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Does financial development moderate the relationship between economic growth and environmental quality?

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ABSTRACT

Mitigating the world's emission levels and ensuring sustainable growth are strategic objectives of modern economies. Yet how financial development affects environmental quality in achieving economic growth is not clearly understood. Therefore, this study aims to analyze the moderating effect of financial development on the economic growth-environmental quality nexus using Australia as a case. Covering the period from 1980 to 2021, this study employs the Autoregressive Distributed Lag (ARDL) model to estimate direct and moderating effects. Empirically, a cointegration relationship is revealed. Moreover, in the long run, both a significant adverse direct effect and an adverse moderating effect of financial development on environmental quality are revealed. This confirms that financial development degrades environmental quality, and its moderating impact worsens the relationship between economic growth and environmental quality. Moreover, economic growth and energy consumption adversely affect environmental quality, while trade openness promotes a healthier environment. The short-run impacts generally align with the long-run findings, except for trade openness. While foreign direct investment plays a neutral role in the long run, it contributes to environmental degradation in the short run. Finally, the empirical findings suggest policy implications for enhancing environmental quality by directing financial allocations towards green avenues.

1. Introduction

Global warming and climate change are among the most controversial and extensively discussed issues worldwide. Primarily, human activities are the root cause of these debatable environmental issues in the present day (Ahmad and Khattak, 2020). However, these environmental issues ultimately adversely impact human life and ecological balance, leading to broader health concerns that affect the entire world. Consequently, mitigating the emissions of greenhouse gases is a necessary step to safeguard human lives from danger (Ehigiamusoe et al., 2022). However, timely actions are vital for achieving environmental targets collectively; otherwise, the consequences will severely impact both nature and humanity (Deschenes, 2014). Due to the adverse impacts, many economies, along with international organizations, have made diverse efforts to initiate measures aimed at reducing emissions levels (Tamazian et al., 2009; Acheampong et al., 2019). Additionally, scholars have deliberately focused on environmental degradation and empirically examined significant driving factors for necessary policy implications.

The environmental effects of various economic variables are explored, with emphasis placed on their outcomes for environmental quality (hereafter EQ), including economic growth (hereafter EG) (Jayanthakumaran et al., 2012; Seetanah et al., 2019) and energy consumption (Shahbaz et al., 2013), among others. Similarly, the finance-environmental relationship is also vital for addressing climate change and global warming issues, as environmental targets may remain unattainable without a sound and viable financial system (Asiedu and Boahen, 2022). Therefore, over the last decade, empirical investigations into the finance-environmental relationship have been widely addressed in various contexts, yet the environmental impact of financial development (hereafter FD) remains inconclusive. Essentially, FD lowers the cost of financing (Acheampong, 2019), leading to alterations in the

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production and consumption patterns of the economy, which adversely affect EQ by increasing pressure on energy and resource demand (Cialani, 2007; Kaika and Zervas, 2013). From a positive perspective, FD assists in investments in renewable energy, technological advancements in energy efficiency, and the transformation of polluting industries toward environmentally healthy industries (Dada et al., 2022; Ruza and Caro-Carretero, 2022).

The direct impact of FD on EQ has been extensively explored (Tamazian et al., 2009; Charfeddine and Ben Khediri, 2016; Shahbaz et al., 2016; Yue et al., 2018; Dada et al., 2022). Importantly, FD is a significant driving force of EG (Hafeez et al., 2019), which indirectly impacts EQ. However, the moderating impact of FD on EQ through the EG channel has received less attention among scholars. Schumpeter's theory of economic development (1911) argued that financial intermediaries play a significant role in EG by identifying and funding businesses that contribute to economic production. This view was later supported by Gurley and Shaw (1955) and Goldsmith (1969), who recognized financial intermediaries as drivers of EG. Typically, financial intermediaries and institutions mobilize savings towards investments, allocate resources, and diversify risk, thereby fostering EG (Greenwood and Jovanovic, 1990). Moreover, King & Levine (1993b); McKinnon (1973); Levine et al. (2000); and Christopoulos and Tsionas (2004) support the argument that FD is a driving force of EG, as it often facilitates the flow of funds to the economy at the lowest cost, propelling economic advancement.

Mainly, FD enables the lowering of the cost of financial transactions and information costs, thus channelling savings into profitable investment avenues (Lynch, 1996; Islam et al., 2013). This leads to enhanced investments and enlarged economic activities, ultimately increasing the production levels of the economy, which in turn increases the demand for energy sources (Sadorsky, 2010). The demand for energy sources ultimately impacts the environment by adding more emissions and degrading its quality. Similarly, FD-driven EG empowers investors to be confident in the economy, they may be inclined to invest in industries that are more pollutant-intensive. These industries often have adverse impacts on EQ due to their high levels of pollution and resource consumption. Such investments can exacerbate environmental degradation, leading to issues such as air and water pollution, habitat destruction, and climate change. In contrast, the indirect impact of FD on EQ through EG can have a positive effect on the environment. This is because energy consumption may decrease if the economy is able to adopt efficient technologies with economic progress (Komal and Abbas, 2015).

The empirical evidence on the indirect environmental impact of FD is necessary to draw policy implications to achieve environmental targets. However, existing research has given less attention to estimating whether FD moderates the environmental impact of EG, as more focus has been placed on the direct impact of FD on EQ. To address the existing empirical gap, this study aims to examine the moderating effect of FD on EQ through the lens of EG, focusing on Australia as a leading developed economy. Australia's financial sector plays a significant role in accelerating EG. However, Australia is also ranked as the world's 14th largest emitter, with a low ranking (55^{th}) in climate change performance. Additionally, the Australian government aims to achieve net-zero emissions by 2050. In these circumstances, the financial sector bears prime responsibility for assisting in reaching environmental targets.

This study sheds light on the moderating role of FD on the EG-EQ nexus offering significant contributions to both academic research and policymaking. Firstly, it enhances academic understanding of the relationships among finance, EG, and the environment. Secondly, the findings provide valuable insights into these relationships, which are crucial for policymakers seeking to redirect the financial sector toward contributing to environmental goals. Thirdly, understanding these relationships assists financial providers in optimizing resource allocation in both public and private sectors to achieve profit targets without sacrificing EQ.

This study is pioneering in its endeavour to address the moderating effect of FD on EQ through the channel of EG in Australia. Furthermore, while a limited number of existing studies have addressed this relationship in other contexts, they have encountered challenges due to the difficulty in measuring FD. Various proxy variables have been utilized in these studies to capture FD, leading to diverse empirical results. In contrast to these studies, the present research employs a wide range of proxies to comprehensively measure all dimensions of FD, namely, financial access, financial depth, financial efficiency, and financial stability.

The remaining sections of the paper are as follows: Section 2 provides a brief overview of the theoretical foundation of the study domain and existing empirical evidence. Section 3 discusses the development of the model, the variables used, and the data utilized in the study. Section 4 presents the key results of the study. Finally, Section 5 concludes the study with policy implications.

2. Literature review

Primarily, FD leads to a reduction in the cost of financing and enhances access to financial facilities for households, the government, and the corporate sector (Nasir et al., 2019). Therefore, FD serves as a crucial driver for channelling necessary funds into investment projects that expand the scale of the economy. As such, a well-developed financial sector not only plays a vibrant role in achieving the efficiency of the financial system but also substantially contributes to EG (Shoaib et al., 2020). Theoretically, the argument of the finance-growth linkage can be traced back to Schumpeter's (1911) assertion that financial intermediaries contribute to economic progress primarily by channelling funds that have a positive impact on productivity growth. Goldsmith (1969); Gurley and Shaw (1955); McKinnon (1973); and Shaw (1973) eventually further reinforced Schumpeter's argument regarding the nexus between finance and EG.

Moreover, Patrick (1966) emphasized the two distinct relationships between finance and EG. In the initial phase of EG, finance facilitates economic progress by channelling funds for capital formation. However, in the later phases of EG, FD is induced by EG itself through increased demand for financial services. Additionally, Levine (1997) further strengthens the finance-economic relationship by arguing that finance serves as the engine of EG by enhancing the efficiency of capital allocation. At the empirical level, the finance-growth nexus has garnered significant attention among scholars. Goldsmith's (1969) study was the first to empirically investigate the impact of FD on EG across 35 economies. It emphasized that FD indeed influences EG within the study context.

Likewise, King & Levine (1993a, 1993b) validated that the level of financial intermediary development serves as a determinant of EG, after controlling for numerous other country-specific characteristics. The pioneering work of Levine and Zervos (1998) provided evidence that the early phase of the banking sector and stock market significantly accelerates EG by increasing economic output, capital stock, and productivity growth. Interestingly, Beck et al. (2000) demonstrated that the development of financial intermediaries enhances capital allocation, thereby promoting long-term economic progress by accelerating productivity growth within the economy. Similarly, Levine et al. (2000) provided statistical evidence confirming that the development of financial intermediaries stimulates EG.

The understanding of the nexus between FD, growth, and EQ has gained much attention among economists for enhancing EQ and making the world more livable (Baloch and Danish, 2022). As discussed above, both theoretically and empirically, it has been proven that FD fosters economic progress, which in turn alters the production and consumption patterns of the economy (Shoaib et al., 2020). Importantly, FD serves as a key driver of EG and income distribution (Greenwood and Jovanovic, 1990; Destek et al., 2020). However, it is not always positive for the environment and can have negative implications as well (Baloch and Danish, 2022). Contrarily, FD generates wealth that accelerates EG, thereby changing the scale of industries and consumption patterns of individuals, which ultimately demands more energy resources, adversely affecting the environment (Le, 2020). However, from a positive standpoint, EG induced by FD creates opportunities for adopting green technologies and renewable energy sources that mitigate environmental consequences (Baloch and Danish, 2022).

Empirically, research on the direct impact of FD on EQ has received significant attention from scholars and has yielded mixed evidence across different economies. The adverse effects of FD on EQ are highlighted in scholarly works by Shahbaz et al. (2016); Charfeddine and Ben Khediri (2016); Aluko and Obalade (2020); Hunjra et al. (2020); and Musah et al. (2022). Conversely, the impact of FD on enhancing EQ is supported by empirical studies conducted by Yue et al. (2018); Majeed and Mazhar (2019); Saud et al. (2019); Atsu et al. (2021); Qamri et al. (2022); Usman et al. (2022); and Xuezhou et al. (2022).

However, empirical investigations into the finance-growth-environmental nexus have not been extensively tested, and only a limited number of evidence is available. Among these studies, Shujah-ur-Rahman et al. (2019) dedicated their research to examining the moderating role of FD on the nexus between EG and environmental degradation in one of the developing contexts, Pakistan. Their findings confirmed that FD significantly moderates the EG-environmental degradation nexus. Additionally, it was evident that FD affects the Environmental Kuznets Curve in Pakistan. A notable study by Jakada et al. (2020), conducted in the African context, supported the notion that FD contributes to environmental degradation by accelerating EG.

Moreover, Acheampong et al. (2020) investigated the moderating role of FD on carbon emissions across different economic settings. Their study confirmed the moderating impact of FD on carbon emissions through EG varies across different economies and at different levels of FD. Specifically, it was found that EG induced by FD in developed and emerging economies leads to environmental degradation by increasing carbon emissions. However, frontier economies and standalone economies showed an insignificant role in this regard. Additionally, the sub-dimensions of FD exhibit diverse impacts on EQ through the EG channel. Interestingly, Acheampong et al.'s (2020) study utilized financial market development and its sub-dimensions to capture FD but neglected a major aspect, financial institutional development, in their empirical investigation.

Furthermore, the moderating role of FD on the nexus between EG and carbon emissions in Turkey was examined by Rjoub et al. (2021). Their study found a significant moderating effect of FD on the relationship between EG and carbon emissions. Specifically, in line with the discoveries of Jakada et al. (2020), Rjoub et al.'s (2021) empirical evidence also revealed that FD impairs EQ by driving progress in the Turkish economy. Moreover, Wang et al. (2022) demonstrated that FD in the Next-11 economies significantly promotes EG by restructuring industries and changing production and consumption patterns, resulting in increased carbon emissions. Additionally, contradicting the views of Rjoub et al. (2021) and Jakada et al. (2020), Udeagha and Breitenbach (2023a, 2023b) confirmed that FD in the South African economy improves EQ by minimizing the adverse impact of economic progress on the environment. However, Udeagha & Breitenbach (2023a, 2023b) partially measured FD by using proxies for the financial institutions development, while excluding dimensions of financial market development from the study.

In summary, existing studies have not adequately addressed the indirect impacts of FD on EQ through the channel of EG, and only a limited number of studies have aimed to explore it. Specifically, there is a lack of country-specific evidence for the Australian context. Only Acheampong et al. (2020) considered Australia as a sample of developed countries and revealed that EG induced by FD degrades EQ by increasing carbon emissions. Moreover, existing studies have utilized various dimensions to capture FD. However, a notable gap exists as these works have not successfully captured FD accurately through both financial markets and financial institutional development. Therefore, this study bridges the gap by investigating the moderating role of FD on EQ through the EG channel in the Australian context.

3. Model construction, econometric strategy, and data

This study focuses on the moderating effect of FD on the linkage between EG and EQ in the Australian economy. To conduct this analysis, we follow the methodology of Shujah-ur-Rahman et al. (2019); Rjoub et al. (2021); and Wang et al. (2022) to develop two distinct models: the main model and the moderating model. The main model is designed to quantify the direct impact of FD on EQ, along with other exploratory variables considered in the study, including EG, energy consumption, trade openness, urbanization, and foreign direct investments. The main model is represented by Equation (1). Equation (2) presents the constructed moderating model, which measures the moderating role of FD on the relationship between EG and the environment. We introduce an interactive variable (FD*EG) to gauge the indirect effect of FD on EQ through economic progress (See Fig. 1).

$$EQ = f(EG, FD, ENG, TO, URB, FDI) \quad (1)$$

$$EQ = f(EG, FD, ENG, TO, URB, FDI, (FD^{*}EG)) \quad (2)$$

Where, EQ represents the environmental quality. FD, ENG, TO, URB, FDI depict financial development, energy consumption, trade openness, urbanization, and foreign direct investment, respectively. $(FD^{*}EG)$ represents the interaction term between financial development and economic growth.

The inclusion of explanatory variables in the model is supported by both theoretical and empirical evidence. Specifically, the inclusion of EG in the estimation model is justified by the Environmental Kuznets Curve (EKC), which elucidates the relationship between EQ and different levels of EG. Primarily, economic activities necessitate energy sources and other natural resources to produce goods and services to meet the demands of the economy (Almeida et al., 2017). As the economy progresses, structural change in the economy from the agricultural sector to the industrial sector demands more energy resources and natural resources, thereby degrading EQ through increased emissions. However, as the economy transitions towards high technology and service-driven sectors, environmental pollution tends to decrease (Orubu and Omotor, 2011). Empirical evidence regarding the environmental impact of EG in the Australian context has yielded a negative effect by Marques et al. (2018) and Rahman and Vu (2020). Consequently, this study also anticipates observing an adverse impact of EG on EQ.

In our econometric estimations, we have tested FD as another explanatory variable for measuring its direct impact on EQ in Australia. FD, in practical terms, refers to the advancement of the financial sector, which facilitates the provision of financial resources to households and the corporate sector at lower financing costs, thus encouraging production and consumption patterns that can have adverse impacts on the environment (Acheampong, 2019). However, it is noteworthy that FD can also have positive effects on EQ by supporting the corporate sector and households in adopting environmentally sustainable production and consumption patterns (Dada et al., 2022). Consequently, empirical studies in this area have yielded mixed results, indicating that the environmental impact of FD varies across different contexts. Given this background, our analysis anticipates either a positive or negative impact of Australia's FD on EQ.

To achieve EG, greater energy resources are required, much of which is sourced from non-renewable sources, ultimately resulting in increased global emissions (Kraft and Kraft, 1978). Additionally, from a theoretical standpoint, the conservation hypothesis emphasizes the relationship between EG and energy, asserting that EG necessitates a greater demand for energy sources (Mirza and Kanwal, 2017). Consequently, the energy consumption induced by EG poses environmental risks by contributing to heightened air pollution. However, from a positive perspective, the

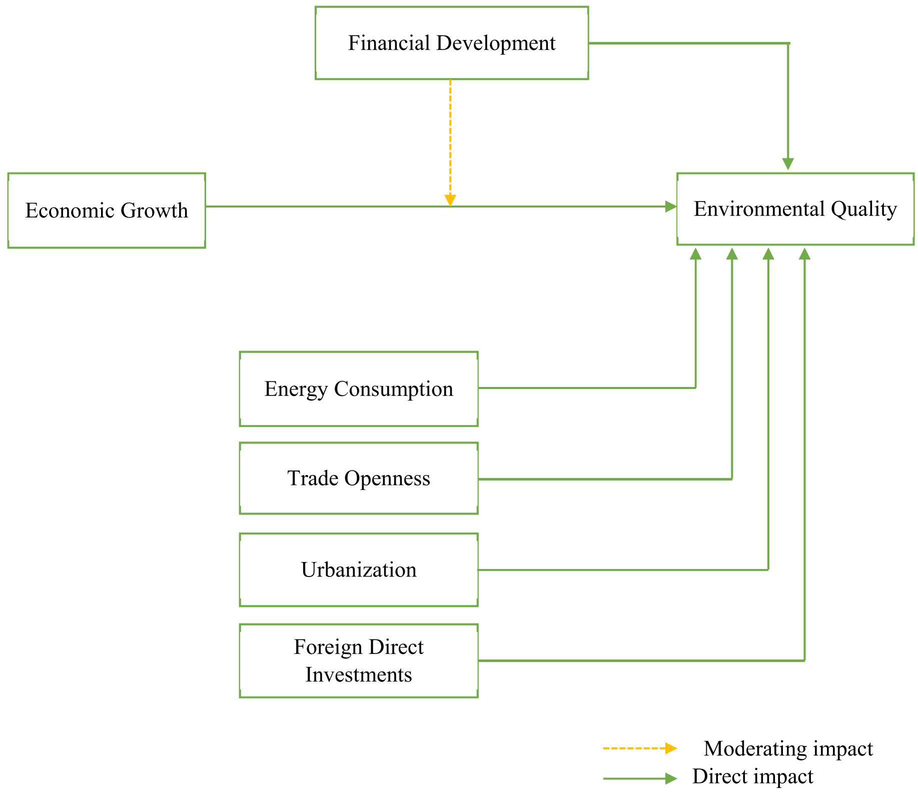

Fig. 1. The moderating effect of FD on EQ: through EG.

heightened demand for energy in advanced economies drives the development of efficient energy utilization strategies, thereby mitigating emissions through technological advancements (Stern, 2006). In light of this rationale, this study aims to assess the impact of energy consumption on EQ in Australia, expecting either a positive or negative impact.

Trade generally enables economies to open up and facilitates the movement of goods and services across borders for consumption or production purposes (Halicioglu and Ketenci, 2016). Accordingly, it has been pointed out that as economies become more open to international trade, the level of environmental damage tends to decrease. This is because more open economies, characterized by higher levels of competition, tend to invest in novel and efficient technologies capable of reducing pollution (Radetzki, 1992; Shafik and Bandyopadhyay, 1992). However, opposing views suggest a mixed effect of trade. Antweiler et al. (2001) argue that trade-induced scale effects may increase pollution, while trade-induced technology effects can mitigate environmental damage. The trade-environmental relationship remains inconclusive, and this study expects either a positive or negative impact of trade on EQ in Australia.

Urbanization is another explanatory variable modelled in the estimated model in this study. Urbanization is a comprehensive process that changes the economic and social structure, along with the population dynamics (Liang et al., 2019). Consequently, the environmental impact of urbanization varies across different economies, depending on the degree of development (Grimm et al., 2008). However, the environmental impact of urbanization remains inconclusive, with diverse perspectives existing. Urbanization exacerbates environmental issues because, unlike low-income cities, wealthy cities demand more resources, adversely affecting the environment (Poumanyvong and Kaneko, 2010). Conversely, urbanization can bring positive outcomes for the environment by strengthening environmental regulations and providing advanced infrastructure and service facilities in urban areas (Poumanyvong and Kaneko, 2010). Therefore, this study anticipates that the environmental impact of urbanization can be either positive or negative.

Foreign Direct Investment (hereafter FDI) fundamentally facilitates EG by providing access to technology, skills, and management expertise, and creating employment opportunities within the host economy (Duodu et al., 2021). However, FDIs also bring about environmental challenges due to increased resource demands in the host nation (Al-mulali & Tang, 2013; Eweade et al., 2024). According to the pollution halo hypothesis, FDI introduces innovative technologies and practices that may degrade EQ in host nations (Al-mulali & Tang, 2013; Duodu et al., 2021). Notably, strengthening environmental regulations in developed countries can lead to the relocation of harmful industries to less regulated destinations while attracting ecologically approachable foreign investments, with the dual aim of enhancing EQ and productivity (Li et al., 2019). Given that Australia is a developed economy, it is reasonable to anticipate a positive impact of FDIs on ensuring EQ within Australia.

Incorporating all variables, the log-transformed models are presented in Equation (3) and Equation (4) below. The log transformation is utilized to overcome the issue of exponential variance within the dataset. The log-transformed main model and the moderating model are presented in Equations (3) and (4), respectively.

$$ln\ EQ_t = \alpha + \beta_1 lnEG_t + \beta_2 lnFD_t + \beta_3 lnENG_t + \beta_4 lnTO_t + \beta_5\ ln\ URB_t + \beta_6 lnFDI_t + \varepsilon_t \tag{3}$$

$$ln\ EQ_t = \alpha + \beta_1 lnEG_t + \beta_2 lnFD_t + \beta_3 lnENG_t + \beta_4 lnTO_t + \beta_5\ ln\ URB_t + \beta_6\ ln\ FDI_t + \beta_7 (lnFD^{*}lnEG)_t + \varepsilon_t \tag{4}$$

3.1. Data

Due to data availability, this study covers the period from 1980 to

2021. While data for all other proxies is available beyond 2021, FD data is only available up to 2021. As a result, the sample period is restricted to 1980–2021. The EQ is the dependent variable, proxied by total greenhouse gas emissions sourced from the World Bank database and national greenhouse gas emission inventories in Australia. Existing empirical literature on FD and the environment has yet to comprehensively address FD, including aspects such as access, depth, efficiency, and stability (Wijethunga et al., 2023). This study addresses the identified gap by measuring FD across all necessary dimensions. Accordingly, the overall FD index from the International Monetary Fund (IMF) is utilized to measure the three dimensions of FD (financial depth, access, and efficiency), while financial stability is not directly covered by the IMF's index. To address this, bank credit-to-bank deposit ratio and stock price volatility are included as proxies for financial stability, sourced from the Global Financial Development Database and Bloomberg database, respectively. To develop a single variable to measure FD, this study employed Principal Component Analysis (PCA) to derive a FD index using all the proxy variables. In addition, EG, energy consumption, trade openness, urbanization, and FDI are utilized as control variables in the study. EG is proxied by per capita gross domestic product. Primary energy consumption per capita, FDI net inflows, total exports and imports of goods and services (as a percentage of GDP), and urban population (as a percentage of total population) serve as proxies for energy consumption, FDIs, trade openness, and urbanization, respectively. All data are sourced from the World Bank database except for urbanization, which is obtained from the Australian Bureau of Statistics. The summary of the descriptive statistics pertaining to the selected proxies in the study is presented in Table 1.

3.2. Econometric strategy

The utilization of non-stationary variables often results in spurious regression and can yield misleading econometric estimations (Greene, 2000). Therefore, prior to commencing the analysis, it is essential to ascertain the stationarity of the dataset. This study achieved it through the application of the Augmented Dickey-Fuller (ADF) test. The null hypothesis of the ADF test posits the existence of a unit root ($\rho = 0$), while the alternative hypothesis suggests the absence of a unit root ($\rho < 0$). Equation (5) presents the ADF test model with a constant term and no trend.

$$\Delta y_t = \alpha + \beta y_{t-1} + \gamma_1 \Delta y_{t-1} + \gamma_2 \Delta y_{t-2} + \ldots + \gamma_p \Delta y_{t-p} + \varepsilon_t \tag{5}$$

Where y_t represents the value of the time series at time t, α is the constant term, β denotes the coefficient of the lagged value of the series, γ_1 , γ_2, γ_p denote coefficients of the lagged differenced values of the series. ε_t represents the error series at time t.

The results of the Augmented Dickey-Fuller (ADF) test are presented in Table 2. Accordingly, LnFD exhibits stationarity in the level series, confirming an order of integration at level series I(0). However, the remaining variables show non-stationarity at the level series. Moreover, all data series confirm stationarity at the first difference and an order of integration of I (1). The mixed order of integration in the dataset suggests that the Autoregressive Distributed Lag (ARDL) model is the most appropriate estimation strategy, as it allows for the inclusion of both I(0) and I(1) variables (Pesaran et al., 2001). The ARDL approach estimates both long-run and short-run dynamics, making it suitable for quantifying the moderating impact of FD on the EG–environmental quality nexus. Furthermore, this study adopts the ARDL approach based on the foundations laid by previous works, including Shujah-ur-Rahman et al. (2019); Rjoub et al. (2021); and Wijethunga et al. (2025) that specify the ARDL models corresponding to the log-transformed versions of the models described in Equations (3) and (4).

$$\begin{aligned}\Delta lnEQ_t = {} & \beta_0 + \sum_{i=1}^{p} \delta_1 \Delta lnEQ_{t-i} + \sum_{i=0}^{p} \delta_2 \Delta lnEG_{t-i} + \sum_{i=o}^{p} \delta_3 \Delta lnFD_{t-i} \\ & + \sum_{i=0}^{p} \delta_4 \Delta lnENG_{t-i} + \sum_{i=0}^{p} \delta_5 \Delta lnTO_{t-i} + \sum_{i=0}^{p} \delta_6 \Delta lnURB_{t-i} \\ & + \sum_{i=0}^{p} \delta_7 \Delta lnFDI_{t-i} + \beta_1 lnEQ_{t-} + \beta_2 lnEG_{t-1} + \beta_3 lnFD_{t-1} + \beta_4 lnENG_{t-1} \\ & + \beta_5 lnTO_{t-1} + \beta_6 lnURB_{t-1} + \beta_7 lnFDI_{t-1} + \varepsilon_t\end{aligned} \tag{6}$$

$$\begin{aligned}\Delta lnEQ_t = {} & \beta_0 + \sum_{i=1}^{p} \delta_1 \Delta lnEQ_{t-i} + \sum_{i=0}^{p} \delta_2 \Delta lnEG_{t-i} + \sum_{i=o}^{p} \delta_3 \Delta lnFD_{t-i} \\ & \sum_{i=0}^{p} \delta_4 \Delta lnENG_{t-i} + \sum_{i=0}^{p} \delta_5 \Delta lnTO_{t-i} + \sum_{i=0}^{p} \delta_6 \Delta lnURB_{t-i} \\ & + \sum_{i=0}^{p} \delta_7 \Delta lnFDI_{t-i} + \sum_{i=0}^{p} \delta_8 (\Delta lnFD_{t-i} {*} \Delta ln\, EG_{t-i}) + \beta_1 lnEQ_{t-1} \\ & + \beta_2 lnEG_{t-1} + \beta_3 lnFD_{t-1} + \beta_4 lnENG_{t-1} + \beta_5 lnTO_{t-1} \\ & + \beta_6 lnURB_{t-1} + \beta_7 lnFDI_{t-1} + \beta_8 (ln\, FD_{t-1} {*} lnEG_{t-1}) + \varepsilon_t\end{aligned} \tag{7}$$

The Akaike Information Criterion (AIC) was used to select the optimal lag length in the ARDL estimation. The bounds test was employed as the primary method to examine the existence of a long-run relationship, which is a prerequisite for estimating the long-run coefficients. Following this, the short-run dynamics were assessed using the Error Correction Model (ECM). The error correction equations for the two models are presented in Equations (8) and (9).

$$\begin{aligned}\Delta ln\, EQ_t = {} & \delta_0 + \sum_{i=1}^{p} \delta_1 lnEQ_{t-1} + \sum_{i=0}^{p} \delta_2 \Delta lnEG_{t-i} + \sum_{i=0}^{p} \delta_3 \Delta lnFD_{t-i} \\ & + \sum_{i=0}^{p} \delta_4 \Delta lnENG_{t-i} + \sum_{i=0}^{p} \delta_5 \Delta lnTO_{t-i} + \sum_{i=0}^{p} \delta_6 \Delta lnURB_{t-i} \\ & + \sum_{i=0}^{p} \delta_7 \Delta lnFDI_{t-i} + \psi ECT_{t-1} + \varepsilon_t\end{aligned} \tag{8}$$

$$\begin{aligned}\Delta ln\, EQ_t = {} & \delta_0 + \sum_{i=1}^{p} \delta_1 lnEQ_{t-1} + \sum_{i=0}^{p} \delta_2 \Delta lnEG_{t-i} + \sum_{i=0}^{p} \delta_3 \Delta lnFD_{t-i} \\ & + \sum_{i=0}^{p} \delta_4 \Delta lnENG_{t-i} + \sum_{i=0}^{p} \delta_5 \Delta lnTO_{t-i} + \sum_{i=0}^{p} \delta_6 \Delta lnURB_{t-i} \\ & + \sum_{i=0}^{p} \delta_7 \Delta lnFDI_{t-i} + \sum_{i=0}^{p} \delta_8 (\Delta lnFD_{t-i} {*} \Delta lnEG_{t-i}) + \psi ECT_{t-1} + \varepsilon_t\end{aligned} \tag{9}$$

4. Empirical results and discussion

As outlined in the estimation strategy, confirming the order of integration is the initial step in the analysis. The unit root results presented in Table 2 validate that the necessary prerequisites for further analysis are met. Accordingly, this study proceeds to estimate the ARDL models specified in Equations (6) and (7). According to the optimal lag selection criteria, the ARDL models were estimated using the lag structure (2, 2, 1,2, 2, 2, 2) for the main model and (2, 2,1, 2, 2, 2, 2,1) for the moderating model. The bounds test results, which are used to determine the existence of a long-run association among the studied variables, are summarized in Table 3. Both models indicate the presence of a statistically significant long-run association among the variables under investigation, thereby justifying the estimation of long-run coefficients.

The long-run and short-run estimates for the main model (direct effect), designed to capture the direct environmental impact of FD, are presented in Table 4. According to the ARDL estimations, all variables are statistically significant and exert an impact on EQ, except for FDIs.

Table 1
Descriptive statistics.

Description	LnEQ	LnEG	LnFD	LnENG	LnTO	LnURB	LnFDI
Mean	20.256	10.192	−0.652	11.065	3.631	4.445	23.203
Maximum	20.532	11.129	0.358	11.188	3.824	4.458	24.906
Minimum	20.012	9.230	−3.245	10.884	3.351	4.432	19.875
Std. Dev.	0.135	0.616	1.031	0.086	0.133	0.006	1.255
Skewness	0.001	0.100	−0.613	−0.458	−0.487	−0.243	−0.401
Kurtosis	2.108	1.604	3.884	1.962	1.959	2.210	2.388
Jarque-Bera	1.390	3.479	2.353	3.351	3.557	1.505	1.781
Probability	0.498	0.175	0.436	0.187	0.168	0.470	0.410

Source: Authors' calculations

Table 2
Results of the unit root test.

Variable	Level series	1st difference	Decision
LnEQ	−1.487	−6.586***	I(1)
LnEG	−0.870	−4.990***	I(1)
LnFD	−2.731*	−7.420***	I(0) & I(1)
LnENG	−1.229	−5.197***	I(1)
LnTO	−1.455	−5.982***	I(1)
LnURB	−1.667	−7.215***	I(1)
LnFDI	−1.611	−9.987***	I(1)

Note: *** & * indicate significance at 1 % and 10 % level, respectively.
Source: Authors' calculations.

Table 3
Results of the bound test.

	Main Model (2,2,1,2,2,2,2) (EQ, EG,FD,ENG,TO,URB,FDI)			Moderating Model (2,2,1,2,2,2,2,1) (EQ,EG,FD,ENG, TO,URB,FDI,FD*EG)		
F statistic	6.285***			5.408		
	Critical Values	I (0)	I (1)	Critical Values	I (0)	I (1)
	10 %	2.21	3.31	10 %	2.15	3.29
	5 %	2.68	3.86	5 %	2.52	3.82
	1 %	3.50	5.12	1 %	3.40	5.03

Note: *** denotes significance at 1 % level.
Source: Authors' calculations.

Table 4
Long-run and Short-run coefficients of the main model.

Long run estimates		Short run estimates	
Variable	Coefficient	Variable	Coefficient
LnEG	1.600*** (3.806)	Δ (LnEG)	1.744*** (3.431)
LnFD	0.084** (2.199)	Δ (LnEG (−1))	1.761***(3.331)
LnENG	1.852*** (3.917)	Δ (LnFD)	0.245***(4.191)
LnTO	−0.164** (−2.294)	Δ (LnFD (−1))	0.249***(4.395)
LnURB	1.280*** (2.967)	Δ (LnENG)	2.794***(3.858)
LnFDI	0.155 (1.062)	Δ (LnTO)	−0.303 (−0.685)
		Δ (LnTO (−1))	0.786 (1.587)
		Δ (LnURB)	1.408*** (4.784)
		Δ (LnURB (−1))	1.896*** (5.995)
		Δ (LnFDI)	0.069**(2.319)
		Δ (LnFDI (−1))	0.099***(3.837)
		COINTEQ	−1.394*** (-8.239)
R-squared	*0.894*	*R-squared*	*0.833*
Adjusted R-squared	*0.794*	*Adjusted R-squared*	*0.758*
Durbin-Watson stat	*2.102*	*Durbin-Watson stat*	*2.102*
Prob*(F-statistic)*	*0.0000*	Prob*(F-statistic)*	*0.0000*

Note: The t-values are given in parentheses. *** & ** indicate significance at 1 % and 5 % level, respectively.
Source: Authors' calculations.

Specifically, a one percent change in FD increases greenhouse gas emissions by 0.084%. This strongly supports the conclusion that FD degrades the EQ of the Australian economy. This finding aligns with existing empirical evidence from Charfeddine and Ben Khediri (2016); Shahbaz et al. (2016); Adams and Klobodu (2018); Esmaeilpour Moghadam and Dehbashi (2018); Aluko and Obalade (2020); and Vo et al. (2021). As the third-largest contributor to the Australian economy, the financial sector is reported to have an adverse impact on EQ, necessitating significant attention to policy initiatives aimed at addressing this issue.

A noteworthy finding is that Australian EG contributes 1.6 % to greenhouse gas emissions for every one percent advancement in the economy. This indicates that EG in Australia has an adverse impact on EQ. As suggested by Almeida et al. (2017), this demonstrates the presence of a scale effect, wherein shifts in the economic structure towards industries with higher energy demands, such as fossil energy sources, and higher demand for natural resources, exacerbate environmental damage in Australia. As depicted in Table 4, the Australian economy has encountered a detrimental effect of energy consumption on the environment. Statistically, a one percent change in energy consumption leads to a 1.852 % increase in greenhouse gas emissions. The underlying reality is that Australia's energy consumption is predominantly reliant on non-renewable energy sources, which contribute to higher levels of harmful emissions to the environment.[1] Further, the coefficient of urbanization also indicates a positive impact on greenhouse gas emissions, underscoring urbanization's role in degrading EQ in Australia. This empirical evidence aligns with the adverse environmental impact of urbanization emphasized by Poumanyvong and Kaneko (2010). The fundamental fact behind this is that 96 % of Australia's population resides in urban areas, thereby placing strain on resource utilization, including energy, water, and other essential resources.[2]

According to the ARDL estimation results, trade openness signals a positive trend towards ensuring EQ in Australia. Statistically, a one percent change in trade openness decreases greenhouse gas emissions by 0.164 %. These findings confirm that as an open economy, Australia's trade openness enhances EQ by reducing greenhouse gas emissions. This empirical validation aligns with the conclusions of Radetzki (1992); Shafik and Bandyopadhyay (1992), who emphasized the positive impact of trade-induced technological effects in defending EQ. Moreover, FDI has an insignificant impact on greenhouse gas emissions, suggesting that it does not play a meaningful role in influencing EQ in Australia. This outcome may be attributed to the offsetting effects of environmentally friendly and polluting components within FDI inflows, resulting in a negligible net long-run impact. This evidence opposes the argument made by Al-mulali and Foon Tang (2013); Li et al. (2019); Duodu et al. (2021); and Wijethunga et al. (2025).

As shown in Table 4, all estimated independent variables—except trade openness—have a statistically significant short-run impact on environmental quality. Consistent with the long-run findings, the

[1] Source: Department of climate change, energy, the environment, and water.
[2] Source: Department of climate change, energy, the environment, and water.

immediate effect of FD also deteriorates environmental quality in Australia by contributing to increased greenhouse gas emissions. The short-run coefficient of 0.245, which is notably higher than the long-run coefficient, indicates a relatively stronger adverse effect in the short term. Similar to financial development, economic growth, energy consumption, and urbanization also worsen environmental conditions in the short run, each exhibiting a more pronounced impact compared to their long-run effects. Notably, unlike its long-run insignificance, foreign direct investment (FDI) shows a significant and negative impact on environmental quality in the short run. This suggests that FDI inflows contribute to increased emissions, aligning with short-run evidence reported by Wijethunga et al. (2025) in the Australian context. The significant and negative error correction term (−1.394) suggests a strong tendency of the system to revert to its long-run equilibrium following a short-run disturbance.

The empirical results of the moderating model are presented in Table 5. Similar to the estimations in the main model, we employed the ARDL model specified in Equation (7) along with the error correction model to estimate the moderating impact. According to the estimated long-run coefficients, all modelled variables are statistically significant except for FDI. EG, FD, energy consumption, and urbanization contribute to increased greenhouse gas emissions and degradation of EQ. However, trade openness has a positive effect on enhancing EQ and reducing pollution.

Prominently, the moderating role of FD in the relationship between EG and the environment is confirmed in the estimated results. Statistically, it is evident that a one percent change in FD × EG leads to a 0.025% increase in greenhouse gas emissions. This validates that FD adversely impacts the quality of Australia's environment by promoting EG, which ultimately increases emissions. This empirical finding demonstrates that FD strongly promotes Australia's economic progress, leading to changes in industry structure and production patterns. These changes significantly alter the scale of the economy, thereby increasing the demand for energy sources and resources, ultimately resulting in environmental degradation. This finding is particularly aligned with the empirical evidence presented by Shujah-ur-Rahman et al. (2019), Jakada et al. (2020), Wang et al. (2022), and Rjoub et al. (2021). Additionally, the short-run coefficient confirms that FD contributes to the adverse environmental impact of economic growth. Specifically, it promotes EG that negatively affects EQ. The results statistically indicate that a 1% joint increase in FD and EG leads to a 0.018% rise in greenhouse gas emissions, thereby degrading EQ in Australia. This suggests that EG, when accompanied by FD, places additional pressure on the environment through increased toxic emissions. Moreover, the short-run moderating impact is relatively smaller than the long-run effect, as the economy requires time to fully respond to changes in FD and related economic activities. The long-run effect captures the total impact after all necessary adjustments have taken place. The remaining variables in the model exhibit consistent effects with those identified in the main model, both in the long run and the short run. The result indicates that if there is a shock or short-run deviation from the long-run relationship between the variables, about 138.7% of that imbalance is corrected in the following period. This strong correction speed suggests a fast and stable return to the long-run relationship between FD, EG, and EQ in Australia.

Table 5
Long-run and Short-run coefficients of the moderating model.

Long run estimates		Short run estimates	
Variable	Coefficient	Variable	Coefficient
LnEG	1.624*** (3.739)	Δ (LnEG)	1.747*** (3.469)
LnFD	0.102* (1.918)	Δ (LnEG (−1))	1.720***(3.209)
LnENG	1.885*** (3.927)	Δ (LnFD)	0.281***(4.723)
LnTO	−0.157** (−2.037)	Δ (LnFD (−1))	0.258***(4.563)
LnURB	1.518*** (3.211)	Δ (LnENG)	2.829***(3.901)
LnFDI	0.183(1.361)	Δ (LnTO)	−0.255 (−0.581)
Ln (FD*GDP)	0.025 **(1.501)	Δ (LnTO (−1))	0.776 (1.582)
		Δ (LnURB)	1.631*** (5.132)
		Δ (LnURB (−1))	1.660*** (5.963)
		Δ (LnFDI)	0.064**(2.193)
		Δ (LnFDI (−1))	0.104***(4.025)
		Δ(Ln(FD*GDP))	0.018** (2.164)
		COINTEQ	−1.387*** (-8.316)
R-squared	*0.896*	*R-squared*	*0.835*
Adjusted R-squared	*0.786*	*Adjusted R-squared*	*0.762*
Durbin-Watson stat	*2.141*	*Durbin-Watson stat*	*2.141*
Prob*(F-statistic)*	*0.0000*	Prob*(F-statistic)*	*0.0000*

Note: The t-values are given in parentheses. *** & ** indicate significance at 1 % and 5 % level, respectively.
Source: Authors' calculations.

The robustness of the estimated ARDL models is confirmed through a range of diagnostic tests. As presented in Table 6, both models show no evidence of serial correlation, absence of heteroskedasticity, and normally distributed residuals, as validated by the serial correlation test, heteroskedasticity test, and Jarque-Bera test, respectively. Additionally, to assess the stability of the model parameters over time, the CUSUM and CUSUM of Squares tests were employed (refer to Figs. 2 and 3). These tests confirm the parameter stability in both models. Overall, the confirmation of model robustness supports the reliability and generalizability of the findings.

5. Conclusion and policy implications

Climate change stands as one of the most debated topics in the modern world, pivotal to achieving sustainability. Consequently, researchers, governments, and policymakers are increasingly focusing on addressing climate change by reducing emission levels globally. Hence, understanding the role of the financial sector in contributing to EQ is crucial. Therefore, this study aims to assess the impact of FD, including both its direct effect and its moderating role through EG, in one of the leading economies, Australia. This study utilizes comprehensive proxies to measure FD and EQ, alongside other explanatory variables such as EG, energy consumption, trade openness, FDI, and urbanization. To achieve its objectives, this study employed the Autoregressive Distributed Lag (ARDL) model, The long-run empirical results primarily indicate that: (1) there is a direct effect of FD on EQ, leading to environmental degradation in Australia; (2) the moderating effect of FD on the EG-environmental relationship also exists, significantly exacerbating environmental degradation; (3) energy consumption and urbanization have adverse impacts on EQ; (4) trade openness improves EQ in Australia. Moreover, the short-run results confirm the impacts identified in the long-run estimates, except for the role of trade openness, which is found to be statistically insignificant, while foreign direct investment (FDI) exerts an adverse effect on EQ in Australia.The finding of the adverse impact of FD on EQ is crucial in Australia and has significant policy implications. Primarily, as the third-largest contributor to the economy, promoting the financial sector needs to be accompanied by policies aimed at enhancing the sustainability of financial transactions within

Table 6
The results of diagnostic tests.

Diagnostic test	Main Model	Moderating Model
Breusch-Godfrey Serial Correlation LM Test	0.686[0.953]	0.925 [0.809]
Heteroskedasticity Test: Breusch-Pagan-Godfrey	1.341 [0.260]	1.354 [0.256]
Jarque-Bera	0.108 [0.947]	0.063 [0.968]

Parenthesis "[.]" indicates the probability values.

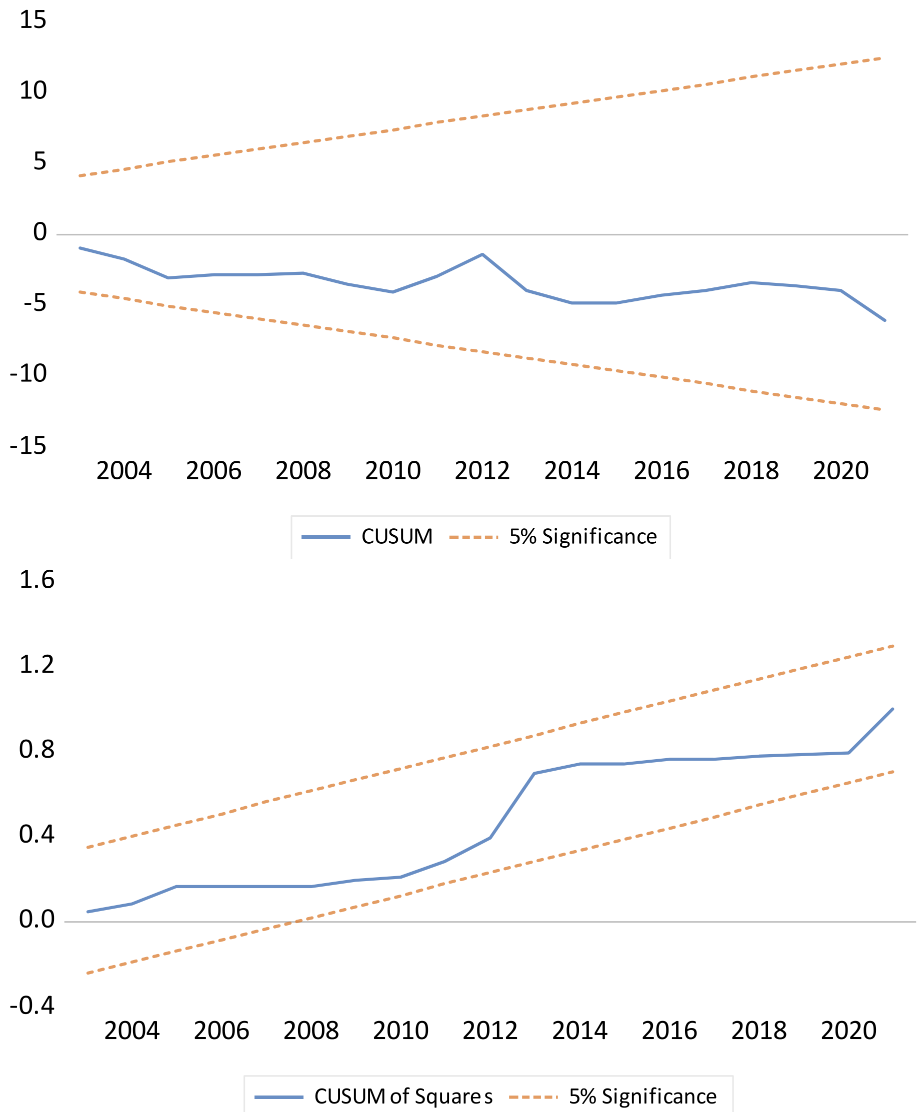

Fig. 2. Cusum and CUSUM of Squares of main model.

financial institutions and markets. Consequently, the financial sector should reconsider its existing investment portfolios and relaunch them to prioritize green investments, thereby optimizing positive impacts on the environment. From a governmental perspective, it is essential to redirect financial institutions and markets toward promoting financial activities that do not compromise the EQ. Similarly, there is a need to raise awareness among investors about environmentally friendly investment portfolios to enhance sustainability.

Furthermore, the moderating role of FD is driven by EG. Specifically, FD × EG increases greenhouse gas emissions and degrades EQ, emphasizing policy implications for achieving environmental targets by 2050. Primarily, the financial sector drives Australia's EG, suggesting significant alterations in the industrial sector are necessary. Essentially, industries should be encouraged to shift from traditional practices to green practices. However, to facilitate this transition, financial assistance from the financial sector is required at lower costs of capital that are bearable for industries. Otherwise, directing funds to industries with traditional practices will lead to further damage to the environment. Additionally, the adverse impact of energy consumption and urbanization on EQ in Australia also underscores several policy implications for mitigating these impacts. Australia relies predominantly on non-renewable energy sources as its primary energy source. However, to address environmental challenges, there is a pressing need to promote the utilization of renewable energy sources with financial assistance available at lower costs. Similarly, policymakers must establish policies aimed at managing the flow of population into metropolitan and urban areas. On the other hand, trade openness promotes environmental sustainability, emphasizing the necessity for governments to further facilitate trade. Additionally, the results indicate that FDI inflows may initially lack adequate environmental safeguards upon entry. Therefore, policymakers in Australia should implement stricter environmental regulations and screening mechanisms for incoming FDI, particularly in emission-sensitive sectors.

The present study explores the moderating effect of FD on EQ through EG. However, a critical limitation of this analysis is the restricted sample period, confined to 2021 due to data unavailability for capturing FD dimensions up to the latest period. Additionally, constrained by data availability, we measured financial stability, using two proxies representing the stock market and banking institutions. Therefore, future researchers have the opportunity to extend this inquiry by incorporating the latest data and a broader range of proxy variables to comprehensively investigate the moderating role of FD in the EG-environmental relationship. Finally, the generalizability of the study's findings to other developed economies is limited due to unique

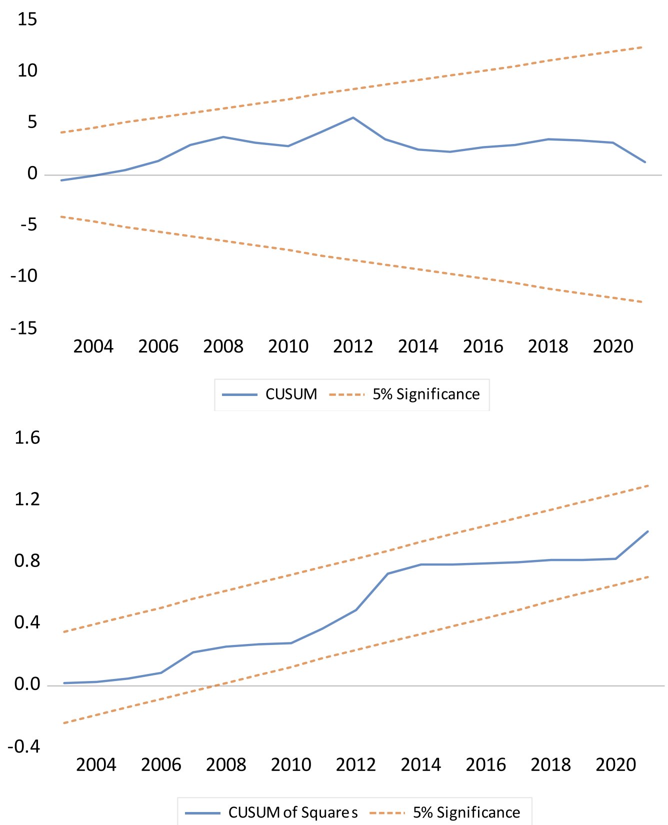

Fig. 3. Cusum and CUSUM of Squares of moderating model.

differences among these countries, particularly in financial and economic structures. This opens an avenue for future researchers to conduct cross-country analyses to better generalize the moderating impact of financial development on the economic growth–environmental quality nexus.

CRediT authorship contribution statement

Ambepitiya Wijethunga Gamage Champa Nilanthi Wijethunga: Writing – original draft, Software, Methodology, Formal analysis, Conceptualization. **Mohammad Mafizur Rahman:** Writing – review & editing, Supervision. **Tapan Sarker:** Writing – review & editing, Supervision.

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.

Data availability

Data will be made available on request.

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