2	-601.1
	(499.1)	(429.1)
Individual Effect	YES	YES
Time Fixed Effect	YES	YES
Fixed Effect Model	YES	YES
Observations	306	375
R-squared	0.585	0.288
Number of ID	93	96

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Different directions of environmental performance are represented in these two sectors. In terms of the EPI 2018 index framework, 'Environmental Health' contains three directions of environmental impact: Air Quality, Water & Sanitation and Health Impacts. It measures the environmental performance that is relevant to human beings. Ecosystem Vitality, on the other hand, includes impacts in the six areas of Water Resources, Agriculture, Forests, Biodiversity and Habitat, Climate and Energy. Due to changes in the data sources used to calculate the index, the EPI index adjusts the selection of indicators with each update. The above regressions do not give us a general answer to the relationship between the two. Based on the above results, secondary indicators with a smaller number of changes and adjustments were selected to further test the relationship. 'Biodiversity and Habitat', 'Agriculture' and 'Climate' are included, and the regression results are shown in Table 5.

Table 5. Stage 2-2 Regression

VARIABLES	(1) Biodiversity	(2) Climate	(3) Agriculture
Gini _ mkt	-0.0112	3.875***	1.041
	(1.211)	(1.360)	(1.948)
log GDP	-27.62*	-22.25	-22.72
	(16.13)	(20.57)	(22.60)
log Forest area	46.79*	41.02	-66.51*
	(26.87)	(38.39)	(36.21)
log Population	-110.2**	36.69	28.23
	(47.43)	(47.63)	(67.70)
log Global trade tax	0.518	-2.994*	-3.270
	(1.251)	(1.711)	(2.997)
Fh _ total	-2.678	-0.153	1.950
	(2.322)	(1.653)	(1.863)
Life expan	1.212	-1.065	-0.252
	(1.045)	(1.672)	(1.439)
Redistribution	-4.550	-1.949	1.591
	(2.859)	(4.707)	(6.166)
2008.year	-0.785		
	(3.433)		
2010.year	17.41***	-18.66***	-16.47***
	(4.145)	(2.170)	(3.254)
2012.year	11.76**	-26.55***	-35.99***
	(5.871)	(4.555)	(5.216)
2014.year	27.63***	-19.41***	-9.482*
	(5.887)	(4.155)	(5.111)
2016.year	45.98***	3.279	0.362
	(6.728)	(6.383)	(6.807)
Constant	1,994**	-501.2	854.5
	(829.6)	(884.6)	(1,052)
Individual Effect	YES	YES	YES
Time Fixed Effect	YES	YES	YES
Fixed Effect Model	YES	YES	YES
Observations	389	276	327
R-squared	0.326	0.468	0.326
Number of ID	96	86	94

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

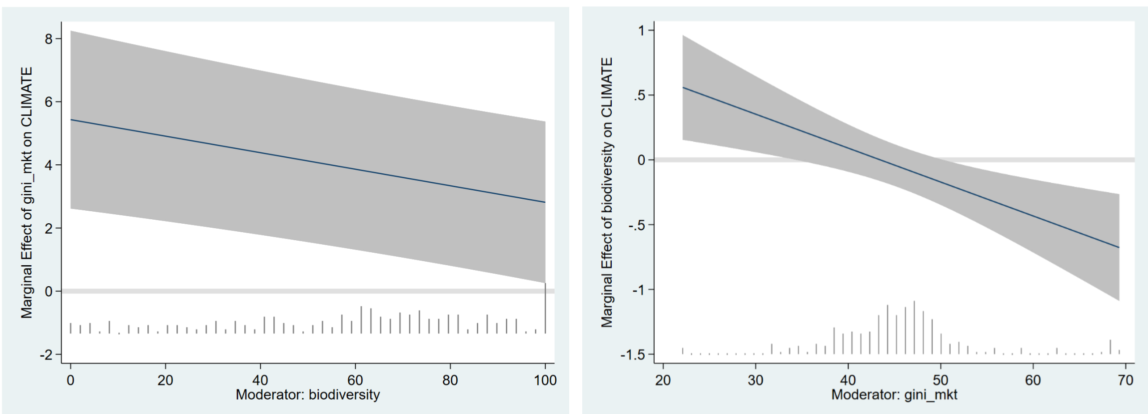
As can be seen from the results in Table 5, economic inequality is specifically significantly correlated with climate change, while there is no correlation with agricultural indicators and biodiversity. There is a positive correlation between increased economic inequality and climate performance, which is consistent with the regression results for stage 1.

5.3. Moderating effect

Climate change is a complex dynamic evolutionary process that can be perturbed by numerous factors. The intensification of human economic activities and the development of scientific and technological civilization in recent centuries have brought climate change issues, including precipitation, global warming and other aspects, to the forefront [39]. After our analysis, we can conclude that the Gini coefficient, as an important economic indicator of the difference in national income of a country, can also reveal the climate situation of a country or region to some extent. Many models of the relationship between the economy and climate change have been developed [40], but they tend to analyse the impact of economic development on climate from a global perspective, without taking into account the impact of internal differences between economic agents on climate. The findings are therefore general in scope and not relevant in the context of national economic differences. On the other hand, changes in the climate of a country or region depend to a large extent on the stability of its original biodiversity from an ecological point of view. Our study combines regional economic differences and complex and variable human activities with local biodiversity to examine the impact on national or regional climate change, which is more comprehensive and effective than a purely economic and ecological approach to either aspect. This view is in line with Cumming's perspective [41].

Similar to Taylor & Irwin [42], we agree that economic differences within a country or region are a critical predictor of declining species diversity, but there are differences in our findings. Taylor & Irwin shows that richer regions pose a greater threat to biodiversity because richer regions accelerate the invasion of alien species, thereby crowding out native species; in contrast, we believe that biodiversity is gradually restored when a country is in a better economic position because richer countries tend to be more concerned with sustainable development and will invest more in ecological issues. The difference between the two findings is based on the essentially different entry points to biodiversity. Further, it has been found that when a country's economy increases and the gap between rich and poor decreases, the number of threatened species becomes smaller [43]. On this basis, the findings of this study can be explored in more depth. When we present such socio-economic conditions and disparities in the form of the Gini coefficient, the effect of this inequality measure becomes clearer and more intuitive, thus establishing an intrinsic link between biodiversity and the Gini coefficient.

In order to initially investigate the significance of the moderating effects of both, this paper uses ordinary least squares regressions for comparison to initially determine the significant moderating effects of biodiversity. As shown in Picture (a), the marginal effect of economic inequality on climate decreases with increasing biodiversity in the ordinary least squares regression and is significant at all stages of biodiversity. The moderating effect of the Gini coefficient in Picture (b) has a non-significant component and is therefore not considered.



(a) INTERFLEX-Moderator: biodiversity

(b) INTERFLEX-Moderator: GINI

In order to explore the moderation effect between the two in detail, we considered three moderation effects, as shown in Table 6. In Moderating effect 1, when exploring biodiversity and the Gini coefficient, and the interaction term between the two as independent variables, and climate as the dependent variable, we find that the Gini coefficient (regression coefficient of 3.925, p<0.001) will have a much greater impact on national climate change than the change in biodiversity (regression coefficient of -0.065, p> 0.1) on climate due to changes in biodiversity (regression coefficient -0.065, p>0.1). More interestingly, the interaction term between biodiversity and the Gini coefficient demonstrated good significance in the predictive model of the regression equation (regression coefficient of -0.026, p<0.01). The regression coefficient is -0.026, p<0.01. This indicates that the greater the magnitude of the positive change in biodiversity and the Gini coefficient, the greater the negative impact on climate. The R^2 of the Step one model increased from 0.468 to 0.495, indicating a significant moderating effect.

Table 6. Test results of moderating effect

VARIABLES	(1) Step one	(2) Moderating effect 1	(3) Moderating effect 2	(4) Moderating effect 3
Cgini _ mkt _ cbiodiversity^2			-0.000798***	
			(0.000225)	
Cgini _ mkt _ cbiodiversity		-0.0262***	0.0546**	-0.0147
		(0.00808)	(0.0270)	(0.0484)
Gini _ mkt	3.875***	3.925***	3.807***	3.897***
	(1.362)	(1.299)	(1.257)	(1.299)
Biodiversity	-0.00444	-0.0655	-0.0539	-0.0677
	(0.0816)	(0.0815)	(0.0787)	(0.0835)
log GDP	-22.36	-21.91	-30.79	-22.66
	(20.68)	(19.77)	(20.55)	(20.16)
log Forest area	41.07	53.21	40.16	53.41
	(38.42)	(39.88)	(38.54)	(39.83)
log Population	35.62	53.93	63.29	53.72
	(52.27)	(55.39)	(52.82)	(55.48)
log Global trade tax	-2.983*	-2.491	-2.585	-2.454
	(1.704)	(1.696)	(1.616)	(1.682)
Fh _ total	-0.155	-1.019	-0.714	-1.003
	(1.658)	(1.659)	(1.576)	(1.674)
Life expan	-1.066	-0.882	0.187	-0.788
	(1.684)	(1.449)	(1.352)	(1.250)
Redistribution	-1.949	-1.151	-1.682	-1.139
	(4.709)	(4.867)	(4.450)	(4.881)
2010.year	-18.57***	-18.37***	-18.93***	-18.38***
	(2.900)	(2.721)	(2.730)	(2.709)
2012.year	-26.45***	-27.62***	-27.93***	-27.66***
	(5.384)	(5.143)	(4.934)	(5.117)
2014.year	-19.24***	-18.54***	-18.81***	-18.53***
	(5.590)	(5.477)	(5.256)	(5.455)
2016.year	3.544	3.510	3.447	3.580
	(8.654)	(8.098)	(7.724)	(8.161)
Cgini _ mkt^2 _ cbiodiversity				-0.000132
				(0.000604)
Constant	-481.2	-936.5	-795.7	-921.7
	(990.1)	(999.9)	(968.4)	(1,005)
Observations	276	276	276	276
R-squared	0.468	0.495	0.523	0.496
Number of ID	86	86	86	86

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The model is then explored in more depth, first considering the moderating effect of including biodiversity as a moderating variable. When controlling for the variable Gini coefficient, the marginal benefits of climate change can be derived by taking the first order partial derivative of the Gini coefficient. This finding suggests that when biodiversity increases in a given area, it has a positive effect on climate conditions, and that an increase in biodiversity has a stabilising effect on local climate, all things being equal in terms of the Gini coefficient. However, there is a law of diminishing marginal utility of biodiversity on the role of economic inequality in climate change, and the results imply that when biodiversity is restored to a certain level, the stabilising effect on climate will gradually saturate, and that richer biodiversity may in some way reduce the positive marginal utility of economic inequality on climate.

In Moderating effect 2, the Gini coefficient is interacted with the squared term of biodiversity and the regression coefficient is strongly significant, which further predicts a non-linear moderating effect of biodiversity, where the marginal utility of economic inequality on climate change increases and then decreases, compared to Moderating effect 1, R^2 increased from 0.495 to 0.523, and the significance of the model increased, indicating that this model has a better explanation for the original data. We found a particular marginal pattern in the effect of economic inequality on climate due to differences in biodiversity (as shown in Figure 3). When biodiversity is low and increasing, on the one hand it can be a potential natural resource, and under current conditions of economic inequality, low biodiversity is valued and protected by the state. The wealth generated by the conservation of biodiversity continues to increase the environmental benefits of economic inequality, increasing the trend towards economic inequality on the one hand, and the contribution of biodiversity conservation to the stability of ecosystems and the climate on the other [44]. Biodiversity conservation also contributes to the stability of ecosystems and climate. As biodiversity crosses the 34.211 threshold and continues to increase, the marginal impact of economic inequality on climate change begins to diminish, due to the significant non-linear moderating effect of biodiversity. This can be explained in two possible ways: first, when biodiversity is at a high and increasing level, pro-environmental behaviour of the rich decreases under the current conditions of economic inequality. The reason for this is that pro-environmental behaviour by the rich is less rewarding and satisfying for them than when biodiversity is low, because the intuitive benefits of continuing to protect and enhance biodiversity are not as obvious when biodiversity is high in the first place. Second, the richer the biodiversity, the less exploited a country's resources are and the more people tend to engage in self-serving economic activities such as logging, agricultural reclamation and other self-serving and polluting activities. In short, economic inequality is less protective of climate when biodiversity is high and increasing. The interaction term was found to be insignificant, suggesting that there is no moderating effect of biodiversity in the curvilinear regression.

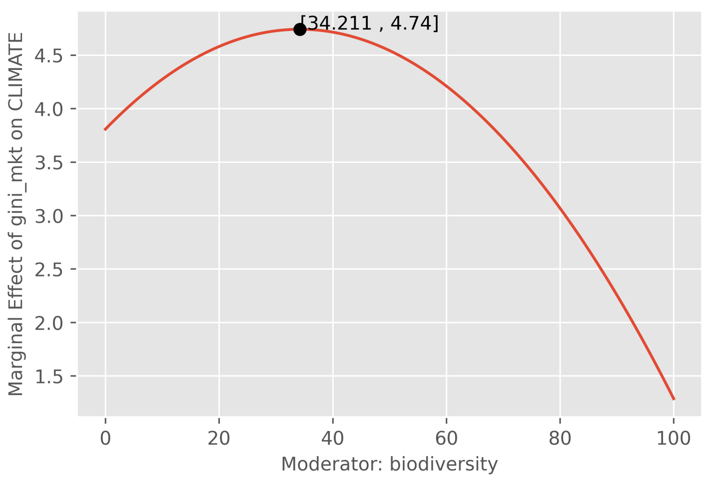


Figure 3. Moderating effect 2

6. Discussion

Combining national Gini coefficients and local biodiversity will help us to better understand the patterns of climate change within regions. Our findings are similar to those of Chen et al. [45], whose study demonstrated the impact of income disparity within countries on their own climate, and that this impact is more pronounced in developing countries; On the other hand, the stabilizing effect of biodiversity as an important factor on local climate change has been verified and confirmed by numerous scholars and studies [46]. Overall, the main contribution of this paper is to add to the existing economic inequality-environment relationship and to find, from a global perspective, that there is a positive relationship between economic inequality and the environment and that its marginal effect varies with the abundance of biodiversity.

7. Conclusion and Implications

7.1. Conclusion

The causes of climate change from multiple perspectives have been a hot topic of research over the years. Environmental change is a key factor in the stability and harmony of the human economy, society and the natural world, and has a crucial impact on global sustainable development. In particular, the increasing economic inequalities in the context of economic development and the destruction of biodiversity by human activities have made climate change an urgent issue to be addressed. This study uses non-equilibrium panel data for 156 countries or regions around the world over the period 2006-2018 as a strong support to delve into the changing relationship between economic inequality and climate change, with biodiversity as a moderator. This paper provides a more comprehensive examination of the relationship between economic inequality and environmental performance through the exploration of economic inequality and environmental performance indices. The main findings include: (I) Overall, economic inequality has a positive effect on environmental performance. (II) Economic inequality has a positive relationship with carbon emissions. (III) Economic inequality significantly affects climate levels, and biodiversity is found to act as a moderating variable with a significant curve modifying effect.

7.2. Implications

The above results complement the existing economic inequality-environment relationship, which in global terms has a positive relationship with the environment and whose marginal effect varies with biodiversity richness. This paper demonstrates that the marginal effect of economic inequality on climate tends to increase and then decrease with biodiversity enrichment. This suggests that policy makers in a given country or region must take into account the level of economic inequality and the biodiversity richness of the country when they want to develop the economy: the higher the level of biodiversity, the lower the utility of economic inequality for climate in the context of high biodiversity levels. This can be explained by the fact that higher levels of biodiversity may reduce the pro-environmental behaviour of the rich. Therefore, countries with high levels of biodiversity need to increase awareness of environmental and climate protection, and give incentives and support to high-income groups to protect the environment and reduce energy consumption, which will help to improve the climate; in a context of low biodiversity levels, increasing the country's biodiversity levels will increase the marginal effect of economic inequality on climate, when greater environmental protection will bring economic benefits and increase the indirect value of biological resources.

8. Limitations and Future Research

The main shortcoming of this paper is the use of a short panel of data consisting of EPI, where the time horizon is small and it fails to examine the relationship from a long-term perspective. Similar to the study in [38], this may cause discrepancies in the model results. Constructing a panel of environmental performance indices is also not recommended, but this paper makes selective use of it as it is currently the most authoritative and comprehensive global environmental indicator available. Future research could construct its own long panel of comprehensive indicators and disaggregate them in order to examine the relationship more comprehensively.

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Appendix A

Table A1. Literature Summary

Author	Nexus	Main Method	Research Data	Result
[36]	Income inequality and carbon emissions	Dynamic panel threshold model	Panel data of 92 countries over the period 1991-2015	Asymmetry negative relationships
[47]	Income inequality and consumption-based greenhouse gas	Non-parametric regression	Country-level data for 1990-2014	Non-liner relationship
[45]	Income distribution and CO2 emissions	Quantile regression	G20 countries 1988 to 2015	Income distribution affects CO2 emission by countries' type
[9]	Income inequality and carbon emissions	Panel smooth transition regression	68 countries 1961 to 2010	Income threshold affects the CO2 emission
[48]	Income inequality and CO2 emissions	Non-parametric modelling	G7 countries, 1870-2014	Relationship vary over the periods
[49]	Renewable energy consumption and income inequality	Dynamic panel data estimation	Developed economies over the period 1990-2014	Negative relationship
[50]	Income inequality and environmental regulation on environmental quality	Panel quantile regression	30 Chinese provinces in China from 1998 to 2017	Income inequality improved environmental quality in a limited interval
[51]	Income inequality and carbon emission	Panel ARDL and quantile regression	50 US states and the District of Columbia 1997-2015	Higher income inequality increases carbon emissions in the short term, but reduce it in the long term
[52]	Income inequality and CO2 emissions	ARDL	Turkey time series data 1984-2014	Deterioration in income distribution will reduce environmental quality
[53]	Carbon emissions, income inequality and economic development	DOLS, FMOLS and CCEMG estimators	1945-2010 for 17 OECD countries	Higher top income inequality leads to a higher CO2 emission, higher Gini index of inequality is negatively associated with CO2 emission
[54]	Income inequality, innovation and carbon emission	Panel estimation	27 provinces of China from 1995 to 2015	Carbon emission increases as the income gap widens
[10]	Income Inequality on Carbon Emissions	Panel regression model	Nationwide micro panel data(2010,2012,2014)	Households in counties with greater income inequality emit more
[13]	Income inequality and CO2 emissions	Spatial econometric regression	41 Belt and Road initiative countries over the period 1997- 2012	Non-linear relation between income inequality and CO2 emissions

[55]	Income inequality and CO2 emissions	FMOLS,ARDL and DOLS model	78 countries from 1990 to 2017	Not significant in the short run. Promotes emission reductions in high income countries
[56]	Income Inequality and Carbon Consumption	Environmental Engel curves	United States between 1996 and 2009	Income is an important driver of household carbon
[57]	Income distribution and environmental quality	Spatial panel regression	31 Chinese provinces during the period 1996-2015	Increases in income inequality improves environmental quality
[26]	Income Inequality and Carbon Dioxide Emissions	Fixed effects model	1980 to 2008, covering 158 countries	The relationship between income inequality and per capita emissions depends on the level of income
[57]	Inequality affect environmental quality	Panel regression model	85 major cities for 1990-2012	Inequality negatively affected air quality in residential and commercial areas during the 1990s but not in industrial areas
[58]	Income inequality, economic growth and energy consumption on CO2 emissions	ARDL	U.S. data the 1967 to 2008 period	More equitable distribution of income in the U.S. results in better environmental quality in the short and long-run

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