

Accounting asymmetries in the long-run nexus between globalization and environmental sustainability in the United States: An aggregated and disaggregated investigation

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ABSTRACT

In recent years, the number of studies on the relationship between globalization and ecological footprint is steadily increasing, yet the literature lacks any formal consensus. Previous studies unveil beneficial as well as harmful effects of globalization on the environment. Furthermore, most of the scholars rely on linear methods to investigate this relationship, which can produce biased outcomes when non-linearities exist in data. Unquestionably, the United States played a leading role in increasing global connectivity; however, the present US administration has demonstrated not only a penchant for isolationism by keeping certain critical resources, technologies, and manufacturing capacities in the US but also the tendency to ignore environmental concerns both domestically and globally. On this backdrop, this study uses asymmetric ARDL, and asymmetric causality methods to investigate the asymmetric relationship between globalization and the ecological footprint of the US. Additionally, the disaggregated asymmetric impacts of social, economic, and political globalization on footprint are also ascertained. The results indicate non-linear cointegration among variables. The long-run estimations reveal that a 1% positive change in overall globalization and in economic globalization increases ecological footprint by 1.32 and 0.72%, respectively, while a similar 1% negative change alleviates footprint by 6.75 and 1.05%, respectively. The outcomes elucidate much more dominant effects associated with negative changes in total and economic globalization. In contrast, positive changes in social globalization improve the environment by mitigating ecological footprint. Interestingly, positive shocks to political globalization stimulate footprint, indicating the validity of the environmental governance failure hypothesis. Further, Granger causality from positive changes in globalization to the footprint is found. Lastly, this study is concluded by comprehensive policy implications, including policy regarding FDI, trade, and enhancing social globalization, among others.

1. Introduction

The word globalization refers to the increasing interdependence among economies at social, economic, and political levels owing to cross-border trade, movement of people, technology, investment, and information flows. More precisely, it can be described as a shift from traditional isolated economies with regulations, barriers, and cultural differences to interdependent, interconnected global economies (Hill, 2007). Globalization, through its political, economic, and social process, can affect economic development (Latif et al., 2018) and environmental sustainability (Saud et al., 2020).

The KOF index proposed by Dreher (2006) provides the most

comprehensive index on globalization by combining economic, political, and social globalization as well as separate indices on each of these three aspects. The index on economic globalization is based on FDI, trade, portfolio investment along with different restrictions such as import barriers, taxes on foreign trade, tariffs rates, and others. Hence, the environmental implications of economic globalization require us to consider the ecological consequences of foreign investment and trade. For instance, the study of Destek and Okumus (2019) suggests that FDI can lead to the formation of pollution havens because foreign investors from the developed countries prefer to transfer pollution intensive technology to countries with relaxed environmental laws. Likewise, Can et al. (2020) also disclose negative ecological effects of FDI. Similarly,

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Shahbaz et al. (2016) suggest multifaceted effects of globalization on the environment and argue that economic globalization facilitates multinational companies in relocating their production facilities to low-income nations not only to pay reduced wages but also to exploit relaxed environment laws, which lead to ecological degradation. In addition, globalization boosts human activities, which escalates the pollution level through increasing transportation, industrial production, and, secondarily, deforestation. Doğan et al. (2019) highlight that trade leads to intensify ecological degradation in all income groups. On the contrary, Ahmed et al. (2019) present the view that economic globalization can play an influential role in environmental sustainability through different channels. First, foreign investors often use efficient and innovative technology which lessens resource consumption and production costs. In order to remain competitive, even local companies adopt a similar technology, which promotes environmental sustainability. Secondly, trade openness can help in developing a service economy based on knowledge through structural transformation. Thirdly, in addition to composition effects, the technique effect of trade in developed countries can bring green technology and better ecological legislations (Ahmed et al., 2020b).

Unquestionably, the role of economic globalization is vital in environmental sustainability; however, it is not the only dimension of globalization that influences the environment. Social globalization covers international mobility through tourism and migration, the flow of information, internet usage, access to television, and press freedom, among others. International travel may affect environmental sustainability by raising ecological degradation by increasing the use of resources in the transportation and hoteling industries, etc. Conversely, the use of information technology may lessen resource usage by dematerialization and substitution effect (Haseeb et al., 2019). Also, knowledge and information flow via access to media, internet, international news, and overseas travel can help in uplifting environmental awareness, which may eventually promote sustainable practices and a better environment (Rudolph and Figge, 2017).

Lastly, political globalization is related to the integration between nations in the form of bilateral contacts as well as agreements with international organizations. Global governance can alleviate environmental degradation by encouraging the participation of nations in international environmental bindings and agreements. Enforcement of global environmental standards can reduce ecological degradation by reducing resource usage. International cooperation can improve technical capacity and know-how of national institutes which may help to reduce anthropogenic pressure on the environment (Lemos and Agrawal, 2006). However, Rudolph and Figge (2017) oppose this view and suggest the presence of the environmental governance failure hypothesis. They argue that global governance has failed to reduce human pressure on the environment because there is no noticeable enforceable global framework on emissions reduction. Current global governance is more about dealing with institutions and arrangements with less accountability, transparency, and democracy. Thus, it can lead to a culture of power abuses and adverse environmental effects since preference is on economic interests rather than sustainable production, consumption, and trade.

Considering these multifaceted effects of globalization, it is not a surprise that previous studies present varied opinions and mixed findings. After the seminal research of Rudolph and Figge (2017) empirical studies on the globalization-ecological footprint nexus are growing. However, Ahmed et al. (2019) argue that the globalization and emissions nexus and the impact of globalization on ecological footprints should be further explored using time-series studies since the existing literature is inconclusive and the effect of globalization may vary across nations. They also demonstrate the need to examine the effect of each dimension of globalization separately. In addition, asymmetries in macroeconomic variables are reasonable to expect since they can be affected by fiscal and monetary policies, foreign trade, business cycle, among others (Rehman et al., 2019). Hence, the reliance on symmetric

methods in the presence of asymmetries can produce biased estimates.

On this backdrop, current paper expands on the existing literature and makes the following contribution to the literature. Firstly, this paper uses an asymmetric estimation framework to study the (asymmetric) linkage between globalization and ecological footprint. Ecological footprint is indeed the most comprehensive tool to track anthropogenic pressure on nature in terms of water, soil, and air (Ahmed et al., 2020b; Nathaniel et al., 2020; Ozturk et al., 2016). Undoubtedly, it is the most appropriate proxy of ecological degradation in recent literature (Ahmed et al., 2020a, 2020c; Alola et al., 2019; Dogan et al., 2020b). Secondly, to make our findings more useful, this study also examines the asymmetric effect of social, economic, and political globalization on footprint. Thirdly, in addition to the long-run estimation, this study also scrutinizes the asymmetric causality between globalization and footprint. Methodologically, this study relies on the famous non-linear ARDL technique suggested by Shin et al. (2014), and the asymmetric causality method suggested by Hatemi-J (2012). To ensure that results are robust, the BDS non-linearity test, non-linear and linear unit root tests and other suitable methods are also applied.

2. Context of the United States

This work is especially useful in the context of the United States which is the country with the second largest ecological footprint (Zafar et al., 2019). According to the KOF index, the United States had total globalization of around 82 out of 100 in 2016, which is higher than countries like China and Japan. At the disaggregated level, political (93) and social globalization (85) levels in the United States were higher than the economic globalization level (67) as can be seen in Fig. 1. The great percent increase in any of the sub-metrics came from economic globalization levels which experienced a massive 73% increase from 1970 to 2016. This is due in part to the relative low initial value (less than 40) for the economic globalization index level in the United States in 1970. Proceeding to the history of globalization in the US, soon after World War II, businesses in the United States were eager to maximize their profits by moving their production facilities to the states with the lowest wages and relatively weak labor unions. This was the start of a globalization process which expanded at a rapid pace in the following years. The United States played an influential role in an effort to develop a world economic order based on commonly accepted rules. A number of institutions were established and agreements were signed to make the world a global village under the leadership of the US. Consequently, a globalization trend was set up which had unprecedented growth from 1990 to 2007; however, after the global recession of 2007, globalization flattened.

Noticeably, as a consequence of the COVID-19 global pandemic, an increasing numbers of articles suggest that this may be the end of globalization. It appears that the US administration is thinking about keeping certain critical resources, technologies, and manufacturing capacities in the US.¹ In addition, the tariff war initiated by US administration in 2018, and the intimidation of Western allies at the NATO and G7 summits are raising questions on the effectiveness of political alliances (Gygli et al., 2019). The US has already influenced global governance to combat climate change by withdrawing from the Paris agreement. To address this critical situation, current research tends to analyze how globalization and its various dimensions influence ecological pressure. This study not only extends the literature on the ecological impacts of globalization, but it is also critical for the development of improved environmental policy in the US, which is a major contributor to global climate change. This work has global importance because the effects of US policies are often not limited to the US.

¹ "COVID-19 Could Be The End Of Globalization" article is available at <https://cleantechnica.com/2020/04/19/covid-19-could-be-the-end-of-globalization-as-we-know-it/> (Accessed april 28, 2020)

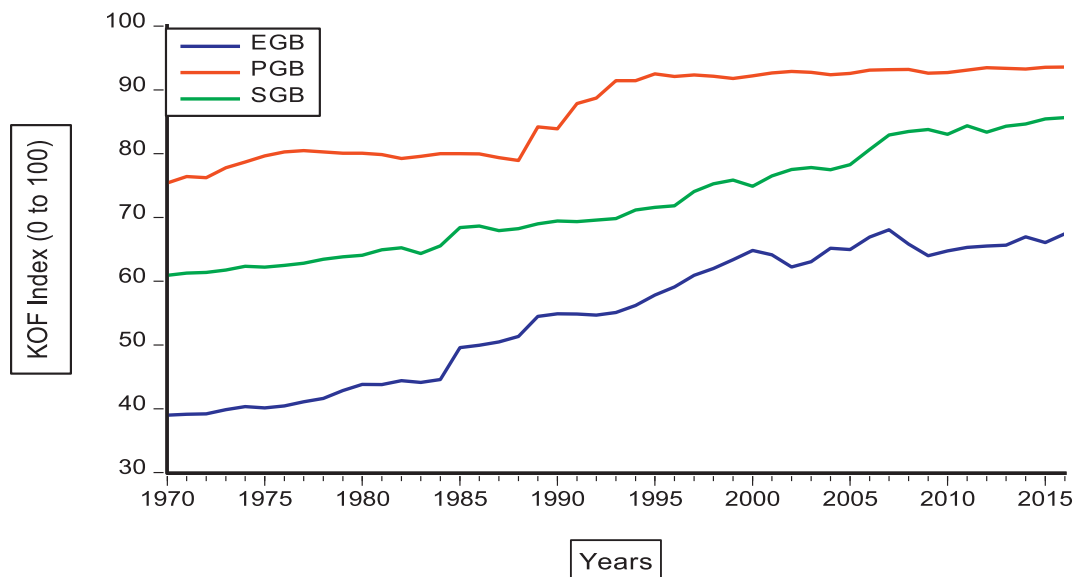


Fig. 1. Trends of economic (EGB), social (SGB), and political globalization (PGB).

3. Literature review

Numerous scholars studied the linear association between globalization and CO₂ emissions and reported both a positive and a negative impact of globalization on pollution emissions (Doytch and Uctum, 2016; Khan et al., 2019; Kwabena Twerefou et al., 2017; Latif et al., 2018; Lv and Xu, 2018; Martens and Raza, 2010; Phong, 2019; Salauddin et al., 2018; Shin, 2004; Xu et al., 2018). In recent years, environmental studies increasingly rely upon ecological footprint as a tool to understand anthropogenic environmental pressures and their implications. In this regard, Figge et al. (2017) initiated a debate on the potential effect of globalization on footprint by using the Maastricht Index as a measure of globalization on a dataset of 171 countries, employing panel regression methods. The findings of their paper suggest that globalization contributes to increasing footprint of a nation, while the decomposition of the index into its three components highlights that only the political dimension mitigates footprint. Interestingly, in a similar study, when Rudolph and Figge (2017) analyzed the short-run effect of globalization on footprint from 1981 to 2009 in a panel of 146 nations using the comprehensive KOF index, the findings were quite different. They concluded that only social globalization negatively affects footprints, while economic globalization is the primary contribution to ecological footprints. However, political globalization does not contribute to anthropogenic pressures on the environment. Nonetheless, these studies only captured the short-run relationship, a relationship which may not be true in the long-run.

Following these studies, Sabir and Gorus (2019) studied the impact of globalization on footprints in Asian countries. They suggest that globalization drives human pressures on the environment and upsurges footprints no matter what proxy of globalization is used. However, their study has some limitations; for instance, they used panel ARDL despite the presence of cross-sectional dependence (CD). Notably, the inability of PMG to counter CD can lead to biased estimates. Similar to this work, Saud et al. (2020) probed the relationship between footprints and globalization in 49 countries along the belt and road from 1990 to 2014. In contrast to the finding from Sabir and Gorus (2019), they reported that globalization alleviates environmental degradation by reducing footprints as well as other important environmental indicators. However, the outcomes of the country-specific analyses indicated differences in results across different countries. This comprehensive study also had some limitations; for instance, it also used PMG method despite the presence of CD.

Proceeding to time-series studies, Ahmed et al. (2019) suggested that time series analysis is more useful to unfold the exact effect of variables like globalization since such variables can affect the environment negatively and positively and their relationship may differ across countries. However, their analysis in Malaysia from 1971 to 2014 did not reveal any significant effect of globalization on the footprint. Even when they decomposed globalization into its three components, the findings were not significant. Interestingly, Suki et al. (2020) revisited this relationship in Malaysia by converting data into the quarterly frequency and using the QARDL method. They conclude that economic and overall globalization increased footprint, while the other two components reduced footprint. Conversely, using DOLS and FMOLS, Ibrahim and Shaimaa (2020) report that globalization reduced the footprint of Egypt over the time period from 1971 to 2014.

The above studies used symmetric techniques in understanding the effect of globalization on footprints. Recently, Chishti et al. (2020) scrutinized the effect of overall globalization on emission accounting for possible asymmetries. Surprisingly, they indicated different effects of negative and positive shocks of globalization in Pakistan, Bangladesh, and India. They emphasized the need to consider asymmetries in environmental literature. Therefore, considering the limitations of previous studies, this work analyzes the asymmetric effect of overall globalization as well as the influence of the disaggregated aspects of globalization on the footprint of the United States.

4. Models and data

This study aims to explore the effect of overall globalization as well as the effect of social, economic, and political globalization on ecological footprint using the United States as a case study. As discussed in the introduction, globalization (KOF index) and its sub-indices can influence footprint either negatively or positively. Further, the ecological footprint has become in recent years a highly used metric to proxy ecological degradation. In the view of Figge et al. (2017), it is necessary to control for GDP (economic growth) while studying the effect of globalization on the footprint. The omission of GDP data may lead to the omitted variable bias problem because GDP (economic growth) is among the leading contributors to ecological degradation (Dogan et al., 2020a; Hu et al., 2020). Ecological deterioration is linked with the expansion in GDP (Bekun et al., 2019b; Dogan et al., 2020). Accordingly, we use the model below to study the overall impact of globalization (KOF index) on the ecological footprint.

Table 1
Variables, measures, and data

Variables used	Measure	Data Source
Environmental degradation	LED	It is proxied by ecological footprint of Consumption (Global hectares per capita). Global Footprint Network
Economic growth	LY	Measured in terms of GDP (per capita constant 2010 US \$) WDI
Globalization	LGB	Total KOF index of globalization Swiss Economic Institute (SEI)
Economic globalization	LEGB	KOF index of economic globalization SEI
Social globalization	LSGB	KOF index of social globalization SEI
Political globalization	LPGB	KOF index of political globalization SEI
Renewable energy	LRE	Renewable energy sources, such as hydro, wind, solar, geothermal, biomass and others in tonnes per capita. BP Statistical Review

$$LED_t = \psi_o + \psi_1 LY_P_t + \psi_2 LY_N_t + \psi_3 LGB_P_t + \psi_4 LGB_N_t + \mu_t \quad (1)$$

In the model above, LED depicts environmental degradation proxied by ecological footprint, LY implies GDP (economic growth), and LGB symbolizes overall globalization. The variables with P indicate positive shocks and the variables with N indicate negative shocks. In the second model, we re-examined this linkage but included renewable energy for robustness purposes since the aggregate model is our main model. The model for robustness is as follows:

$$LED_t = \psi_o + \psi_1 LY_P_t + \psi_2 LY_N_t + \psi_3 LGB_P_t + \psi_4 LGB_N_t + \psi_5 LRE_P_t + \psi_6 LRE_N_t + \mu_t \quad (2)$$

The first two models are related to aggregate analysis. We have avoided including more variables in the model since the data period is restricted from 1970 to 2016 and in the case of annual data with a reasonable lag length, controlling for more variables may produce biased results, considering the fact that this methodology divides one variable into two shocks. After the aggregate analysis is complete, we move towards examining the influence of social, economic, and political index of globalization on the footprint.

$$LED_t = \psi_o + \psi_1 LY_P_t + \psi_2 LY_N_t + \psi_3 LEGB_P_t + \psi_4 LEGB_N_t + \mu_t \quad (3)$$

$$LED_t = \psi_o + \psi_1 LY_P_t + \psi_2 LY_N_t + \psi_3 LSGB_P_t + \psi_4 LSGB_N_t + \mu_t \quad (4)$$

$$LED_t = \psi_o + \psi_1 LY_P_t + \psi_2 LY_N_t + \psi_3 LPGB_P_t + \psi_4 LPGB_N_t + \mu_t \quad (5)$$

In Eqs. 3, 4, and 5, LEGB (economic globalization), LSGB (social globalization), and LPGB (political globalization) indices are used instead of using aggregate KOF index.

This work relies on yearly data from 1970 to 2016. The starting period is based on data availability for globalization, while the ending period (2016) is selected based on data unavailability of footprint after 2016. The data on ecological footprint, Globalization, GDP, and renewable energy are obtained from the Global Footprint Network, the KOF index (Dreher, 2006; Gygli et al., 2019), the World Bank, and BP statistics (BP Statistical Review, 2017), respectively. Following the majority of previous studies, this work converted all variables into their natural logarithm to increase the reliability of analysis and to normalize the data. Also, it will enable us to interpret coefficients as elasticities. The definitions of the variables are presented in Table 1.

5. Econometric strategy

The econometric strategy of this paper involves the use of non-linear methods for exploring the long-run impact and causal associations. Before applying non-linear ARDL, it is useful to inspect the non-linearities in the variables. To do so, this work employed the popular BDS test proposed by Broock et al. (1996). After fulfilling this pre-requirement, this paper opted for the unit-root analysis using the non-linear KSS method suggested by Kapetanios et al. (2003). Along with the KSS, this work also used the popular ADF test.

However, extensive criticism on the outcomes of traditional unit root techniques inspired us to employ the recently developed Narayan and Popp (2013) test which is famous for generating consistent results accounting for two breaks in data. It is noteworthy that the use of this test is just to check whether variables are stationary at levels since the previous tests may not differentiate between structural break and unit root. Even though non-linear ARDL can handle fractional integration, the linear or non-linear ARDL cannot be used in case the dependent variable does not have a unit root at level; thus, it is plausible to use the unit root test that could account for structural breaks.

5.1. Asymmetric ARDL

After satisfying that data series are not stationary at I(2), we applied the non-linear (asymmetric) ARDL. This technique is useful to test for the presence of non-linear cointegration among variables. It also estimates not only the long-run but also the short-run relationships of regressors with the dependent variable. According to Shin et al. (2014), the flexibility of this technique to use an optimal lag length can handle the issue of potential multicollinearity. Besides, it can even handle fractional integration as well as potential autocorrelation and endogeneity concerns (Shahbaz et al., 2017). Along with all these benefits, the ability of symmetric ARDL to generate consistent results for small samples makes it one of the preferred choices for time-series analysis even with relatively few (30 to 80) observations.

The non-linear ARDL decomposed variables into their respective negative and positive changes. Hence, in our main model, globalization and economic growth will be decomposed into negative and positive changes. In Eq. 1, we have already expressed variables into respective shocks (LY_P, LY_N, and LGB_P, LGB_N). Moreover, the partial sum of changes, in economic growth and globalization, for the first model are as follows.

$$LY_P = \sum_{i=1}^t \Delta LY_P_i + \sum_{i=1}^t \max(\Delta LY_i, 0) \quad (6)$$

$$LY_N = \sum_{i=1}^t \Delta LY_N_i + \sum_{i=1}^t \min(\Delta LY_i, 0) \quad (7)$$

$$LGB_P = \sum_{i=1}^t \Delta LGB_P_i + \sum_{i=1}^t \max(\Delta LGB_i, 0) \quad (8)$$

$$LGB_N = \sum_{i=1}^t \Delta LGB_N_i + \sum_{i=1}^t \min(\Delta LGB_i, 0) \quad (9)$$

We have not written the partial sum of changes for other models since too many equations will be cumbersome for readers. Nevertheless, Eqs. 1 to 5 given in the previous section can be rewritten into the following non-linear ARDL models, respectively.

$$\begin{aligned}
\Delta(LED)_t = & \psi_o + \sum_{k=1}^p \psi_{1k} \Delta(LED)_{t-k} + \sum_{k=0}^p \psi_{2k} \Delta(LY_N)_{t-k} + \sum_{k=0}^p \psi_{3k} \Delta(LY_N)_{t-k} + \sum_{k=0}^p \psi_{4k} \Delta(LGB_P)_{t-k} \\
& + \sum_{k=0}^p \psi_{5k} \Delta(LGB_N)_{t-k} + \psi_1(LED)_{t-1} + \psi_2(LY_P)_{t-1} + \psi_3(LY_N)_{t-1} + \psi_4(LGB_P)_{t-1} \\
& + \psi_5(LGB_N)_{t-1} + \mu_t
\end{aligned} \tag{10}$$

$$\begin{aligned}
\Delta(LED)_t = & \psi_o + \sum_{k=1}^p \psi_{1k} \Delta(LED)_{t-k} + \sum_{k=0}^p \psi_{2k} \Delta(LY_P)_{t-k} + \sum_{k=0}^p \psi_{3k} \Delta(LY_N)_{t-k} + \sum_{k=0}^p \psi_{4k} \Delta(LGB_P)_{t-k} \\
& + \sum_{k=0}^p \psi_{5k} \Delta(LGB_N)_{t-k} + \sum_{k=0}^p \psi_{6k} \Delta(LRE_P)_{t-k} + \sum_{k=0}^p \psi_{7k} \Delta(LRE_N)_{t-k} + \psi_1(LED)_{t-1} + \psi_2(LY_P)_{t-1} \\
& + \psi_3(LY_N)_{t-1} + \psi_4(LGB_P)_{t-1} + \psi_5(LGB_N)_{t-1} + \psi_6(LRE_P)_{t-1} + \psi_7(LRE_N)_{t-1} + \mu_t
\end{aligned} \tag{11}$$

$$\begin{aligned}
\Delta(LED)_t = & \nu_o + \sum_{k=1}^p \nu_{1k} \Delta(LED)_{t-k} + \sum_{k=0}^p \nu_{2k} \Delta(LY_P)_{t-k} + \sum_{k=0}^p \nu_{3k} \Delta(LY_N)_{t-k} + \sum_{k=0}^p \nu_{4k} \Delta(LEGB_P)_{t-k} \\
& + \sum_{k=0}^p \nu_{5k} \Delta(LEGB_N)_{t-k} + \nu_1(LED)_{t-1} + \nu_2(LY_P)_{t-1} + \nu_3(LY_N)_{t-1} + \nu_4(LEGB_P)_{t-1} \\
& + \nu_5(LEGB_N)_{t-1} + \mu_t
\end{aligned} \tag{12}$$

$$\begin{aligned}
\Delta(LED)_t = & \nu_o + \sum_{k=1}^p \nu_{1k} \Delta(LED)_{t-k} + \sum_{k=0}^p \nu_{2k} \Delta(LY_P)_{t-k} + \sum_{k=0}^p \nu_{3k} \Delta(LY_N)_{t-k} + \sum_{k=0}^p \nu_{4k} \Delta(LSGB_P)_{t-k} \\
& + \sum_{k=0}^p \nu_{5k} \Delta(LSGB_N)_{t-k} + \nu_1(LED)_{t-1} + \nu_2(LY_P)_{t-1} + \nu_3(LY_N)_{t-1} + \nu_4(LSGB_P)_{t-1} \\
& + \nu_5(LSGB_N)_{t-1} + \mu_t
\end{aligned} \tag{13}$$

$$\begin{aligned}
\Delta(LED)_t = & \nu_o + \sum_{k=1}^p \nu_{1k} \Delta(LED)_{t-k} + \sum_{k=0}^p \nu_{2k} \Delta(LY_P)_{t-k} + \sum_{k=0}^p \nu_{3k} \Delta(LY_N)_{t-k} + \sum_{k=0}^p \nu_{4k} \Delta(LPGB_P)_{t-k} \\
& + \sum_{k=0}^p \nu_{5k} \Delta(LPGB_N)_{t-k} + \nu_1(LED)_{t-1} + \nu_2(LY_P)_{t-1} + \nu_3(LY_N)_{t-1} + \nu_4(LPGB_P)_{t-1} \\
& + \nu_5(LPGB_N)_{t-1} + \mu_t
\end{aligned} \tag{14}$$

Table 2
Descriptive statistics

	ED	Y	GB	EGB	SGB	PGB	RE
Mean	9.7991	37994.02	71.1376	54.6694	72.1330	86.6104	0.3151
Median	9.9008	36797.80	72.1043	55.0759	69.8069	91.4174	0.3147
Maximum	11.096	52534.37	82.2051	68.0585	85.6237	93.5616	0.4420
Minimum	8.1043	23207.22	58.4338	38.9959	60.9072	75.3984	0.2258
Std. Dev.	0.7902	9369.545	8.1846	10.2845	8.1376	6.6519	0.0417

Table 3
BDS test to check non-linearity

T-Stat	M = 2	M = 3	M = 4	M = 5	M = 6
	BDS stat	BDS stat	BDS stat	BDS stat	BDS stat
LED	0.11301*	0.1648*	0.1778*	0.1688*	0.1238*
LY	0.1983*	0.3348*	0.4290*	0.4954*	0.5451*
LGB	0.1923*	0.3225*	0.4137*	0.4795*	0.5288*
LEGB	0.2007*	0.3393*	0.4357*	0.5025*	0.5493*
LSGB	0.1836*	0.3071*	0.3926*	0.4503*	0.4949*
LPGB	0.1623*	0.2650*	0.3323*	0.3728*	0.3993*
LRE	0.0526*	0.0454*	0.0267*	0.0133***	0.0036

Note: * and *** implies 1% and 10% level of significance.

Table 4
ADF (linear test) and KSS (non-linear) unit root test

Variable	Augmented Dickey-Fuller (ADF)		Non-linear (KSS) test	
	Level	Difference	Level	Difference
	T-Stat	T-Stat	KSS stat	KSS stat
LED	-0.8648	-6.8787*	-0.676	-4.273*
LY	-1.6248	-4.9418*	-0.652	-5.255*
LGB	-1.1693	-6.4990*	-0.703	-5.194*
LEGB	-1.2656	-5.9736*	-1.424	-4.490*
LSGB	-0.0407	-6.4641*	-0.333	-4.738*
LPGB	-1.5040	-2.7773***	-2.104	-5.156*
LRE	-2.0539	-7.4632*	-2.037	-7.142*

Note: *, ** and *** denote significance at 1%, 5% and 10% respectively.

Table 5
Narayan-Popp method with two breaks

Variables	Model M1 intercept			Model M2 intercept & slope		
	T-Stat	Break 1	Break 2	T-Stat	Break 1	Break 2
LED	-1.615	1979	1983	-1.735	1979	1983
LY	-3.069	1981	1990	-2.434	1981	1991
LGB	-1.838	1984	1988	-1.861	1984	1988
LEGB	-1.671	1984	1988	-3.693	1984	2001
LSGB	-3.202	1984	1996	-3.984	1984	2006
LPGB	-4.906**	1988	1991	-5.091***	1988	1993
LRE	-2.801	1986	2000	-4.336	1987	2000

Note: *** and * specify 10, and 5% level of significance, respectively.

Table 6
Bound test results of asymmetric cointegration

Models investigated	F-statistics	BDM T-stat	AIC Lags
(LED/LY_p,Y_N, lGB_P, LGB_N)	5.4097**	-4.8324*	[1,2,0,0,2]
(LED/LY_p,Y_N, lGB_P, LGB_N, LRE_P, LRE_N)	5.5048*	-5.5689*	[1,2,0,0,2,0,0]
(LED/LY_p,Y_N, lEGB_P, LEGB_N)	5.5483**	-4.8233*	[1,1,0,0,2]
(LED/LY_p,Y_N, lSGB_P, LSGB_N)	4.4137***	-3.8632***	[1,1,0,0,0]
(LED/LY_p,Y_N, lPGB_P, LPGB_N)	4.0431***	-4.0157**	[1,2,0,0,0]

Note: *, **, and *** show significance level of 1%, 5%, and 10%, respectively.

Table 7
Long-run results of asymmetric ARDL (aggregate analysis)

Model 1 = (LED/LY_p,Y_N, lGB_P, LGB_N)					
Model 2 = (LED/LY_p,Y_N, lGB_P, LGB_N, LRE_P, LRE_N)					
Long-run results			Long-run Results		
(Model 1)			Robustness Analysis (Model 2)		
Variables	Coefficient	t-stat	Variables	Coefficient	t-stat
LY_P	-0.2606	-1.5492	LY_P	-0.2697	-1.0657
LY_N	2.3756*	4.8799	LY_N	2.0189*	4.5467
LGB_P	1.3178*	3.6719	LGB_P	1.4915*	4.7033
LGB_N	6.7461*	4.9174	LGB_N	3.9016**	2.4259
C	2.3308*	88.9781	LRE_P	-0.1669**	-2.3908
			LRE_N	-0.0751	-0.9334
			C	2.3433*	103.9496
cointEq(-1)	-0.5694*	-3.9539	cointEq(-1)	-0.7821*	-4.8235
Diagnostic test			Diagnostic test		
R-Square	0.9484		R-Square	0.9579	
AdjustedR ²	0.9347		AdjustedR ²	0.9435	
DW	2.0047		DW	2.2150	
Statistics			Statistics		
J-B	0.4420 [0.8016]		J-B	0.8233 [0.6625]	
Normality			Normality		
χ^2 LM	0.1678 [0.8462]		χ^2 LM	1.0493 [0.3627]	
χ^2 ARCH	1.1589 [0.2880]		χ^2 ARCH	0.5123 [0.4782]	
χ^2 RESET	0.8754 [0.3555]		χ^2 RESET	1.4682 [0.2464]	

Note: * and ** signify 1% and 5% significance level, respectively.

Eq. 10 indicates the model with economic growth and overall globalization. The long-run portion is expressed in the second part of this model with Ψ_1 to Ψ_5 symbolizing long-run parameters. This study intends to examine the long-run impacts; however, short-run parameters are also articulated in the first part of models since asymmetric ARDL estimates both short and long-run dynamics.

As for as the null $H_0 : \Psi_1 = \Psi_2 = \Psi_3 = \Psi_4 = \Psi_5 = 0$ and the alternative hypothesis ($H_1 : \Psi_i \neq \Psi_2 \neq \Psi_3 \neq \Psi_4 \neq \Psi_5 \neq 0$) for cointegration are concerned, the procedure of the non-linear ARDL does not differ from that of the linear ARDL. In this study, we compared critical bound values of Narayan (2005) with the F-statistic computed by the non-linear ARDL. The presence of the long-run equilibrium relationship necessitates critical bound values less than F-statistics. After estimating the cointegration and long-run impacts of variables on environmental degradation, we conducted a number of robustness tests. Finally, we relied on a Wald test to check whether long-run asymmetries are significant.

5.2. Asymmetric causality

The reaction to a positive shock may be different from that of a negative shock, which makes it plausible to allow for asymmetries in the causal analysis. Therefore, in the last part of the analysis, we used the asymmetric causality methods developed by Hatemi-J (2012). This technique uses the theoretical framework of the Toda and Yamamoto technique; however, it has the ability to decompose variables into positive and negative shocks by adding non-linear impacts. In the first step, this approach divides variables into respective shocks, then its check

Table 8
Long-run results of asymmetric ARDL (N-ARDL) diagggregated analysis

Model 3 = (LED/LY_p,Y_N, LEGB_P, LEGB_N)						
Model 4 = (LED/LY_p,Y_N, LSGB_P, LSGB_N)						
Model 5 = (LED/LY_p,Y_N, LPGB_P, LPGB_N)						
Variables	Model 3		Model 4		Model 5	
	Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat
LY_P	-0.2347	-0.6541	0.7782	0.4762	-0.2306	-0.9562
LY_N	3.2672*	6.8175	3.3777*	6.7478	3.6843*	5.1649
LEGB_P	0.7192***	1.7023	—	—	—	—
LEGB_N	1.0533*	3.9639	—	—	—	—
LSGB_P	—	—	-0.9404**	-2.4239	—	—
LSGB_N	—	—	1.5671	0.9214	—	—
LPGB_P	—	—	—	—	0.8481**	2.6793
LPGB_N	—	—	—	—	-3.4030	-0.9687
C	2.36371*	62.4506	2.2734*	62.3207	2.3205*	47.8877
CointEq(-1)	-0.5477*	-4.6356	-0.5557*	-4.3215	-0.4078*	-3.8091
Diagnostic test	Model3		Model 4		Model 5	
R-Square	0.9395		0.9319		0.9261	
AdjustedR ²	0.9257		0.9190		0.9118	
DW Statistics	2.2540		1.9017		2.0797	
J-B Normality	0.4117 [0.9315]		1.1371 [0.5663]		1.2071 [0.5468]	
χ^2 LM	0.8349 [0.4428]		0.08856 [0.9155]		0.4481 [0.6426]	
χ^2 ARCH	1.3742 [0.2478]		1.0730 [0.3062]		1.2913 [0.2624]	
χ^2 RESET	1.0501 [0.3127]		0.0034 [0.9534]		2.5378 [0.1207]	

Note: *, **, and *** signify 1%, 5%, and 10% significance level, respectively.

causality from a positive shock to positive shocks and from a negative shock to negative shock under the VAR framework. The rejection of the null hypothesis of no asymmetric causality requires the modified WALD statistics greater than bootstrap critical values. This causality is based on the bootstrap process, which makes it advantageous for small samples. According to [Hatemi-J \(2012\)](#), the critical values of this test are generated using bootstrap simulations with leverage correction; thus, they are robust not only for time-varying volatility but also for non-normality. Summing up, asymmetric causality allows asymmetric structure, better power and size properties, robustness against ARCH and non-normality, which makes it a useful technique to identify causal associations.

6. Results and discussion

Now we proceed to results and their interpretation. Summary statistics in [Table 2](#) indicate that PGB (political globalization) has the highest mean (86.61) compared to Social (72.13) and Political globalization (71.38). However, the standard deviation of economic globalization (10.28) is more than social (8.13) and political globalization (6.65). Even though the United States is more politically integrated, economic globalization increased by almost 73% over the period of analysis compared to 40 and 27% increase in the social (SGB) and political globalization (PGB) during the same period, respectively.

Next, the BDS test is applied and the estimates in [Table 3](#) unfold non-linearities among all variables because the respective *p*-values against most of the BDS statistics were essentially zero. The existence of non-linearities indicates the need to employ non-linear estimation methods to understand the relationships among variables.

Thus, we used the non-linear KSS method and the findings in [Table 4](#) direct that variables are stationary at the first difference, while they have a unit root at levels. These conclusions are also supported by the ADF test results in [Table 4](#). The decision making procedure in both these methods demands *p*-values less than 0.10 to reject the null hypothesis.

Sometimes these methods may generate unreliable estimates because they fail to differentiate between structural break and unit root ([Akadiri et al., 2019](#)). Therefore, The Narayan-Popp test (results shown in [Table 5](#)) is employed which can certainly differentiate between breaks and unit roots. The critical values for this test are available in [Table 3](#) of

[Narayan and Popp \(2010\)](#). The estimates of this method show that only PGB (political globalization) is stationary at levels.

Hence, it is clear that the dependent variable is not stationary at level, so we can move towards the next step. We used optimum lags 2 under AIC for the analysis. The estimates in [Table 6](#) imply that there is cointegration because the F-statistic in every model is more than the critical value. The BDM T-stats are also significant; hence, it is an indication of the long-run equilibrium relationship among variables, which is necessary to estimate long-run elasticities ([Adedoyin et al., 2020](#); [Bekun et al., 2019a](#)).

After ensuring all necessary conditions are met, we employed the N-ARDL method. The long-run outcomes are presented in [Table 7](#). Along with long-run estimations, we also report the lagged ECT because of its importance. The coefficient for a positive change in globalization (LGB_P) is positive and the *p*-value is essentially zero, implying a positive effect of LGB_P on environmental degradation (LED). More precisely, a 1.31% increase in ED is the consequence of a 1% positive change in globalization. Whereas, a similar 1% negative shock leads to a massive 6.74% reduction in environmental degradation. Most

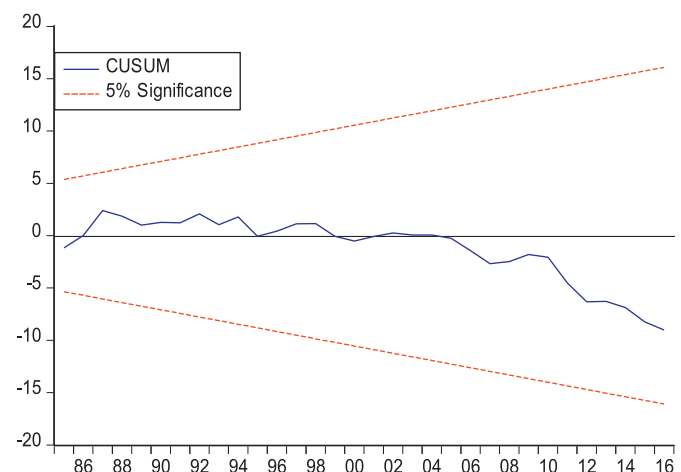


Fig. 2. CUSUM (Model 1)

importantly, the substantial differences in coefficients point towards the significance of asymmetries. The conclusion that an increase in globalization footprint is quite different from the findings of [Ahmed et al. \(2019\)](#) and [Saud et al. \(2020\)](#) for Malaysia and a panel of countries along the belt and road, respectively.

However, this result supports the conclusion of ([Suki et al., 2020](#)) that overall globalization drives environmental degradation (ED) by increasing the ecological footprint of a nation. These findings also confirm the estimates of [Sabir and Gorus \(2019\)](#) and [Figge et al. \(2017\)](#). This result looks plausible since globalization can drive environmental degradation by increasing human activities including transportation, industrial production, and secondarily, deforestation ([Shahbaz et al., 2016](#)).

Unlike these studies, our findings also suggest that reductions in globalization reduces environmental degradation more than the unfavorable effects of an increase in globalization. This result is quite different from the previous studies that mainly use linear methods to explain this linkage. Further, in this model, a positive change in LY (economic growth) has no significant effect on ED but a negative shock to LY reduces environmental degradation. LY is a control variable and not the focus of the study; however, it is important to note that this confirms economics theory. Gains in economic output combine increased output and technical gains, while decreases in economic output do not lead to losses in technology levels.

Since this model is the focal point of this study, we run a robustness check by including a variable for renewable energy usage. The effects of a positive and negative change in globalization and GDP are very much consistent with the previous model. Hence, we can claim that our findings are robust. LRE_P (a positive shock in renewable energy) reduces footprint, which is backed by the conclusions of [Nathaniel et al. \(2020\)](#) who report that renewable energy is a vital option for reducing footprint in the CIVETS countries. The negative shock increases footprint but this effect is not statistically significant.

Now we proceed to the disaggregated analysis ([Table 8](#)) to understand how each dimension of globalization affects footprint. The impact of economic globalization is very much consistent with the impact of overall globalization. It supports our initial claim that the overall impact of globalization depends mainly on the effect of economic globalization. LEGB_P stimulates footprint, while LGB_N reduces footprint. The coefficient for LEGB_P is 0.7192, while the coefficient of for LEGB_N is 1.0533; thus, the impact of a negative shock is more pronounced than the impact of a positive shock. The finding that LEGB_P raise footprint supports the findings of [Rudolph and Figge \(2017\)](#) who used a panel of 146 nations and also of [Suki et al. \(2020\)](#) who studied the case of Malaysia. It also partially agrees with the findings of [Ahmed et al. \(2019\)](#) that EGB upsurges carbon footprint.

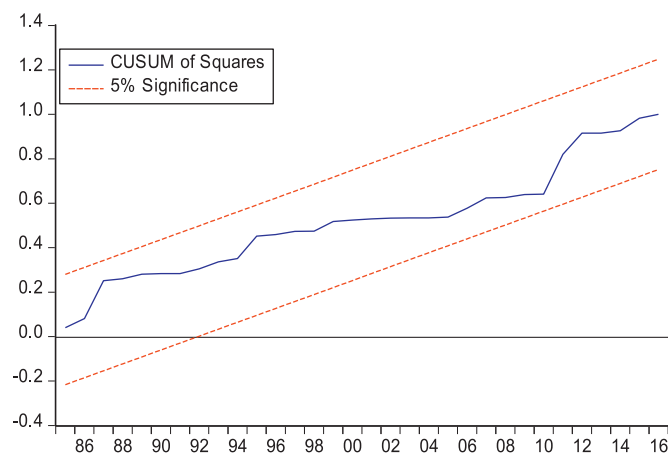


Fig. 3. CUSUMSQ (Model 1)

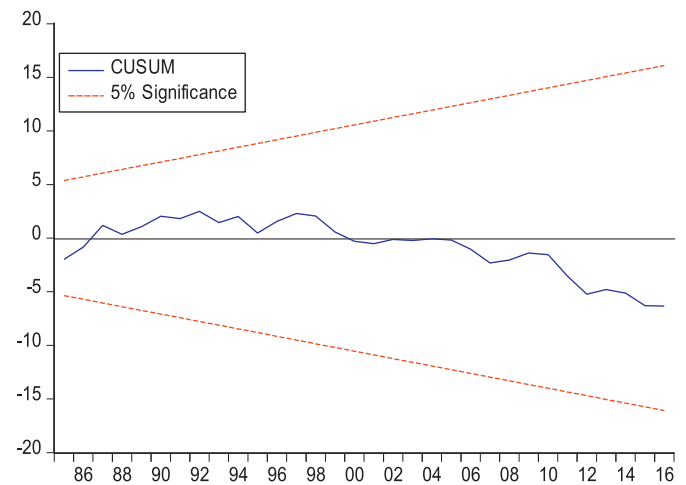


Fig. 4. CUSUM (Model 2)

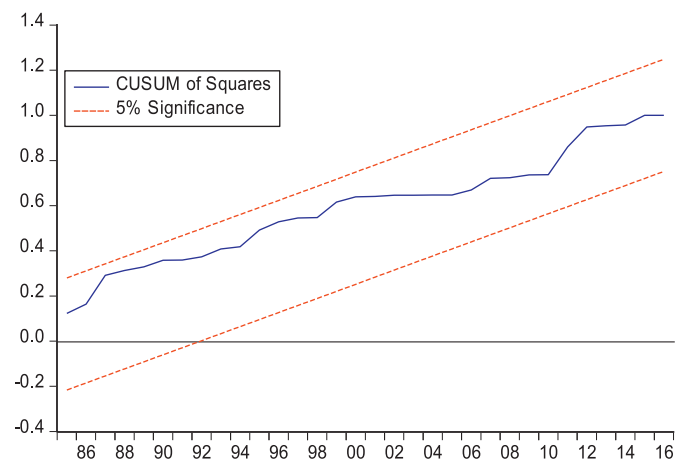


Fig. 5. CUSUMSQ (Model 2)

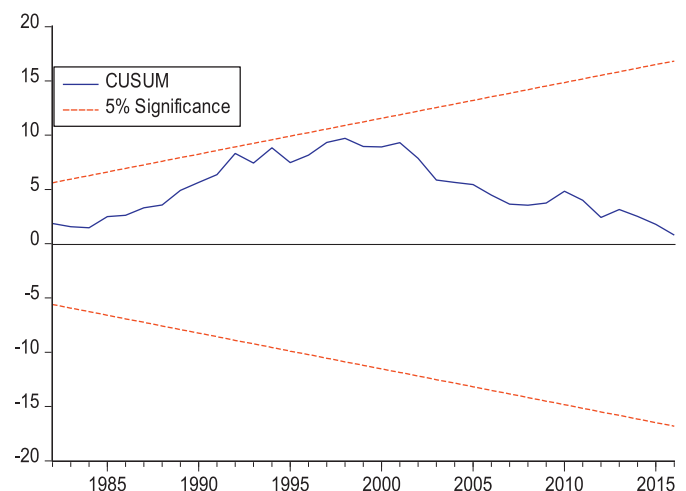


Fig. 6. CUSUM (Model 3)

Nonetheless, most of the existing studies do not explain the impact of negative and positive shocks in EGB on footprint. Our finding is very reasonable because economic globalization is known to be a major contributor to the massive amount of anthropogenic pressure placed on

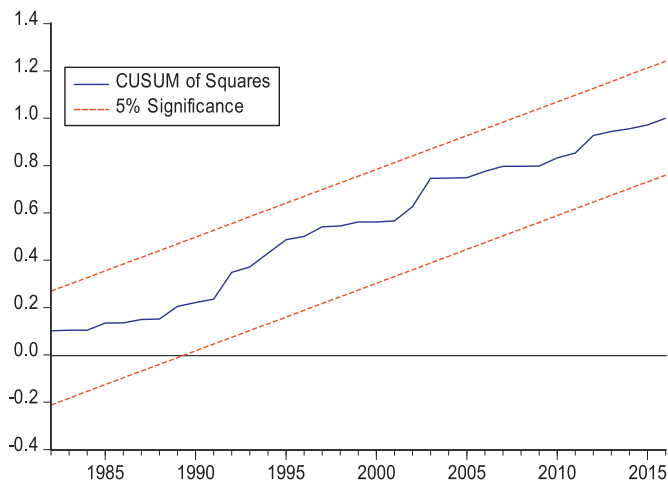


Fig. 7. CUSUMSQ (Model 3).

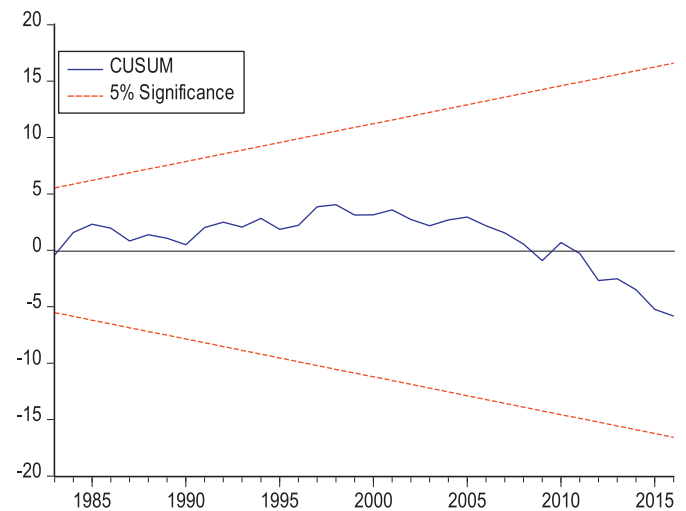


Fig. 10. CUSUM (Model 5)

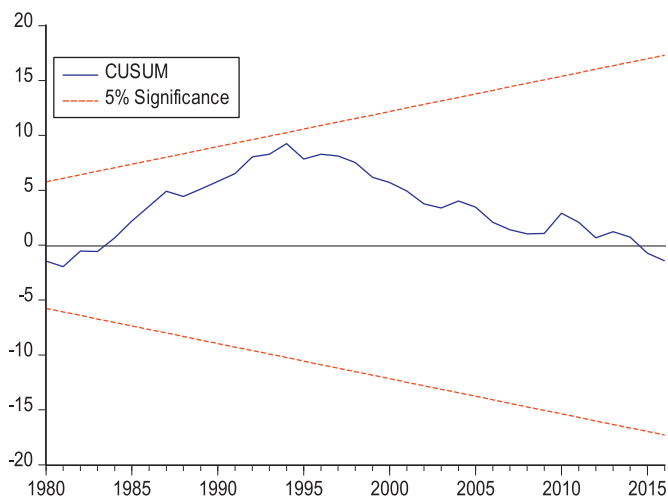


Fig. 8. CUSUM (Model 4)

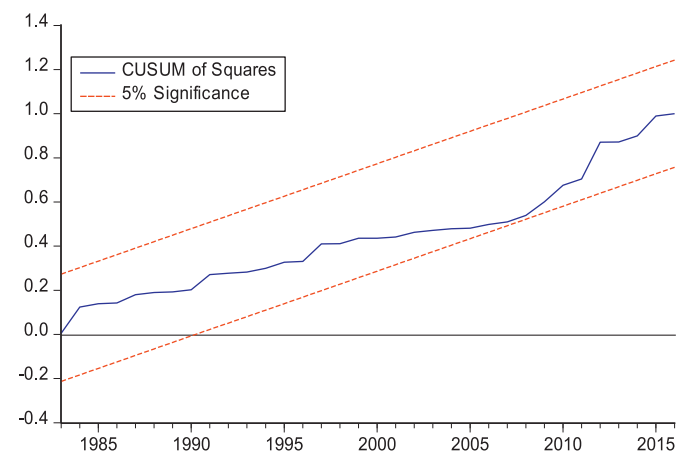


Fig. 11. CUSUMSQ (Model 5)

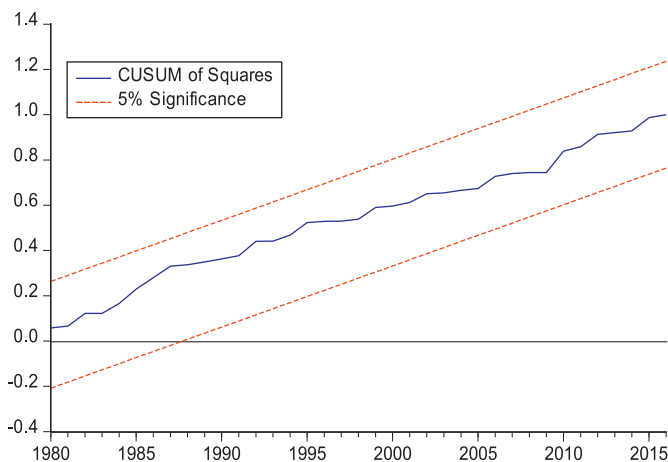


Fig. 9. CUSUMSQ (Model 4)

the environment. Because, FDI and trade expand business activities, resulting in a massive surge in resource consumption in every sector of the economy. Additionally, foreign investors can focus on increasing their profits by disregarding environmental concerns. Hence, economic

Table 9

Long-run asymmetries (WALD test)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5
	F-stat	F-stat	F-stat	F-stat	F-stat
LY	12.4636*	10.5521*	5.5928**	11.0255*	8.6786*
LGB	7.5957*	6.9226*	—	—	—
LEGB	—	—	3.5500**	—	—
LSG	—	—	—	5.8876*	—
LPG	—	—	—	—	3.2309**
LRE	—	1.7705	—	—	—

Note: * signifies 1% significance level.

globalization not only increases ED but also is a major reason behind the unsustainable nature of globalization. In model 3, the effects of LY (economic growth) are very much consistent with the findings discussed in model 1 and model 2.

Moving on to model 4, a positive change in LSG (social globalization represented by LSG_P) reduces footprint and a negative change in social globalization (represented by LSG_N) was not found to have a statistically significant effect on the ecological footprint. A reduction in LED associated with a positive change in social globalizations in line with studies such as [Suki et al. \(2020\)](#) and [Rudolph and Figge \(2017\)](#), which used linear methods to disclose a similar outcome. This is understandable because social globalization covers the flow of

Table 10
Asymmetric causality test

Causal direction	Wstat	CV	CV	CV
		1%	5%	10%
LY_P GR. Cause LED_P	4.246***	19.626	6.297	3.995
LY_N GR. Cause LED_N	0.011	8.851	4.214	3.047
LED_P GR. Cause LY_P	0.003	9.096	5.181	3.397
LED_N GR. Cause LY_N	1.538	13.991	6.167	3.719
LGB_P GR. Cause LED_P	5.923**	13.077	4.588	3.119
LGB_N GR. Cause LED_N	0.326	9.095	4.505	3.116
LED_P GR. Cause LGB_P	0.173	9.070	4.918	3.089
LED_N GR. Cause LGB_N	0.305	16.605	6.208	4.244
LGB_P GR. Cause LY_P	1.099	10.802	5.046	3.256
LGB_N GR. Cause LY_N	0.235	10.964	4.451	3.289
LY_P GR. Cause LGB_P	6.223**	9.608	5.045	3.505
LY_N GR. Cause LGB_N	4.953*	18.855	6.671	3.869

Note: *, and ** refers to significance of 10 and 5% level, respectively.

information, internet usage, exposure to media, and freedom of the press, which helps in increasing awareness about sustainability and also in the promotion of sustainable environmental practices.

Also, it is evident from previous literature that the use of information and communication technologies (ICT) reduces ED by decreasing reliance upon materials derived from natural resources (Haseeb et al., 2019). Furthermore, the effect of LY (economic growth) in model 4 is quite similar to the results of the previous models indicating the robustness of our results.

Proceeding to our last model, surprisingly, the effect of LPGB_P is positive, implying that political globalization increases ED in the United States; however, LSGB_N does not influence ED. This finding contradicts the conclusion of Suki et al. (2020) that political globalization mitigates footprint. This novel finding supports the environmental governance failure hypothesis proposed by Rudolph and Figge (2017), which states that global governance has failed to reduce anthropogenic pressure due to no noticeable global framework on emission reduction. Additionally, global governance lacks accountability, democracy, and transparency.

It also signals that the United States is more inclined towards its economic interests rather than towards focusing on environmental sustainability, and prioritizing economic outcomes can undermine global efforts to combat climate change. For instance, the US withdrawal from the Paris agreement demonstrated reduced interest in global governance and a lack of commitment to addressing climate change. It is evident from the findings that a negative change in political globalization will not reduce environmental degradation. Similar to previous models, the effect of LY is consistent in model 5.

In Tables 7 and 8, the lagged ECT is negative, significant, and between 0 and 1, which corroborates cointegration and describes the speed of adjustment. In the lower part of Tables 7 and 8, the diagnostic test results suggest that the first two models in the aggregated analysis as well as the three models used for disaggregated analysis do not suffer from heteroskedasticity (χ^2 ARCH) and autocorrelation (χ^2 LM). Additionally, the functional form of all five models is validated, and residuals have a normal distribution, which can be seen from the insignificant p -values of the χ^2 LM and J-B Normality tests. The stability of all five models is assessed by the employing the widely used parameter stability tests of Brown et al. (1975). The generated CUSUM and CUSUMSQ Plots reported in Figs. 2 to 11 indicate that blue lines depicting CUSUM and CUSUMSQ are well inside 5% significance level (indicated by red lines) in every model. It implies that parameters of all estimated models are stable, and the results are appropriate for policy implications.

Given the considerable differences in the coefficients of negative and positive changes in all dimensions of globalization, there was no apparent need to check the significance of long-run asymmetries. However, we report the long-run asymmetries in Table 9 for the sake of transparency. The results show that asymmetries in overall globalization (LSGB) as well as in LEGB, LSGB, and LPGB are significant. Also,

asymmetries in LY (economic growth) are significant.

In the last step, this paper used an asymmetric causality method to investigate the asymmetric causality among variables in model 1, which is our primary model. We use the causality method of Hatemi-J (2012) which is based on the fact that the reaction to a negative shock may be different than that of a positive shock. This approach investigates the direction of the relationship from a positive-to-positive and negative-to-negative shocks.

The estimates of the causality test are presented in Table 10. From the results, it can be seen there is an asymmetric causality from LY_P (positive change in economic growth) to LED_P (positive change in footprint). Similarly, LGB_P (positive change in globalization) causes LED_P (positive change in footprint), supporting our long-run estimates.

Thus, these results suggest that changes in globalization do indeed contribute to environmental degradation. Lastly, LY_P and LY_N (positive and negative shocks in economic growth) cause positive changes in globalization (LGB_P) and negative changes in globalization (LGB_N), respectively. This finding is very important for policymaking, and it indicates that changes in globalization may not hinder economic development in the USA.

7. Conclusion and policies

This study explored the long-run asymmetric effects of globalization on environmental degradation in the US, using the ecological footprint as a proxy for environmental degradation. Additionally, this study also described the asymmetric effect of social, economic, and political globalization on the footprint of the US. In the first step, the BDS test is employed to assure the non-linearities in variables. Next, unit root analysis based on non-linear and linear tests is performed, followed by the Narayan-Popp unit root test. After inspecting the unit root properties of variables, the study examined the non-linear cointegration using the bound test under the asymmetric framework as well as the BDM test. The findings indicate non-linear cointegration among all aggregated and disaggregated models.

The long-run estimates discovered that a positive shock in globalization stimulates environmental degradation (increases footprint), while a negative shock in globalization alleviates footprint. The results of our main aggregated model were rechecked for robustness by including renewable energy in model 2. Our results were robust to the inclusion of the use of renewable energy. In the next step, we analyzed the disaggregated effect of each dimension of globalization on the footprint of the US. The estimates of the disaggregated analyses revealed that the effect of economic globalization (LEGB) on footprint is very much similar to the effect of total globalization on footprint in the US, i. e., LEGB_P leads to increase footprint, while LEGB_N mitigates footprint and is in fact the dominant effect of the two. This finding suggests that either the studies that examine the effect of total globalization on the environment mainly capture the effect of economic dimensions of globalization or that the environmental effects economic globalization outweigh the effects of social and political globalization. The long-run asymmetric effect of social globalization indicates that LSGB_P (positive shocks to social globalization) reduce footprint; however, LSGB_N (negative shocks to social globalization) do not affect footprint. Finally, the asymmetric effect of political globalization indicates that LPGB_P (positive shocks to political globalization) drive environmental degradation rather than promoting sustainability which supports the environmental governance failure hypothesis. After the results of these models were analyzed, numerous robustness tests were performed to check the stability of models, and estimates of the Wald test indicated the significance of long-run asymmetries. To complement the analysis, we employed an asymmetric causality test. The results revealed asymmetric causality from positive shocks in globalization to positive changes in footprint and from economic growth (both positive negative shocks) to globalization.

These novel findings have immense significance in the context of

environmental policies in the US and beyond. From our findings, it is clear that current US policies have failed to attain environmentally beneficial effects from globalization, and in fact represent a departure from environmentally cognizant economic policy. Therefore, de jure components of trade such as trade regulations, taxes, tariffs, and trade agreements should consider environmental viability, not only the financial gains. Policymakers should focus on supporting green energy projects and technology by formulating appropriate regulations and offering special incentives on foreign investment and foreign trade. Such policy will be helpful in reaping the benefits of renewable energy, as we already found that renewable energy helps to mitigate footprints in the second model presented in this paper.

An increase in social globalization is a strong option for developing environmentally friendly policy since it mitigates footprints. In social globalization, the information components like the use of the internet, freedom of the press, and access to reliable media should be enhanced with a view to enhance ecological awareness. The findings of this study also indicate that political globalization is not effective in reducing footprints; in fact, it leads to further environmental degradation. Thus, the current administration needs to take global environmental governance more seriously and efforts should be made to increase transparency and democracy in environmental institutes. The US should lead the world to design an effective global framework to combat climate change instead of focusing on its own economic interests. This self-centered and short-sighted policy narrative disproportionately affects the environmental and economic reality in developing nations in part through the consequences of climate change.

The results from this study are still applicable outside of the US, especially in other highly developed nations. In an era in which globalization, the largest economics in the world, and the environment are all subject to the whims of autocrats, emphasizing the importance of policies which address both sustainability and globalization related issues is critical. While this study presents a case study of the impact of globalization on the environment in the US, the current political situation in the US can serve as a case study for the rest of the world, albeit, unfortunately, through negative consequences.

This study describes the aggregated and disaggregated linkage between globalization and footprint of the US using asymmetric methods. Since the economic and social globalization indices are based on many variables, additional studies on economic and social globalization which decompose these indices into different sub-indices will be useful in deepening our understanding of each component of globalization and their impacts on the environment. Future studies could also replicate this work in other major economies since the asymmetric impact of different aspects of globalization may vary in different countries. Also, comparative studies on globalization and ecological footprint can be conducted using asymmetric methodologies to highlight disparities in the association between globalization and environmental sustainability across countries.

Authors' contributions

ZA Conceptualization; Methodology; Formal Analysis; Writing – Original Draft; Writing – Reviewing & Editing. **MC** Writing – Original Draft; Validation; Writing – Reviewing & Editing. **HL** Data Curation; Writing – Original Draft; Writing – Reviewing & Editing; Supervision; Project Administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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