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Nonlinear and Nonparametric Causal Relationship Between Financial Inclusion, Energy Efficiency, and Sustainable Environment in Developed Economies

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Abstract

A sustainable environment is as important as the economy's growth, but, unfortunately, economic growth is environmentally unsustainable. Hence, there is a need to adopt efficient ways to help maintain a sustainable environment. The present research is designed to evaluate the association between financial inclusion, energy efficiency, and a sustainable environment in developed economies. The World Bank has regarded financial inclusion as a crucial element for attaining seven Sustainable Development Goals. So, there is a need to examine the causal association between financial inclusion, energy efficiency, and a sustainable environment. We employed the linear Granger causality test, Brock-Dechert-Scheinkman test for nonlinearity, and parameter stability testing. These techniques confirmed the presence of a nonlinear association and structural breaks between proposed variables. Later, the nonparametric causality in the quantiles technique has been employed for the analysis. The findings reveal that financial inclusions play a crucial role in maintaining a sustainable environment, but it is necessary to adopt energy efficiency policies to mitigate emissions. Furthermore, the recommendations for policymakers, government, and future scholars are discussed in the paper.

Keywords Financial inclusion · Energy efficiency · Causality in quantiles · Developed economies

Introduction

The natural environment has been threatened by global warming and climate change. Environmental experts contend that uncontrolled human competition for resources is a primary cause of global warming (Khan et al., 2020). All developed countries face

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the same challenge: how to develop their economies sustainably. Recently, many ways have been introduced to foster economic growth, improve financial stability, and decrease global warming. A recent study of Lee et al. (2019) highlighted the challenging role of financial inclusion in maintaining sustainability and financial efficiency. Financial inclusion was listed as one of the nine sustainable development agendas in Seoul at the G20 Summit (GPFI, 2011).[1]

Financial inclusion tends to be an essential element for financial development because it stimulates performance of financial entities and sectors (Jingpeng et al., 2022). Theoretically, financial inclusion encompasses detrimental and advantageous effects on the environment. The positive aspect is its ability to provide businesses and individuals with better availability to useful financial strategies, enabling investments in sustainable initiatives. In contrast, increasing the accessibility of financial services promotes rapid industrialization and manufacturing, resulting in higher CO_2 emissions that contribute to climate crisis (Le et al., 2020). Furthermore, Khan et al. (2019) comprehended that buyers are able to acquire energy-intensive household goods and appliances such as refrigerators, vehicles, and air conditioners when their financial involvement is increased. Nonetheless, their usage threatens the environment due to rising greenhouse gas emissions (GHG). So, it is necessary to evaluate the contributing part of financial inclusion in an eco-friendly and sustainable environment because many countries are still struggling to mitigate GHG emissions.

Sustainable environment and energy efficiency have emerged as major issues for many countries, especially in light of a rapid increase in natural resource exploitation (Dabbous & Tarhini, 2021). Farrell (1957) was the first to introduce the idea of energy efficiency into the literature. According to Marques et al. (2019), 70% of emissions result from excessive energy consumption. The prior research affirmed that higher energy consumption constitutes negative externalities. The main reason is the central involvement of almost all sectors in the excessive consumption of energy for various purposes. For example, households, industrial, agriculture, construction, and commercial sectors use energy for several purposes that ultimately cause air pollution, noise pollution, global climate change, solid waste disposal, and water pollution. Hence, there is a need to consider the different pathways to energy efficiency to encourage environmental sustainability without compromising economic growth. The most reliable approach to overcome detrimental effects is the productive use of energy. Energy efficiency is an efficient technique for lowering GHG emissions, fostering economic progress, and addressing energy security (Guoyan et al., 2022). To meet these objectives, significant investments in green technology have been made in recent years (Wurlod & Noailly, 2018).

The empirical consequences revealed that economical activities contribute in deteriorating environmental quality. The developed economies are the highest-emitting nations (Yasin et al., 2020). "China, the European Union, and the USA" are the top three contaminators of gases which contribute to 41.5% in the total world emissions. In comparison, the lowest hundred economies are responsible for releasing 3.6% of emissions. Most surprisingly, about two-thirds of the global greenhouse

[1] The First G20 Global Partnership for Financial Inclusion (GPFI) Forum, https://www.gpfi.org/

gas emissions are produced by the ten leading emitting countries.[2] In 2018, the top fifteen nations that contributed more than 66% of the world's economic development emitted around 72% of global carbon emissions (World Bank, 2018). British Petroleum's statistical information reveals that the prime 15 emitters, such as the USA (15.1%), Japan (3.3%), Germany (2.1%), Canada (1.6%), and France (0.8%), contribute more than three-fourths of overall pollution. Similarly, the World Bank data on CO_2 emissions (metric tons per capita-2016) reveal the following: Canada (15.09), Germany (8.840), the UK (5.777), Japan (8.944), and the USA (15.502). It shows that these economies are the primary cause of environmental degradation, but their strategies for a sustainable environment cannot be ignored. Hence, these statistics motivate us to focus on the analysis of developed economies.

Our contributions to the literature are fourfold. First, this paper determines the association between financial inclusion, energy efficiency, and a sustainable environment. This is a pioneering research to determine emerging concepts under a single research framework. Second, a "nonparametric causality-in-quantiles approach" has been used in data analysis. Third, we take into consideration the first (mean) and second moments (variance) for exploring the nonlinear and nonparametric causal relationship between proposed variables. Hence, it produces more efficient and comprehensive estimates than former studies using simple correlation and connectedness procedures. Fourth, as per our literary findings, no one has studied the impact of financial inclusion on energy efficiency (FI ---> EE) and sustainable environment (FI ---> SE), and the influence of energy efficiency on the sustainable environment (EE ---> SE) through nonparametric causality-in-quantiles approach, specifically by targeting developed economies. Economic development decreases poverty, provides essential resources, and raises the standard of living. However, the development process has drawbacks, especially when economic prosperity is given priority over the natural environment (Yasmeen et al., 2019). Massive economic growth in developed economies has resulted in substantial improvements in the quality of life; yet, as developed economies pursue the route of advancement, they remain the largest carbon emitter. Hence, it motivates us to target developed economies for our research.

The remaining paper is structured as follows: an introduction is followed by a detailed literature review. Then, in the third chapter, the relevant methodology is discussed. The fourth section is all about the data analysis and relevant reasoning of the existing analysis. The last part highlights the conclusion of this paper, which describes the implications of the findings and future literary directions.

Literature Review

The emerging concepts of the present era are financial inclusion, energy efficiency, and a sustainable environment. All these approaches have gained the attraction of many policymakers and researchers as well. However, no one has studied these three

[2] World Resources Institute (2020) See: https://www.wri.org/insights/interactive-chart-shows-changes-worlds-top-10-emitters

concepts together yet. This section has been categorized into two parts. The first includes studies related to financial inclusion and development. The second section tells the work that studied energy efficiency.

Financial Inclusion and Development

The first literary strand highlights the relation between financial inclusion and different facets of financial growth as well as with economic growth (Babajide et al., 2015; Mehrotra & Yetman, 2015; Kim, 2016; Sharma, 2016; Neaime & Gaysset, 2018; Kim et al., 2018). Financial inclusion is both an outcome and a catalyst of economic development (Sharma, 2016). For instance, scholars take into consideration the countries of the Organization of Islamic Cooperation for exploring and suggesting the critical contribution of financial inclusion for economic development (Kim et al., 2018). Also, the authors argued that financial inclusion improves the economy across thirty-one countries (Sethi & Acharya, 2018). The positive link between financial inclusion and growth was recently discovered by Van et al. (2021). The scholars targeted low-income nations with diminished financial inclusion level.

After reviewing the literature, it is revealed that few scholars study the nexus between financial inclusion and sustainability. For instance, the authors considered thirty-one Asian countries for investigating whether financial inclusion improves financial sustainability and performance (Le et al., 2019). For that purpose, scholars employed "Feasible Generalized Least Squares." The findings divulged that higher financial inclusion reduces financial efficiency but improves financial sustainability. Likewise, Le et al. (2020) revealed that energy consumption, urbanization, industrialization, and financial inclusion upsurge CO_2 emissions. Another study by Usman ei al. (2021) targeted the emerging question of whether environmental footprints and economic growth get better after the utilization of financial inclusion and renewable and non-renewable energy. The authors contemplated the fifteen highest emitting countries. After analysis, they revealed the utilization of economic bloom and non-renewable energy are highly accountable for environmental degradation. On the contrary, green energy and improvement in finance assist in mitigating negative externalities of environment. Considering this, Zaidi et al. (2021) proposed that energy consumption in the OECD countries get accelerated financial inclusion, hence, ultimately increasing CO_2 emissions.

Energy Efficiency

The second body of literature focuses on energy efficiency. Energy efficiency attracted global attention after the 1970s oil crisis (Wang & Nie, 2018), and comprehensive scholarly literature has emerged to measure economies and the end-use sector's energy efficiency. Dogan et al. (2020) argued that it contributes in the energy framework of long-term growth and sustainability. The development of energy-efficient technologies can minimize energy consumption at both the residential and commercial levels. Lee (2015) investigates the energy efficiency factors that are considered drivers and barriers to sustainable development. The findings concluded that energy efficiency is greatly affected by economic factors such as taxes on energy, capital budget, and loans for investments in energy efficiency. Furthermore, Rajbhandari and Zhang (2018) targeted fifty-six high- and middle-income counties to understand whether energy efficiency fosters economic growth by employing a panel vector autoregression. For middle-income economies, the results indicate long-run bidirectional causality between lower energy consumption and higher economic growth. This result implies that energy-efficient policies can generate an additional growth dividend for middle-income economies. Marques et al. (2019) researched by focusing on the industrial sectors of the European Union Countries. The authors designed the research to understand the interconnection among energy efficiency and sustainable growth. For analyzing the short- and long-term relationships, a nonlinear ARDL model has been used. According to the researchers, the investment results in rising energy efficiency while also decreasing greenhouse gas emissions. Economic development is causing countries to become more energy efficient. It is confirmed by recent research by Dell'Anna (2021) that investments in energy efficiency foster a sustainable environment.

After reviewing the literature in detail, it is observed that several scholars highlight the connection of financial inclusion, economic development, and CO_2 emissions. However, the prior work used conventional statistical techniques. For instance, nonlinear ARDL, feasible generalized least squares, common correlated effects estimator technique, panel cointegration, panel causality, etc. Still, no one employs the recent technique, i.e., nonparametric causality-in-quantiles. Similarly, prior research considers energy efficiency with growth and technological advancement, but none studied the relationship between financial inclusion and sustainable environment and energy efficiency and sustainable environment. Thus, the aim of the present research is to address the current literary shortcomings. This study is crafted to examine the relationship in developed economies by employing the nonparametric causality-in-quantiles technique. This technique was used by authors Balcilar et al. (2016), Raza et al. (2018), Shahbaz et al. (2017), and Bhatia et al. (2018), who acknowledged its potential to generate robust findings. This viewpoint enriches the existing literature and opens up new avenues for future research.

Data and Methodology

Data

The present research includes three essential variables: financial inclusion, energy efficiency, and sustainable environment. We consider the data from 1990 to 2016 of developed economies, i.e., "Canada, France, Germany, Italy, Japan, the UK, and the USA." Financial inclusion is measured by "a new broad-based index of financial development."[3] Furthermore, energy efficiency is measured by "GDP per unit

[3] This index was first created as part of the IMF Staff Discussion Note "Rethinking Financial Deepening: Stability and Growth in Emerging Markets" (Sahay et al., 2015).

Table 1 Variables measurement and source

Variables	Measurement	Source
Financial inclusion	Novel index of financial development	International Monetary Fund
Energy efficiency	GDP per unit of energy use (PPP $ per kg of oil equivalent)	World Bank
Sustainable environment	CO_2 emissions (metric tons per capita)	World Bank

of energy use (PPP $ per kg of oil equivalent)," and a sustainable environment is evaluated based on "CO_2 emissions (metric tons per capita)." The data on financial inclusion has been extracted from International Monetary Fund (IMF)[4] , and the remaining variables have been taken from World Bank.[5] The details of the data are reported in Table 1.

Methodology

The approach of nonparametric causality in quantiles was introduced in 2016 by Balcilar, Bekiros, and Gupta. Research by Shahbaz et al. (2017) proposed a similar model; thus, following this research, we also employ Balcilar et al. (2016) approach for identifying the association between financial inclusion, energy efficiency, and sustainable environment. It has been selected for the analysis because this approach offers greater benefits than the conventional causality test (Raza et al., 2021). Such as assisting in finding nonlinear causality. Furthermore, it is resistant to the extreme values in the data and captures the general nonlinear dynamic linkages.

It was established through the combination of two econometrics frameworks, i.e., Jeong et al. (2012) and Nishiyama et al. (2011). From Jeong et al. (2012), the concept of nonparametric quantile causality is taken, and from Nishiyama et al. (2011), the kth order nonparametric causality framework is taken. Based on Jeong et al. (2012), we describe the quantile-based causality in the θ quantile as X_t does not cause Y_t concerning the lag-vector of:

$\{y_{\mathrm{t}-1}, y_{t-p}, \mathrm{X}_{\mathrm{t}-1}, X_{t-p}\}$, if:

$$\mathrm{Q}\theta = \left(y_t | y_{t-1}, y_{t-p}, \mathrm{X}_{t-1}, X_{t-p}\right) = Q\theta\left(y_t y_{t-1}, y_{t-p}\right), \quad (1)$$

X_t probably causes y_{t} in the θ-quantile for $\{y_{t-1}, y_{t-p}, \mathrm{X}_{t-1}, X_{t-p}\}$, if:

$$\mathrm{Q}\theta = \left(y_t | y_{t-1}, y_{t-p}, \mathrm{X}_{t-1}, X_{t-p}\right) \neq Q\theta\left(y_t y_{t-1}, y_{t-p}\right), \quad (2)$$

In the second equation, $\mathrm{Q}\theta = (\gamma_{\mathrm{t}}.)$ symbolizes the $\theta - th$ quantile of y_t that depends on t, and the quantiles are bound among 0 or 1, i.e., 0 < θ < 1. The

[4] https://data.imf.org/?sk=F8032E80-B36C-43B1-AC26-493C5B1CD33B

[5] https://www.worldbank.org/en/home.

following vectors "$y_{t-1} \equiv (y_{t-1,} y_{t-p})$, $X_{t-1} \equiv X_{t-1}$, ... $X_{t-p})$, $Z_t = (X_t, y_t)$" are defined to explain the causality-in-quantiles test comprehensively. The $Fy_t \,|\, y_{t-1}(\gamma_t | y_{t-1})$, $Fy_t \,|\, Z_{t-1}(\gamma_t | Z_{t-1})$ defines the conditional distribution, which signifies the distribution functions y_t conditioned on vectors Z_{t-1} and y_{t-1}, respectively. The $Fy_t \,|\, Z_{t-1}(y_t | Z_{t-1})$ is supposed to be entirely continuous in y_t for nearly all Z_{t-1}. By indicating $Q\theta(Z_{t-1}) \equiv Q\theta(\gamma_t | Z_{t-1})$, and $Q\theta(y_{t-1}) \equiv Q\theta(\gamma_t | y_{t-1})$, we construct $Fy_t \,|\, Z_{t-1}\{Q\theta(Z_{t-1}) | Z_{t-1}\} = \theta$ having a probability of one. Therefore, the hypotheses that need to be tested are mentioned below and are developed based on the first and second equations:

$$H_0 : P\left\{Fy_t | Z_{t-1}\left\{Q\theta\left(\gamma_{t-1}\right) | Z_{t-1}\right\} = \theta\right\} = 1, \tag{3}$$

$$H_1 : P\left\{Fy_t | Z_{t-1}\left\{Q\theta\left(y_{t-1}\right) | Z_{t-1}\right\} = \theta\right\} < 1, \tag{4}$$

As argued by Jeong et al. (2012), $J = \{\varepsilon_t E(\varepsilon_t | Z_{t-1}) F_Z(Z_{t-1})\}$ is used to measure the distance, where ε_t shows the error, and the function of marginal density Zt−1 is shown by $F_Z(Z_{t-1})$. The null hypothesis displayed in Eq. (3) is considered to be correct if:

"$E[1\{y_t \leq Q\theta(y_{t-1}) Z_{t-1}\}] = \theta$" or it can be equivalent to "$1\{y_t \leq Q(y_{t-1})\}] = \theta + \varepsilon_t$."

Here, $1\{\bullet\}$ displays the indicator function. The Jeong et al. (2012) distance function is explained below:

$$J = E\left[\left\{Fy_{t|}z_{t-1}\left\{Q\theta\left(\gamma_{t-1}\right) | Z_{t-1}\right\} - \theta\right\}^2 F_Z\left(Z_{t-1}\right)\right], \tag{5}$$

Thus, in the fifth equation, a feasible kernel-based causality in-quantiles test statistic for the fixed θ-quantile is explained as:

$$\hat{J}_T = \frac{1}{T(T-1)h^{2p}} \sum\nolimits_{t=p+1}^{T} \sum\nolimits_{s \neq P+1}^{T} \quad s \neq t^K \left(\frac{Z_{t-1} - Z_{s-1}}{h}\right) \hat{\varepsilon}_t \hat{\varepsilon}_s, \tag{6}$$

where bandwidth is symbolized by h, the sample size is symbolized by t, a kernel function is symbolized by $K(.)$, lag order is symbolized by p, and the unknown regression error is symbolized by $\hat{\varepsilon}_t$ and is calculated as:

$$\hat{\varepsilon}_t = 1\left\{y_t \leq \hat{Q}\theta\left(y_{t-1}\right)\right\} - \theta, \tag{7}$$

In Eq. (7), $\hat{Q}\theta\left(y_{t-1}\right)$ represents the estimate of the $\theta - th$ conditional quantile of y_t given y_{t-1}, whereas $\hat{Q}\theta\left(y_{t-1}\right)$ can be estimated by using the nonparametric kernel method shown below:

$$\hat{Q}\theta\left(y_{t-1}\right) = \hat{F}^{-1}_{yt|yt-1}\left(\theta y_{t-1}\right), \tag{8}$$

where $\hat{F}_{yt|yt-1}\left(y_t y_{t-1}\right)$ describes the Nadarya-Watson kernel estimator and can be calculated by:

$$\hat{F}_{yt|yt-1}\left(y_t y_{t-1}\right) = \frac{\sum_{s=p+1,s\neq t}^{T} L\left(\frac{y_{t-1}-y_{s-1}}{h}\right) 1\left(\mathrm{y}_s \leq y_t\right.}{\sum_{s=p+1,s\neq t}^{T} L\left(\frac{\mathrm{y}_{t-1}-y_{s-1}}{h}\right)}, \tag{9}$$

Equation (9) includes the kernel function that is represented by $L(\cdot)$ and bandwidth is displayed as h. In the present study, we need to examine whether causality runs from financial inclusion to energy efficiency, from financial inclusion to a sustainable environment, and from sustainable environment to financial inclusion and energy efficiency. Moreover, it is stated that causality-in-variance indicates the volatility transmission; thus, in the case of the mean first moment, if there is no causality, there are still chances that it would be available in variance. Additionally, through the extension of Jeong et al. (2012), the researchers developed the second moment's causality test (i.e., variance in causality). Also, in the highest or second moments, we cannot easily detect the availability of causality because of some complications. It is argued that if in the mth moment, the causality is rejected, so it does not depict similar results, i.e., non-causality in the kth moment for $m < k$; hence, there is a need to carefully defined the procedures for the test. Thus, for this purpose, the nonparametric Granger quantile causality technique, introduced by Nishiyama et al. (2011), is employed in the present research. The aim of applying this technique is to determine the availability of causality in higher-order moments (variance). Hence, by using Eq. (10), the presence of causality for Y_t can be checked:

$$y_t = g\left(\mathrm{y}_{t-1}\right) + \sigma\left(X_{t-1}\right)\varepsilon_{\mathrm{t}}, \tag{10}$$

In tenth equation, the white noise process is denoted by ε_t. The unfamiliar roles are illustrated and Y_t's stationary properties are fulfilled by σ (•) and g (•). When σ (•) is a general nonlinear function so, in this scenario, the predictive power of X_{t-1} to Y_t^2 can be represented, but the prior mention illustration does not permit the linear or nonlinear causalities from X_{t-1} to Y_t. Hence, it is illustrated by Eq. (10) that in the nonlinear function, i.e., σ (•), the squares for X_{t-1} do not enter necessarily. So, the following equations, i.e., Eqs. (11) and (12), are formulated from Eq. (10). These are the hypotheses representing null and alternate hypothesis equations for causality in variances:

$$\mathrm{H}_0 : P\left\{F\mathrm{y}_{\mathrm{t}}^2|\mathrm{Z}_{\mathrm{t}-1}\left\{\mathrm{Q}\theta\left(\gamma_{t-1}\right)|Z_{t-1}\right\} = \theta\right\} = 1, \tag{11}$$

$$\mathrm{H}_1 : P\left\{F\mathrm{y}_{\mathrm{t}}^2|\mathrm{Z}_{\mathrm{t}-1}\left\{\mathrm{Q}\theta\left(\gamma_{t-1}\right)|Z_{t-1}\right\} = \theta\right\} < 1, \tag{12}$$

To obtain the viable test statistic by using tenth equation, replace y_t in equations from sixth to ninth, with y_{t}^2. The problem regarding the causality in the conditional first moment (mean) states that after applying Jeong et al. (2012) approach, the issue of causality in the second moment (variance) can be addressed. Furthermore, the model mentioned below is the interpretation of causality in the higher moments:

$$y_t = g\left(\mathrm{X}_{t-1}, y_{t-1}\right) + \varepsilon_t, \tag{13}$$

As a result, the causality-in-higher-order quantiles can be described as follows:

$$H_0 : P\{Fy_t^k|Z_{t-1}\{Q\theta(y_{t-1})|Z_{t-1}\} = \theta\} = 1 \text{ for } k = 1, 2, K, \quad (14)$$

$$H_1 : P\{Fy_t^k|Z_{t-1}\{Q\theta(\gamma_{t-1})|Z_{t-1}\} = \theta\} < 1 \text{ for } k = 1, 2, K, \quad (15)$$

To conclude the above-discussed concept, we indicated that in the θ quantile X_t granger cause Y_t up to *k*th moment by using Eq. (14) to construct the test statistic of Eq. (6) for each k. The authors argue that the merger of unlike statistics for each $k = 1, 2, \ldots,$ K into one is difficult because they are equally correlated (Nishiyama et al., 2011). Thus, along with limited modifications, the sequential testing method is applied to solve the mentioned issue. In the first step, the nonparametric Granger causality is checked in the 1st moment by considering K = 1. In this step, the null hypothesis rejection does not indicate no-causality in the 2nd moment. However, it provides a strong prediction of the presence of Granger causality in the 2nd moment. Thus, we again run the test by taking K = 2 (Balcilar et al. 2016). Hence, the testing of causality using quantiles is dependent on three crucial selections, which include h (bandwidth), selection of kernel type for L (•), and K (•) and *p* (lag order). For the preference of h (bandwidth), we opt the least squares cross-validation method. The selection of *p* (lag order) is based on the Schwarz information criterion (SIC). It gauges the issue related to over-parameterization, which is usually associated with nonparametric methodologies. Also, it accounts for the parsimoniousness when choosing lags compared to other alternative lag-length selections. For L (•) and K (•), we employed the Gaussian-type kernels.

Data Analysis

Descriptive Analysis

The second table (Tables 2 & 3) includes descriptive statistical analysis, i.e., “mean, standard deviation, minimum and maximum value, kurtosis, skewness, Jarque-Bera normality test, and augmented Dickey-Fuller test (ADF).” The lowest value of mean of the sustainable environment is noted in France 5.737, and the highest value of mean is in the USA 18.555. In the case of financial inclusion, Italy depicts the lowest mean, i.e., 66.442, and the USA shows the highest mean value, which is 82.265. The lowest mean value of energy efficiency tends to be of Canada 4.121, while Italy records the highest mean value of 10.312.

The analysis of skewness suggests the highly skewed data, and the kurtosis figure reveals the series to be fat-tailed distributed. Hence, the data is abnormally distributed, and figures of Jarque-Bera (J-B) also support the results. At 1%, 5%, and 10%, respectively, the JB statistics and ADF test findings recommend a complete no-acceptance the null hypothesis. This establishes a justification for using “the causality-in-quantile test” instead of the conventional “linear Granger causality test.” In addition to the descriptive statistics, a graph of the three variables portrays a trend chart (see Fig. 1).

Table 2 Results of descriptive statistics

Variables	Mean	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	J-B
Canada							
SE	16.196	17.589	14.753	0.907	0.124	1.561	9.597**
FI	75.839	89.923	46.574	12.651	– 0.864	2.591	14.204***
EE	4.121	6.193	2.623	1.124	0.235	1.668	8.979**
France							
SE	5.737	6.707	4.261	0.599	– 0.866	2.899	13.539***
FI	67.411	85.943	40.067	13.827	– 0.726	2.114	13.026***
EE	7.295	11.777	4.496	2.181	0.477	1.948	9.078**
Germany							
SE	9.983	11.745	8.747	0.813	0.350	2.340	6.161*
FI	71.671	79.502	51.595	6.518	– 1.128	3.595	24.502***
EE	7.989	13.251	4.175	2.559	0.523	2.017	9.275**
Italy							
SE	7.172	8.220	4.342	1.004	– 1.316	3.768	33.848***
FI	66.442	80.331	39.214	14.581	– 0.898	2.043	18.643***
EE	10.312	16.194	7.152	2.538	0.750	2.280	12.444***
Japan							
SE	9.375	9.892	8.571	0.335	– 0.550	2.259	7.923**
FI	73.463	86.292	56.776	9.747	– 0.318	1.615	10.458**
EE	7.904	12.403	5.327	2.037	0.709	2.237	11.663***
UK							
SE	8.513	9.885	5.574	1.135	– 1.004	2.820	18.306***
FI	80.724	95.292	57.668	10.782	– 0.919	2.530	16.205***
EE	8.903	16.489	4.659	3.490	0.550	2.135	8.813**
USA							
SE	18.555	20.216	15.306	1.415	– 0.930	2.278	17.907***
FI	82.265	89.590	57.166	10.456	– 1.527	3.723	44.323***
EE	5.409	8.626	3.095	1.693	0.337	1.842	8.082**

J-B Jarque-Bera test of normality

***, **, and * denote the rejection of null hypothesis at the 1%, 5%, and 10% respectively

Source: Authors' estimations

Empirical Analysis

The "linear Granger causality test" has been employed for the analysis of the causal association between proposed variables. The test is established upon the linear vector autoregression VAR model. Table 4 implies that most countries accept the null hypothesis, claiming no granger causality between proposed associations. Thus, it is concluded that no granger causality exists between financial inclusion and sustainable environment and energy efficiency, and energy efficiency does not granger cause a sustainable environment.

Table 3 Results of augmented Dickey and Fuller test of stationary

Variables	$I(0)$		$I(1)$	
	C	C&T	C	C&T
Canada				
SE	− 1.412	− 1.843	− 3.161**	− 3.938**
FI	− 1.989	− 2.141	− 3.604***	− 4.319***
EE	1.592	− 2.665	− 3.340**	− 3.748**
France				
SE	0.603	− 0.662	− 4.564***	− 5.061***
FI	− 1.764	0.164	− 3.049**	− 4.432***
EE	1.843	− 0.881	− 3.793***	− 4.587***
Germany				
SE	0.603	− 0.662	− 3.564***	− 4.574***
FI	− 2.072	− 1.529	− 3.377**	− 4.228***
EE	3.034	− 0.449	− 3.474**	− 5.090***
Italy				
SE	0.477	0.343	− 3.168*	− 3.625**
FI	− 2.064	− 1.141	− 3.367**	− 4.080***
EE	2.155	− 0.056	− 2.656*	− 3.933**
Japan				
SE	− 1.777	− 2.508	− 2.897**	− 4.010**
FI	− 1.834	− 1.661	− 3.526***	− 3.963**
EE	2.748	− 0.010	− 3.161**	− 4.459***
UK				
SE	1.879	0.390	− 3.884***	− 4.557***
FI	− 2.164	− 1.622	− 2.888*	− 4.472***
EE	2.950	0.645	− 2.789*	− 5.035***
USA				
SE	0.660	− 1.488	− 3.910***	− 4.682***
FI	− 1.520	− 1.777	− 3.132**	− 3.975**
EE	1.523	− 1.752	− 3.126**	− 4.549***

*, **, and *** indicates significance level respectively at 1%, 5%, and 10%

Source: Authors' estimation

The outcomes of the Brock-Dechert-Scheinkman (BDS) test are represented in Table 5 for nonlinearity. Brock et al. (1996) proposed this test to determine the nonlinear dependency among the variables and the linear Granger causality test. There is a probability of having a nonlinear association because of many other factors, such as macroeconomic policies, structural breaks, fluctuations in an economic cycle, and financial crises. Moreover, Brock et al. (1996) stated that it is a nonparametric approach. Based upon the correlation integral of the series, the nonlinear structure and independence in a time series can be tested. Also, BDS statistics play an essential role in two domains. Firstly, it is involved in detecting the deterministic chaos.

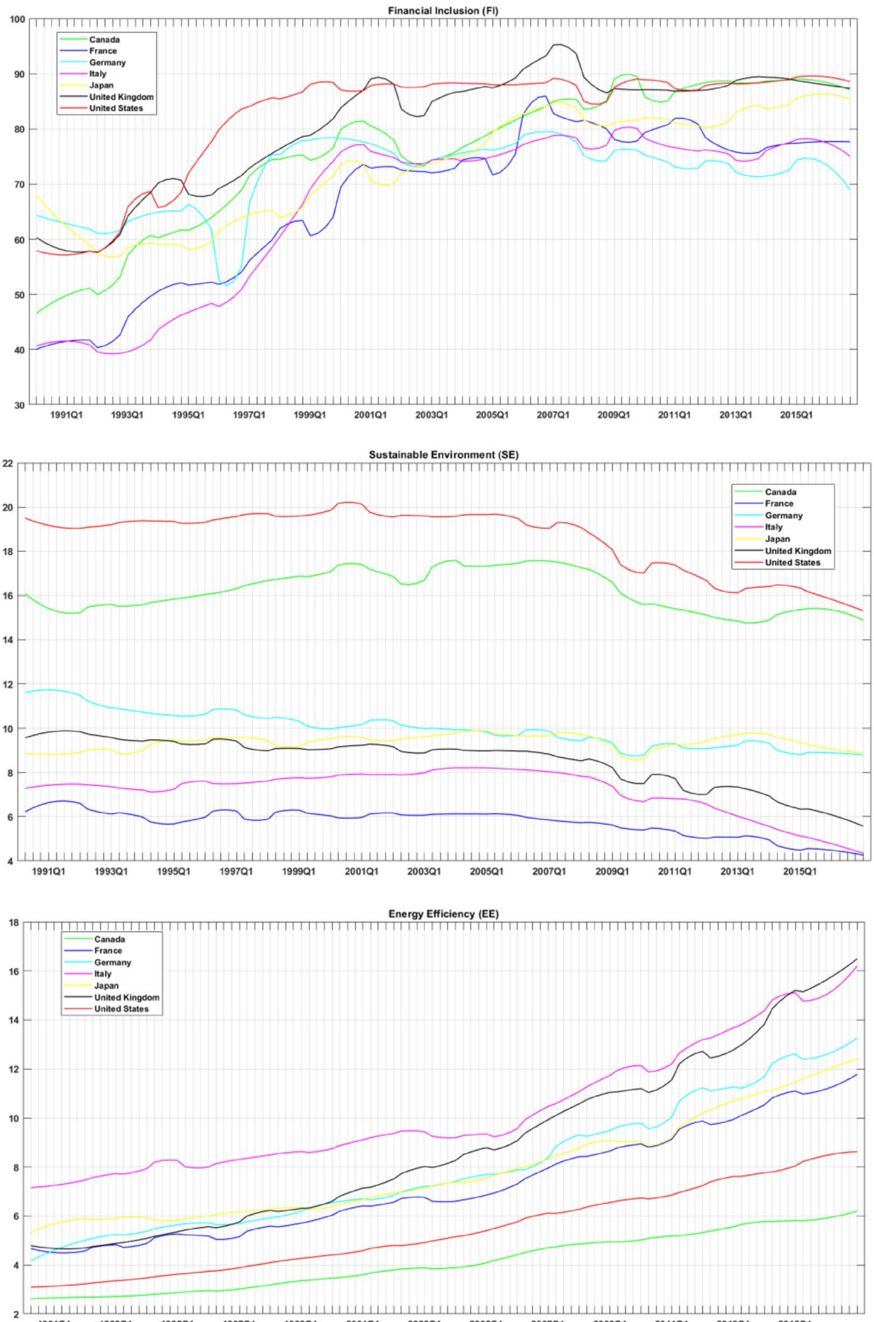

Fig 1 Trend chart of financial inclusion, energy efficiency, and sustainable environment

Table 4 Linear Granger causality test

Variables	*f*-stats	*p*-value
Canada		
FI ---> SE	1.059	0.351
FI ---> EE	4.868	0.010
EE ---> SE	2.278	0.108
France		
FI ---> SE	0.148	0.862
FI ---> EE	0.466	0.629
EE ---> SE	0.211	0.810
Germany		
FI ---> SE	0.037	0.964
FI ---> EE	0.130	0.878
EE ---> SE	3.242	0.043
Italy		
FI ---> SE	3.203	0.045
FI ---> EE	0.736	0.482
EE ---> SE	3.817	0.025
Japan		
FI ---> SE	0.975	0.381
FI ---> EE	1.754	0.178
EE ---> SE	1.085	0.342
UK		
FI ---> SE	0.274	0.761
FI ---> EE	1.020	0.364
EE ---> SE	2.212	0.115
USA		
FI ---> SE	2.095	0.128
FI ---> EE	0.687	0.506
EE ---> SE	3.379	0.038

The table reports the *F*-statistic and prob. value for the no Granger causality restrictions imposed on a linear model under the null hypotheses H0

Source: Authors' estimations

Moreover, the estimated model's goodness of fit can be tested by the BDS. Furthermore, it functions as a residual diagnostic tool. Therefore, this test is employed on the residuals of the variables. It is revealed from the results that at 1% significance, the null hypothesis of i.i.d residuals is rejected across various dimensions (m). The finding concluded that a nonlinear association exists between the variables.

The full-sample tests of causality suppose the constant parameters of the parameters of the VAR. This supposition is most likely to be violated though the structural changes in the underlying full-sample time series. Additionally, the authors argued that invalid results because of full-sample causality tests appear in unstable causal links between series (Balcilar & Ozdemir, 2013). Therefore, in existing research,

Table 5 BDS test for nonlinearity

Variables	m = 2		m = 3		m = 4		m = 5		m = 6	
	z-stats	*p-value*	*z-stats*	*p-value*	*z-stats*	*p-value*	*z-stats*	*p-value*	*z-stats*	*p-value*
Canada										
SE	43.624	0.000	45.891	0.000	48.761	0.000	53.127	0.000	59.456	0.000
FI	28.883	0.000	30.709	0.000	32.995	0.000	36.349	0.000	40.943	0.000
EE	49.490	0.000	52.638	0.000	56.920	0.000	63.322	0.000	72.257	0.000
France										
SE	25.299	0.000	26.188	0.000	27.564	0.000	29.991	0.000	33.654	0.000
FI	34.660	0.000	36.836	0.000	39.515	0.000	43.533	0.000	49.042	0.000
EE	41.996	0.000	44.278	0.000	47.448	0.000	52.451	0.000	59.475	0.000
Germany										
SE	37.907	0.000	39.887	0.000	42.589	0.000	46.800	0.000	52.746	0.000
FI	24.354	0.000	25.809	0.000	27.327	0.000	29.626	0.000	32.853	0.000
EE	38.797	0.000	40.942	0.000	44.051	0.000	48.745	0.000	55.322	0.000
Italy										
SE	19.179	0.000	19.792	0.000	20.766	0.000	22.443	0.000	24.890	0.000
FI	28.693	0.000	30.648	0.000	33.041	0.000	36.529	0.000	41.309	0.000
EE	31.677	0.000	33.285	0.000	35.535	0.000	39.088	0.000	44.190	0.000
Japan										
SE	30.144	0.000	30.757	0.000	31.926	0.000	33.914	0.000	36.957	0.000
FI	42.276	0.000	44.833	0.000	48.317	0.000	53.580	0.000	60.715	0.000
EE	31.688	0.000	33.079	0.000	35.292	0.000	38.988	0.000	44.205	0.000
UK										
SE	26.214	0.000	27.123	0.000	28.588	0.000	31.054	0.000	34.993	0.000
FI	29.692	0.000	31.508	0.000	33.752	0.000	37.023	0.000	41.711	0.000
EE	40.590	0.000	42.716	0.000	45.727	0.000	50.416	0.000	57.054	0.000
USA										
SE	25.472	0.000	26.505	0.000	28.000	0.000	30.432	0.000	34.035	0.000
FI	19.823	0.000	21.071	0.000	22.579	0.000	24.759	0.000	27.746	0.000
EE	47.199	0.000	49.944	0.000	53.746	0.000	59.525	0.000	67.668	0.000

The entries indicate the z-statistics BDS test based on the residuals of considered variables. *m* denotes the embedding dimension of the BDS test. All hypotheses are rejected at 1% of significance level

Source: Authors' estimations

we have employed Andrews (1993) and Andrews and Ploberger (1994) parameter (in) stability test to identify two crucial aspects: the first is to investigate whether a nonlinear relationship exists between variables and, secondly, to determine the availability of structural breaks. Financial inclusion, energy efficiency, and sustainable environment are included in the VAR (1) model; furthermore, the findings of parameter stability testing are mentioned in Table 6. Hence, it is concluded from the results that the null hypothesis of stability is not accepted at 1% significance. Furthermore, the rejection is evident by the following three tests: Max-F, Ave-F,

Table 6 Parameter stability testing

Variables	Maximum LR *F* statistics		Exp LR *F* statistics		Ave LR *F* statistics	
	Stats.	Prob.	Stats.	Prob.	Stats.	Prob.
Canada						
FI ---> SE	692.438	0.000	343.151	0.000	431.475	0.000
FI ---> EE	186.787	0.000	89.758	0.000	95.722	0.000
EE ---> SE	211.951	0.000	102.323	0.000	112.991	0.000
France						
FI ---> SE	125.190	0.000	158.891	0.000	141.515	0.000
FI ---> EE	261.181	0.000	127.835	0.000	94.515	0.000
EE ---> SE	77.192	0.000	134.604	0.000	146.441	0.000
Germany						
FI ---> SE	145.441	0.000	169.580	0.000	101.310	0.000
FI ---> EE	440.313	0.000	216.302	0.000	190.526	0.000
EE ---> SE	90.901	0.000	143.128	0.000	169.939	0.000
Italy						
FI ---> SE	49.736	0.000	21.864	0.000	17.726	0.000
FI ---> EE	117.682	0.000	55.797	0.000	39.449	0.000
EE ---> SE	482.143	0.000	237.132	0.000	215.428	0.000
Japan						
FI ---> SE	113.434	0.000	115.478	0.000	110.443	0.000
FI ---> EE	41.145	0.000	17.742	0.000	31.546	0.000
EE ---> SE	26.193	0.000	12.220	0.000	24.046	0.000
UK						
FI ---> SE	260.126	0.000	125.887	0.000	65.118	0.000
FI ---> EE	213.781	0.000	102.958	0.000	69.587	0.000
EE ---> SE	153.490	0.000	72.472	0.000	55.188	0.000
USA						
FI ---> SE	649.846	0.000	321.089	0.000	117.808	0.000
FI ---> EE	212.357	0.000	102.223	0.000	88.829	0.000
EE ---> SE	277.073	0.000	134.468	0.000	143.474	0.000

Parameter stability test by Andrews (1993) and Andrews and Ploberger (1994) with the null hypothesis of parameter stability

Source: Authors' estimations

and Exp-F. Therefore, the confirmation regarding both, i.e., the nonlinear association between proposed variables and structural breaks, is confirmed by the BDS and parameter (in) stability's results. Using the linear Granger causality and ignoring the nonlinear dynamic behavior of the series leads to misspecification errors, resulting in non-reliable and invalid inferences (Ajmi et al., 2015). Hence, the causality-in-quantiles test has been employed for the minimization of this issue. Furthermore, the authors argued that the test of causality-in-quantiles is more suitable against outliers, structural breaks, nonlinear dependence, and jumps (Ullah et al., 2021).

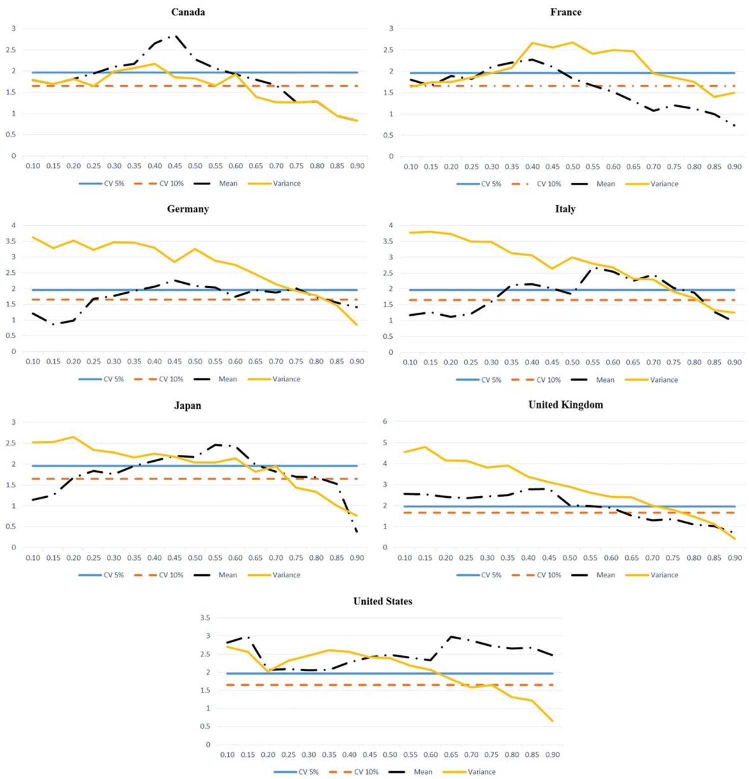

Fig. 2 **A** Causality in mean and variance from financial inclusion to sustainable environment. **B** Causality in mean and variance from financial inclusion to energy efficiency. C Causality in mean and variance from energy efficiency to sustainable environment

Analysis Based on Causality-in-Quantiles Approach

Figure 2A, B, and C represent the findings of causality in mean and variance. The graphs include horizontal and vertical axis. On the vertical axis, a nonparametric causality test is displayed, while quantiles are illustrated on the horizontal axis. The significance levels are 5% and 10%, with critical values of 1.96 and 1.65, respectively. These critical values are signified by thin horizontal lines (5% critical value) and thin double-dashed lines (10% critical value). Results are reported in Tables 7, 8, and 9.

Figure 2A and Table 7 illustrate the outcomes of causality in mean and variance from financial inclusion to a sustainable environment. Based on the graph of Canada, it is stated that we reject the null hypothesis at the 10% significance level, i.e., 1.65, showing financial inclusion does not granger cause a sustainable environment. The rejection is observed over the following quantiles (0.20–0.65), and the acceptance is observed from 0.7 and onwards. The results at 5% critical value, i.e., 1.96 show that the null hypothesis is rejected at the quantiles

Fig. 2 (continued)

0.25–0.55; however, non-rejection of the null hypothesis is found at the quantile ranges from 0.60 to 0.75. The quantile causality test in variance depicts that 10% critical value (1.65), the null hypothesis is rejected at almost all quantiles, but the acceptance is found at the region (0.55–0.60) and (0.65–0.90). Variance results in terms of 1.96 (5%) significant level display the acceptance of null hypothesis almost at all quantiles (0.10–0.30) and (0.44–0.90), whereas a rejection is found only at quantile range 0.30–0.40.

The graph of France indicates the outcomes of the quantile causality analysis concerning mean and variance. The mean at 10% critical value, i.e., 1.65, indicates the rejection of alternate hypotheses in most regions. At the same time, accepting the alternate and rejecting the null at quantiles that lie in the range of 0.10 to 0.50. The same results are illustrated at the 5% critical value (1.96) that rejects the alternate hypothesis at most quantiles and accepts at quantiles from 0.3 to 0.45. However, with respect to variance, 10% critical value (1.65) display the acceptance of alternate hypothesis at all quantiles, excluding the quantiles range from 0.80 to 0.90. On the other hand, at a 5% critical value (1.96), the rejection of alternate hypothesis is found at all regions apart from the quantiles 0.35–0.70.

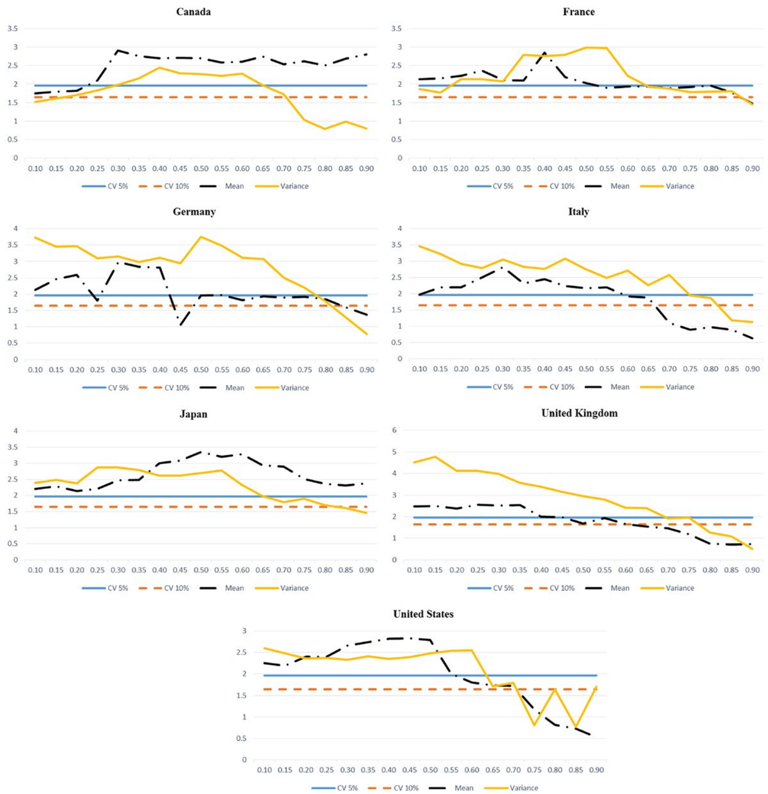

Fig. 2 (continued)

The graph of Germany displays findings of quantile causality concerning the mean and variance. The mean shows that most quantiles suggest accepting the alternate hypothesis at 10% critical value, i.e., 1.65. In comparison, alternate hypothesis is rejected at quantiles 0.10–0.25. Furthermore, 5% critical value (1.96) reveals the rejection of alternate hypothesis nearly at all quantiles, but acceptance is found from 0.40 to 0.50. The variance results indicate that the null hypothesis is rejected in all quantiles; however, from 0.80 to 0.90, an acceptance is reported at 10% critical value (1.65). Likewise, 5% critical value, i.e., 1.96, indicates the rejection of null and acceptance of alternate hypothesis at all quantiles except from 0.75 to 0.90.

The results of Italy depict that the mean at a critical value of 1.65 (10%) shows acceptance of null hypothesis at few quantiles, but mostly quantiles indicate the rejection of null hypothesis, ranging 0.30 to 0.80. The 5% critical value, i.e., 1.96, depicts the same results: almost at all quantiles, the alternate hypothesis is accepted except 0.10–0.30 and 0.80–0.90. The test of quantile causality with respect to variance reveals that both critical values, i.e., 5% and 10%, oppose the null hypothesis almost at every stage. However, acceptance can be seen at the quantiles range from 0.80 t o 0.90.

Table 7 Results of causality in mean and variance from financial inclusion to sustainable environment

Quantiles	Canada		France		Germany		Italy		Japan		UK		USA	
	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance
0.10	1.788	1.788	1.799	1.631	1.213	3.635	1.175	3.773	1.142	2.523	2.556	4.549	2.814	2.706
0.15	1.697	1.697	1.660	1.739	0.862	3.291	1.258	3.809	1.251	2.525	2.535	4.784	2.996	2.564
0.20	1.810	1.810	1.892	1.749	0.986	3.521	1.116	3.736	1.681	2.650	2.426	4.145	2.064	2.016
0.25	1.947	1.647	1.816	1.854	1.672	3.227	1.217	3.504	1.837	2.337	2.350	4.134	2.086	2.317
0.30	2.099	1.990	2.102	1.963	1.773	3.469	1.595	3.484	1.761	2.276	2.430	3.818	2.050	2.463
0.35	2.171	2.071	2.207	2.090	1.929	3.454	2.122	3.135	1.955	2.155	2.497	3.911	2.062	2.610
0.40	2.653	2.165	2.270	2.662	2.060	3.296	2.146	3.064	2.081	2.250	2.768	3.370	2.271	2.561
0.45	2.855	1.855	2.107	2.559	2.263	2.845	2.014	2.636	2.198	2.177	2.801	3.109	2.410	2.409
0.50	2.282	1.824	1.833	2.674	2.095	3.263	1.833	2.996	2.167	2.040	2.015	2.897	2.486	2.386
0.55	2.066	1.656	1.665	2.409	2.032	2.882	2.676	2.805	2.456	2.034	1.969	2.615	2.397	2.185
0.60	1.921	1.921	1.521	2.500	1.746	2.758	2.544	2.673	2.425	2.135	1.894	2.423	2.337	2.064
0.65	1.793	1.393	1.301	2.466	1.950	2.461	2.260	2.317	1.991	1.819	1.514	2.402	2.978	1.808
0.70	1.666	1.266	1.079	1.948	1.878	2.136	2.459	2.292	1.818	1.943	1.298	2.006	2.879	1.580
0.75	1.258	1.258	1.198	1.852	2.009	1.925	2.032	1.913	1.692	1.432	1.364	1.808	2.732	1.650
0.80	1.285	1.285	1.120	1.748	1.724	1.788	1.880	1.718	1.684	1.338	1.097	1.479	2.661	1.319
0.85	0.947	0.947	0.994	1.397	1.552	1.478	1.283	1.327	1.529	1.001	1.017	1.131	2.681	1.223
0.90	0.826	0.826	0.728	1.501	1.405	0.857	0.955	1.247	0.384	0.765	0.711	0.424	2.476	0.652

Entries correspond to the quantile causality test statistic for the null hypothesis that financial inclusion does not granger cause sustainable environment

** and * indicates rejection of null of hypothesis no-causality at 5 and 10% levels respectively

Source: Authors' estimations

Table 8 Results of causality in mean and variance from financial inclusion to energy efficiency

Quantiles	Canada		France		Germany		Italy		Japan		UK		USA	
	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance
0.10	1.879	1.705	1.229	1.234	1.458	2.162	2.417	1.625	1.221	1.325	1.224	1.995	1.859	2.614
0.15	1.855	1.664	1.937	1.699	1.970	1.010	2.550	1.666	1.149	1.810	1.826	2.003	2.081	2.628
0.20	2.204	1.827	1.830	1.713	1.995	2.948	2.711	2.189	1.814	1.971	1.963	2.805	2.075	2.789
0.25	2.343	1.828	2.099	1.825	2.231	2.812	2.474	2.723	1.898	2.053	1.977	2.487	2.087	2.606
0.30	2.331	2.304	2.104	1.935	2.357	2.853	2.454	2.534	2.000	2.064	2.399	2.720	2.932	2.605
0.35	2.515	2.150	2.340	1.943	2.393	2.950	2.290	2.429	2.066	2.014	2.569	2.207	2.913	2.589
0.40	2.845	2.435	2.477	2.040	2.616	2.031	2.144	2.507	2.363	1.910	2.876	2.548	2.919	2.535
0.45	2.641	1.924	2.632	2.150	2.422	1.921	1.894	2.499	2.669	1.832	2.835	2.216	3.141	2.706
0.50	2.539	1.897	2.490	2.585	2.581	1.825	2.974	2.519	2.660	1.853	2.398	2.866	3.218	2.651
0.55	2.005	1.702	2.662	2.505	2.428	1.779	1.927	2.379	2.398	1.948	2.183	2.919	3.003	2.819
0.60	1.940	1.317	2.510	2.503	2.220	1.694	1.350	2.691	2.315	1.661	1.939	2.926	2.838	2.772
0.65	1.862	1.218	2.267	2.117	2.010	1.940	1.592	1.950	2.338	1.323	1.805	2.975	2.502	2.782
0.70	1.752	1.375	1.980	1.712	1.963	2.012	1.259	1.781	2.402	1.408	1.597	2.666	1.950	2.728
0.75	1.880	1.118	1.877	1.790	1.911	2.641	1.261	1.638	2.032	1.363	0.775	2.480	1.760	2.583
0.80	1.529	0.740	1.845	1.599	1.854	2.326	1.074	1.187	1.767	1.155	0.712	1.846	1.695	2.584
0.85	1.524	0.820	1.691	1.753	1.600	2.351	0.914	1.088	1.568	0.614	0.507	1.609	1.533	2.446
0.90	0.701	0.694	1.633	1.547	1.641	2.201	0.624	0.930	1.493	0.562	0.467	1.361	1.494	2.388

Entries correspond to the quantile causality test statistic for the null hypothesis that financial inclusion does not granger cause energy efficiency

** and * indicates rejection of null of hypothesis no-causality at 5 and 10% levels respectively

Source: Authors' estimations

Table 9 Results of causality in mean and variance from energy efficiency to sustainable environment

Quantiles	Canada		France		Germany		Italy		Japan		UK		USA	
	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance
0.10	1.754	1.520	2.132	1.872	2.134	3.727	1.977	3.463	2.208	2.395	2.470	4.513	2.255	2.606
0.15	1.798	1.608	2.153	1.780	2.454	3.446	2.196	3.228	2.288	2.485	2.490	4.782	2.190	2.482
0.20	1.816	1.703	2.221	2.131	2.584	3.461	2.204	2.918	2.141	2.382	2.373	4.119	2.399	2.364
0.25	2.099	1.837	2.370	2.130	1.796	3.103	2.500	2.785	2.201	2.873	2.550	4.126	2.407	2.374
0.30	2.909	1.985	2.115	2.079	2.976	3.153	2.821	3.053	2.475	2.868	2.519	3.975	2.665	2.329
0.35	2.759	2.151	2.102	2.794	2.837	2.982	2.320	2.830	2.487	2.789	2.532	3.564	2.738	2.418
0.40	2.702	2.451	2.848	2.760	2.808	3.112	2.444	2.759	2.999	2.612	2.005	3.394	2.819	2.349
0.45	2.708	2.295	2.192	2.793	1.059	2.945	2.242	3.079	3.084	2.616	1.990	3.159	2.832	2.397
0.50	2.705	2.267	2.024	2.988	1.959	3.748	2.170	2.747	3.349	2.699	1.684	2.962	2.792	2.487
0.55	2.581	2.228	1.898	2.976	1.978	3.480	2.195	2.493	3.206	2.782	1.937	2.785	2.008	2.545
0.60	2.605	2.287	1.942	2.227	1.817	3.117	1.925	2.706	3.286	2.327	1.666	2.414	1.808	2.553
0.65	2.742	1.970	1.931	1.930	1.939	3.069	1.884	2.267	2.931	1.976	1.537	2.396	1.734	1.713
0.70	2.535	1.726	1.888	1.882	1.889	2.491	1.104	2.574	2.902	1.787	1.459	1.927	1.723	1.794
0.75	2.622	1.039	1.927	1.782	1.925	2.191	0.900	1.951	2.511	1.902	1.188	1.958	1.178	0.803
0.80	2.500	0.787	1.961	1.799	1.838	1.780	0.974	1.866	2.364	1.695	0.750	1.267	0.818	1.645
0.85	2.687	0.987	1.780	1.804	1.592	1.278	0.893	1.181	2.306	1.602	0.701	1.077	0.731	0.765
0.90	2.805	0.799	1.475	1.455	1.375	0.776	0.638	1.134	2.381	1.456	0.735	0.514	0.527	1.703

Entries correspond to the quantile causality test statistic for the null hypothesis that energy efficiency does not granger cause sustainable environment

** and * indicates rejection of null of hypothesis no-causality at 5 and 10% levels respectively

Source: Authors' estimations

The graph of Japan indicates the quantile causality test analysis with respect to mean that at 10% critical value, i.e., 1.65, certain quantiles demonstrate rejection of alternate hypothesis, including 0.10–0.20 and 0.75–0.90, while the remaining scale from 0.25 to 0.70 portrays alternate hypothesis acceptance. Similarly, the alternate hypothesis is rejected at most quantiles except at quantiles varying from 0.35 to 0.65 at a crucial value of 1.96 (5%). The variance results specify that at 5% critical value, i.e., 1.96, the alternate hypothesis is accepted over certain quantiles, except for those ranging from 0.65 to 0.90. Similarly, except for 0.70 to 0.90, nearly all quantiles of the critical value 10% (1.65) show acceptance of the alternate hypothesis.

The UK results indicate that concerning mean, the null hypothesis at a critical value of 1.96 (5%) is rejected at most of the quantiles, whereas acceptance is found at quantiles range from 0.60 to 0.90. Also, the null hypothesis at a critical value of 1.65 (10%) depicts similar results. In terms of variance, the results concluded that at 5% significance level, i.e., 1.96, the null hypothesis is rejected at almost all quantiles but accepts the null hypothesis at quantiles ranges from 0.72 to 0.90. Also, we find a similar pattern at a critical value of 10%, i.e., 1.65.

The test of quantile causality analysis for mean highlights that in the situation of the USA, at both critical values, i.e., 1.65 (10%) and 1.96 (5%), all quantiles accept the alternate hypothesis. However, quantile causality test analysis concerning variance indicates that at a critical value of 10%, i.e., 1.65, the alternate hypothesis is accepted at most quantiles except quantiles ranging from 0.76 to 0.90. Similarly, the acceptance of alternate hypothesis is found almost at all quantiles of the critical value 1.96 (5%) except from 0.60 to 0.90.

The results disclose that financial inclusion is a strong analyst in maintaining a sustainable environment. Furthermore, it is apparent that financial inclusion act as a CO_2 emission-abating measure for the countries of concern. Hence, the higher the use of financial services and products, the better will be the sustainable environment. The economies flourish immensely when individuals or businesses invest in green and clean technologies, bonds, and green initiatives. Hence, appropriate financial inclusions play a substantial part in fostering a sustainable environment. According to Qin et al. (2021), financial inclusion has a favorable effect on environmental sustainability because it may serve as a framework to boost the availability, affordability, and adoption of healthy environmental practices, plummeting its contribution to climate change. Our results align with the prior outcomes that claimed that promoting financial inclusivity can help diminish economic growth's adverse environmental impacts to restore environmental sustainability (Zaidi et al., 2021; Renzhi & Baek, 2020).

According to the analysis, the USA is the most dominating economy because, at a federal level, the USA has implemented several programs to expand financial inclusion (Niankara & Muqattash, 2020). However, the UK, Germany, Japan, and France depict that financial inclusion results in a sustainable environment at some quantiles, but some indicate contrasting results. Nevertheless, the results are similar to the prior studies (Usman et al., 2021; Sharifi & Murayama, 2014). Financial inclusion provides individuals and industries with better access to useful and competitive financial schemes, making green technology developments more effective and leading to a sustainable environment.

Figure 2B and Table 8 illustrate the results of causality in mean and variance from financial inclusion to energy efficiency. In Canada, the quantile causality test in mean indicates that at 10% significance level, i.e., 1.65, the alternate hypothesis is embraced by most number of quantiles, except the quantile range 0.80–0.90. However, some quantiles accept the alternate and reject the null at the 1.96 (5%) critical value that says financial inclusion does not granger cause energy efficiency. At some quantiles, the hypothesis is accepted, i.e., 0.10–0.15 and 0.65–0.90. The quantile causality test in variance, at the 10% crucial value, i.e., 1.65, displays the acceptance of the alternate hypothesis, ranging from 0.10 to 0.55. The remaining quantiles reject the alternate that ranges from 0.55 to 0.90. On the other hand, the null hypothesis is accepted at most quantiles with a crucial value of 1.96, i.e., 5%, other than the quantiles varying from 0.25 to 0.45.

France's findings reveal that the mean at 10% critical value (1.65) accept the alternate hypothesis in nearly all quantiles. Rejection, on the other hand, is seen only at the quantile 0.10. Similarly, at 5% crucial value, i.e., 1.96, the alternate hypothesis is accepted at most quantiles, excluding the ranges 0.10–0.20 and 0.75–0.90. The quantile causality test of variance reveals that at 10% crucial value (1.65), the alternate hypothesis is accepted in most quantiles except the 0.10 to 0.15 range. In comparison, most quantiles show rejection of the alternate, with the exception of quantile (0.40–0.65), which has a critical value of 1.96 (5%).

In Germany's graph, the quantile causality analysis concerning mean accept the alternate hypothesis at all quantiles of 10% critical value (1.65). It means that the null hypothesis, i.e., financial inclusion, does not cause energy efficiency to be rejected. Likewise, 5% critical value (1.96) shows the acceptance of alternate at most of the quantiles apart from the quantiles range from 0.10 to 0.15 and 0.80 to 0.90. In terms of variance, it is projected that at 10% critical value, i.e., 1.65, the alternate is accepted at all quantiles, but a minor rejection is observed at the quantile 0.15. The same results are seen at 5% critical value (1.96), accepting alternate hypothesis at most of the quantiles excluding the range 0.10 to 0.15 and 0.45 to 0.65.

In the case of Italy, to some extent, similar results are observed in both analyses, i.e., in mean and variance as well. The mean results reveal that at 5% critical value, i.e., 1.96, the quantiles initially accept the alternate hypothesis, i.e., from 0.10 to 0.55. Then, rejection of alternate hypothesis is found at the quantiles range from 0.55 to 0.90. The mean follows the same pattern at 10% critical value, i.e., 1.65. The analysis of quantile causality in variance, at a critical value of 1.96 (5%), depicts acceptance at most of the quantiles except at quantiles 0.10–0.15 and 0.65–0.90. Similarly, at 10% critical value, i.e., 1.65, a rejection of null and acceptance of the alternate hypothesis takes place in most of the quantiles apart from the quantile 0.75–0.90.

The results of Japan followed a similar pattern at both critical values. In terms of mean, the acceptance of alternate hypothesis is observed at most of the quantiles except at quantiles range from 0.10 to 0.35 and from 0.75 to 0.90, at 5% critical value (1.96). On the other hand, at 10% critical value, i.e., 1.65, the alternate hypothesis is accepted at most quantiles, but a rejection is noticed at quantiles, ranging from 0.10 to 0.15 and 0.85 to 0.90. In terms of variance, the rejection of alternate hypothesis is found at all quantiles at a critical value of 1.96 (5%).

However, at a critical value of 1.65 (10%), most of the quantiles depict acceptance of alternate, and few portray the rejection that ranges from 0.10 to 0.15 and from 0.60 to 0.90.

In terms of the UK, it is observed that the test of quantile causality in mean at 5% critical value, i.e., 1.96, most of the quantiles accept the null hypothesis, but some quantiles reject it, ranging from 0.10 to 0.20 and 0.65 to 0.90. At 10% critical value (1.65), most of the quantiles accept the alternate hypothesis at 0.15–0.70, whereas, remaining depict the rejection of the alternate hypothesis. The variance results show that at 5% critical value (1.96), most quantiles reject the null hypothesis, and acceptance is noticed at quantiles ranging from 0.80 to 0.90. At 10% critical value (1.65), rejection is found at all quantiles except at quantiles ranging from 0.85 to 0.90.

In the USA case, the quantile causality with respect to mean shows that at both critical values, almost all quantiles accept the alternate hypothesis except the quantiles range from 0.70 to 0.90 (at 5%) and from 0.85 to 0.90 (at 10%). If we look at the variance results, then it is noticed that all quantiles accept the alternate hypothesis at both critical values.

It is culminated from the analysis that financial inclusion does Granger cause energy efficiency in almost all developed economies. The alternate hypothesis has been accepted at various quantiles. We find out that the most influential economies are the USA and the UK, but other states depict similar results in some regions. Hence, it has been corroborated that the financial sector is important in promoting low-carbon energy transition (Chenet et al. 2019).

The results are consistent with the research of Yu and Tang (2023), which claimed a significant energy efficiency improvement due to financial inclusion. Therefore, it is clear that due to the increasing energy costs and environmental issues triggered by greenhouse gas emissions, efficient energy use is becoming more common in developed economies. Financial inclusion strives to provide companies and people with reasonable and long-term access to financial services and products. Hence, adequate financial services and convenient products attract people and businesses. When people and businesses are financially supported, and all use the official ways (banks) for financial purposes, it will eventually foster a willingness to purchase energy-efficient products, invest in energy-efficient technologies, and adopt ways that mitigate the adverse effect of the environment. This energy trend is reflected in the increasing energy efficiency of consumer devices and appliances throughout time. In addition, many potential homebuyers are getting energy assessments before finalizing the deal (Yan et al., 2020).

Figure 2C and Table 9 illustrate the results of causality in mean and variance from energy efficiency to sustainable environment. It can be seen in the case of mean that the critical value of 1.96, i.e., 5%, the alternate hypothesis is accepted at all quantiles excluding the quantiles range from 0.10 to 0.25. Furthermore, the results of Canada depict acceptance of alternate hypothesis at all quantiles when we have a critical value of 10%, i.e., 1.65. It claims that energy efficiency granger causes the sustainable environment. In terms of variance, the 5% critical value (1.96) shows the acceptance of the alternate hypothesis at some quantiles, except at 0.10–0.25 and 0.65–0.90. In contrast, the 10% critical value (1.65) accepting the alternate hypothesis at majority regions, excluding quantiles 0.7–0.90.

In France, the test of quantile causality concerning mean indicates that at a crucial value of 1.96, i.e., 5%, the majority of quantiles reject the null hypothesis, with the exception of quantiles ranging from 0.85 to 0.90. The same trend can be seen at the 10% critical value, i.e., 1.65. The graphical representation of variance displays that at 5% critical point, i.e., 1.96, most of the quantiles accept the alternate hypothesis except for 0.10–0.15 and 0.70–0.90. Similarly, except for the 0.90 quantiles, the remaining all quantiles accept the alternate hypothesis at a crucial value of 1.65, i.e., 10%.

In Germany, the quantile causality results with respect to mean indicate that at a significance level of 5%, i.e., 1.96, initially, the quantiles accept the alternate hypothesis, but a rejection is noticed at quantiles range from 0.40 to 0.90. Similarly, when we have a critical value of 10% (1.65), the alternate hypothesis is accepted at all quantiles, but a slight downward curve is observed at quantiles 0.45 and 0.85 to 0.90, showing the rejection. In terms of variance, all quantiles reject the null hypothesis at 5% (1.96), except the quantiles, which range from 0.80 to 0.90. The same result is seen at the critical value of 10% (1.65).

The Italy results in terms of mean depict that alternate hypothesis is accepted at the initial quantiles at 5% critical value, i.e., 1.96, but rejection is observed at the quantiles that range from 0.65 to 0.90. The same result is observed at a critical value of 1.65 (10%). In contrast, the variance results depict the acceptance of the alternate and rejection of null at all regions but with the exception of the quantiles range from 0.75 to 0.90 (at 5%) and from 0.83 to 0.90 (at 10%).

Japan's findings with respect to mean show that at both critical values, i.e., 1.96 (5%) and 1.65 (10%), all quantiles oppose the null hypothesis that says "energy efficiency does not granger cause the sustainable environment." The variance results indicate rejection at most of the quantiles apart from the quantiles that range from 0.65 to 0.90, at 5% critical value (1.96). The same pattern is observed at 10% critical value (1.65).

The UK results reveal in terms of mean that the majority of the quantiles reject the alternate hypothesis, but the remainder of the quantiles, such as 0.10 to 0.40, indicates acceptance of alternate hypothesis at 5% critical value (1.96). At 1.65 (10%) critical value, similar results are observed, i.e., accepting at most of the quantiles and rejecting at quantiles range from 0.10 to 0.50. In variance, the results display that at both critical values, i.e., 5% and 10%, initially quantiles accept the alternate hypothesis, but the exception is observed at 0.76–0.90 quantiles.

The findings of the USA with respect to mean show that at 5% crucial value of 1.96, the quantiles initially accept the alternate hypothesis, but rejection is observed at quantiles ranging from 0.55 to 0.90. All quantiles show acceptance of the alternate hypothesis at a crucial value of 1.65 (10%) but reject the alternate hypothesis at regions ranging from 0.70 to 0.90. The quantile causality analysis of variance findings shows that at 5% crucial value, i.e., 1.96, the quantiles accept the alternate hypothesis in most areas, but rejection of alternate and acceptance of null is seen at quantiles 0.65–0.90. Similarly, 10% crucial value, i.e., 1.65, depicts that the alternate hypothesis is accepted by all quantiles, excluding the quantile 0.70 to 0.90.

The findings confirm that energy efficiency is more noteworthy in fostering a sustainable environment than financial inclusion. All countries reject the null hypothesis and accept the alternate hypothesis, i.e., energy efficiency granger causes a sustainable environment. The developed countries have moved far, with green-clean technology, eco-friendly transportation, energy-efficient products, green housing, and many more. These policies help them in attaining a sustainable environment. Also, Le Quéré et al. (2019) claimed that eighteen developed countries had lessened CO_2 emissions by evolving energy efficiency policy measures and targets from subsidies to mandates. In developed countries, technical advancement, environmental protection, and policies regarding implementing environmental laws and regulations have immensely lowered conventional energy intensity, resulting in a better sustainable environment. Furthermore, when countries strive to eliminate energy waste, it results in various benefits. Such as decreasing demand for energy imports, lowering greenhouse gas emissions, and lowering the costs on a household and economy-wide level. All these aspects collectively appear to be beneficial for sustainability.

In contrast, we can see that in some regions, the alternate hypothesis is rejected, indicating that energy efficiency does not granger cause a sustainable environment. The estimated global energy consumption has increased from 1950 to 2019. The developed countries' reliance on non-renewable resources destroys conventional resources and causes adverse environmental effects such as CO_2 emissions, which cause air pollution and climate change (Zhu et al., 2020).

Conclusion

Two of the most significant challenges that nations all over the globe are now confronting are climate change and the development of effective environmental management. This study has assessed the nonlinear and nonparametric causal association among financial inclusion, energy efficiency, and sustainable environment. For that reason, we focus on developed countries "(i.e., Canada, France, Germany, Italy, Japan, the UK, and the USA)." The outcomes disclosed the occurrence of a nonlinear association among the variables. Then, the outcomes of nonparametric causality in the quantiles techniques depict that financial inclusion leads to a sustainable environment in most of the developed economies. However, Canada and Japan depict the affirmation of null hypothesis. The findings of causality in mean and variance from financial inclusion to energy efficiency show that developed economies such as the USA, UK, Germany, Italy, France, and, to some extent, Canada have an impact of financial inclusion on energy efficiency. Lastly, energy efficiency plays a major role in maintaining sustainable environment, as majority of developed economies' quantiles accept the alternate hypothesis.

In light of the estimated findings, this research suggests some useful implications, such as access to finance and financial inclusion should be promoted in a more relevant manner by policymakers. The governments should ensure that all people and businesses are financially stable and have the right to perform sustainable transactions. Initiatives need to be taken all over the globe in order to strike a balance between environmental legislation and financial inclusion initiatives. Furthermore, it is the core responsibility of policymakers and supervisory bodies to provide sufficient environmental and climate financing to all sectors so that they can deal with increasing CO_2 emissions. Financial institutions should avoid releasing funds to manufacture hazardous commodities and ensure that these funds are spent on environmentally sustainable programs. Moreover, the governments of these countries should promote environmentally sustainable initiatives by offering low-interest financing and establishing a robust check and balance system. Additionally, it is suggested to propose financing strategies for environmentally sustainable initiatives in all economies. It will eventually promote technological innovations and eco-friendly operations in all carbon-intensive industries. In order to achieve long-term sustainability and minimum ecological footprint, the economies must have efficient financial institutions and markets that solely function on green and sustainable policies.

According to the study's findings, governments' green policies and technology are essential to drive energy efficiency developments. A noticeable rise in the number of high-quality institutions and green technology would help reduce energy consumption. To ensure a sustainable environment, it is recommended to introduce clean energy standards, regulations on power plants, and carbon pricing. It is suggested that all developed economies must impose a carbon tax on industrial emissions, strengthen automotive and fuel economy requirements to achieve zero pollution for new vehicles, and implement clean building standards that require all new buildings to be entirely electrified. For a sustainable environment, we recommend encouraging the use of public transportation to reduce energy consumption. Also, promote sustainable transport by introducing CO_2-free modern vehicles and embracing near-zero-emission building construction by incorporating it into government planning. These measures will help in energy efficiency and eventually lead to a sustainable environment.

In the upcoming time, a comparative analysis can be conducted between developed and developing economies; between European and Asian Countries; it will provide an in-depth overview of countries' financial stability and how they are protecting the environment. Additionally, this study can be extended by incorporating other techniques such as nonparametric quantile-on-quantile, quantile ARDL approach, and wavelet-based quantile-on-quantile approach. It will allow comparisons of the results obtained from diverse methodologies, data frequencies, and analysis periods.

Declarations

Conflict of Interest The authors declare no competing interests.

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