The Carbon Conundrum: Exploring CO_2 Emissions, Public Debt, and Environmental Policy

Mohd Shahidan Shaari [1] , Amri Sulong [2], Abdul Rahim Ridzuan [3, 4, 5, 6, 7] ,
Miguel Angel Esquivias [8*] , Evan Lau [1]

[1] Faculty of Economics and Business, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia.

[2] Department of Commerce, Politeknik Seberang Perai, Malaysia.

[3] University of Religions and Denominations, Qom 37491-13357, Iran.

[4] Institute for Big Data Analytics and Artificial Intelligence (IBDAAI), Universiti Teknologi MARA, Shah Alam, 40450, Malaysia.

[5] Faculty of Business and Management, Universiti Teknologi MARA, Melaka Campus, Alor Gajah, 78000, Malaysia.

[6] Accounting Research Institute (ARI), Universiti Teknologi MARA, Shah Alam, 40450, Malaysia.

[7] Centre for Economic Development and Policy (CEDP), Universiti Malaysia Sabah, Kota Kinabalu, 88400, Malaysia.

[8] Department of Economics, Faculty of Economics and Business, Airlangga University, Surabaya, 60268, Indonesia.

Abstract

This study addresses a critical gap in the literature by examining the impact of CO_2 emissions on public debt in Malaysia, employing a non-linear autoregressive distributed lag (ARDL) approach spanning from 1980 to 2020. This methodology captures the non-linear relationship between CO_2 emissions and public debt, providing nuanced insights into how environmental factors shape fiscal dynamics. Despite encountering challenges arising from the limited body of literature on this specific relationship, the study highlights key findings with profound implications for policymakers. The inverse correlation between trade openness and public debt underscores the influence of international trade on Malaysia's fiscal landscape, while a positive association between investment and public debt emphasizes the importance of prudent debt management for economic growth. Furthermore, the negative relationship between higher foreign direct investment and long-term public debt highlights the need to foster an investor-friendly environment. A pivotal contribution is the confirmation of a positive link between CO_2 emissions and public debt, urging policymakers to prioritize emission reduction strategies, implement carbon pricing, and promote green technologies. This research offers a comprehensive understanding of the intricate interplay between CO_2 emissions and public debt, providing valuable insights for informed policy decisions in the Malaysian context.

1- Introduction

In recent years, the global concern surrounding mounting public debt has intensified, with Japan standing out as holding the highest public debt-to-GDP ratio at 221.32% [1]. This is primarily attributed to demographic factors, including an aging population and declining birth rates, which have led to reduced tax revenues and increased social security expenditure. Although existing literature has identified various determinants of public debt, the studies

conducted by Halebić & Moćević [2], Were & Madete [3], and Jarju [4] collectively offer valuable insights into the intricate dynamics shaping public debt. Halebić & Moćević's [2] examination of determinants such as budget deficit, trade balance, unemployment rate, population size, and institutional changes provides a comprehensive understanding of the factors influencing public debt. The positive correlation between public debt and budget deficits aligns with established economic principles, emphasizing the effect of fiscal policies on debt levels. However, negative associations with the trade balance, population size, and institutional changes introduce nuances, underscoring the complex interplay between economic variables. Were & Madete [3] identify the positive influence of external debt on public investment, adding complexity to the discourse. Although initially advantageous, the revelation of a negative long-term effect emphasizes the need to consider the sustainability and implications of accumulating external debt. This finding raises questions about the long-term viability of relying on external borrowing to fuel public investment because obligations to service and repay debt can impede the availability of net resources for future investments. Jarju's [4] findings on the long-term effects of trade openness and gross fixed capital formation provide additional dimensions to this discussion. The increasing influence of these factors suggests the need to carefully consider trade policies and capital formation strategies for managing public debt. Conversely, the diminishing effects of GDP growth, official exchange rates, and government effectiveness on public debt levels underscore the importance of holistic economic policies in maintaining fiscal stability. In synthesizing these studies, it is evident that addressing the global challenge of rising public debt requires a nuanced understanding of the multifaceted factors that influence its dynamics.

Building on prior research, which has primarily focused on the conventional determinants of public debt, such as fiscal policies and economic indicators, this study delves into a critical yet underexplored dimension by examining the connection between environmental degradation and public debt in Malaysia. Although existing literature has largely neglected the environmental aspect of fiscal dynamics, our study aims to bridge this gap and contribute to a more comprehensive understanding of the factors influencing public debt. By explicitly investigating the implications of escalating environmental degradation on public debt, this study extends the current discourse by shedding light on the intersection of environmental sustainability and fiscal responsibility in the Malaysian context. This nuanced exploration distinguishes our study from others and emphasizes its unique contribution to the existing body of knowledge.

Environmental degradation, including pollution, deforestation, and resource depletion, results in substantial economic costs [5]. These costs may manifest as healthcare expenses to treat pollution-related illnesses, decreased agricultural productivity owing to soil erosion, or the need for costly infrastructure repairs after natural disasters caused by environmental degradation. These additional economic burdens strain government budgets and increase public debt. Environmental degradation often leads to natural disasters, such as hurricanes, floods, and wildfires [6]. The government must allocate significant resources to respond to these emergencies, including funding for disaster relief, infrastructure rebuilding, and supporting affected communities. These costs can escalate quickly and contribute to public debt if not managed adequately. Many countries are under pressure to transition to more sustainable practices as the world becomes more aware of the need to combat environmental degradation and climate change. This transition may involve investing in cleaner technologies, enforcing stricter environmental regulations, or moving away from industries with high environmental footprints. These initiatives often require significant upfront investments that can add to public debt in the short term.

This study addresses the challenges stemming from the limited body of literature on CO_2 emissions and public debt relationships in Malaysia, hindering a comprehensive understanding of the complex dynamics between environmental factors and fiscal policies. In response to the nonlinear nature of this relationship, this study employed sophisticated methodologies. It delves deeply into the intricate interplay of the factors that influence public debt, including trade openness, investment, and foreign direct investment (FDI). To overcome these challenges, this study employs a nonlinear autoregressive distributed lag (ARDL) approach to provide nuanced insights into the CO_2 emissions and public debt relationship. Beyond these methodological contributions, this study significantly advances our understanding of environmental and fiscal interconnections in Malaysia. Critical findings underscore the inverse correlation between trade openness and public debt as well as the positive association between investment and public debt. These insights offer valuable guidance for policymakers in shaping effective fiscal and economic strategies and addressing the often-neglected environmental dimension. Importantly, this study emphasizes the need for environmental policies, suggesting actions such as prioritizing emission reduction and promoting green technologies. This emphasis on environmental considerations in fiscal decision-making contributes to informed policy decisions in Malaysia, highlighting the importance of integrating sustainability into economic strategies.

In employing an asymmetric co-integration and dynamic model of public debt spanning from 1980 to 2020 in Malaysia, our study not only addresses the research question but also contributes methodologically and conceptually to the broader academic and policymaking landscape. This analytical approach is particularly significant as it sheds light on the intricate nexus between environmental degradation and public debt, providing nuanced insights that extend beyond the conventional understanding of fiscal dynamics. Methodological innovation employing asymmetric co-integration allows for a more nuanced exploration of the complex relationship between CO_2 emissions and public debt. By considering both short- and long-run dynamics, our study captures the asymmetry in the response of public debt to

environmental degradation, adding a layer of sophistication to the analysis. The temporal scope of this study, spanning four decades, allows a comprehensive examination of trends and patterns, offering a longitudinal perspective on the evolving dynamics of environmental factors and fiscal policies in Malaysia. This extended timeframe enhances the robustness of our findings and provides a historical context for policymakers to assess the long-term implications of environmental policies on public debt. Moreover, the potential benefits of our research extend beyond academia and have direct implications for policymakers. A deeper understanding of the economic ramifications of environmental degradation empowers policymakers to formulate targeted strategies centered on environmental protection, resource management, and prudent fiscal planning. The insights gained from studying how environmental damage affects government debt can guide the development of informed policies and ensure a balanced approach that addresses both economic and environmental sustainability. Therefore, our study not only contributes to academic discourse by advancing methodological rigor and providing nuanced insights into the CO_2 emissions and public debt relationship but also serves as a valuable resource for policymakers. By bridging the gap between theory and practice, our research contributes to the arsenal of practical tools required to craft policies that promote a more sustainable and resilient future for Malaysia.

1-1- An Overview of Total Government Debt in Malaysia

Figure 1 presents a comprehensive overview of Malaysia's government debt as a percentage of GDP, spanning almost two decades, from 2002 to 2020. This dataset is invaluable for discerning critical trends in government debt dynamics, making it essential for understanding Malaysia's fiscal wellbeing. The significance of studies that focus on public debt in Malaysia becomes clear when we examine the implications of these data. Throughout this timeframe, the data depict a consistent upward trajectory in government debt as a proportion of the GDP. Particularly noteworthy is the remarkable spike observed in 2020, when government debt surged to 62.03%. This extraordinary increase can primarily be attributed to the far-reaching economic repercussions of the COVID-19 pandemic. From a quantitative perspective, 2002–2020 witnessed a substantial increase, with government debt increasing by approximately 44.11%. Such a pronounced escalation has prompted profound inquiries concerning the nation's long-term fiscal viability. This signals the pressing need for research endeavors in this domain, which can serve as a compass to gauge the sustainability of Malaysia's public finances. It also aids in determining whether there is a potential risk of debt reaching unsustainable levels, which, in turn, could engender economic instability. This figure underscores the imperative role of studies on public debt in Malaysia. It is a critical foundation for assessing fiscal health, understanding the implications of debt trends, and guiding prudent policymaking to safeguard Malaysia's economic stability and sustainability.
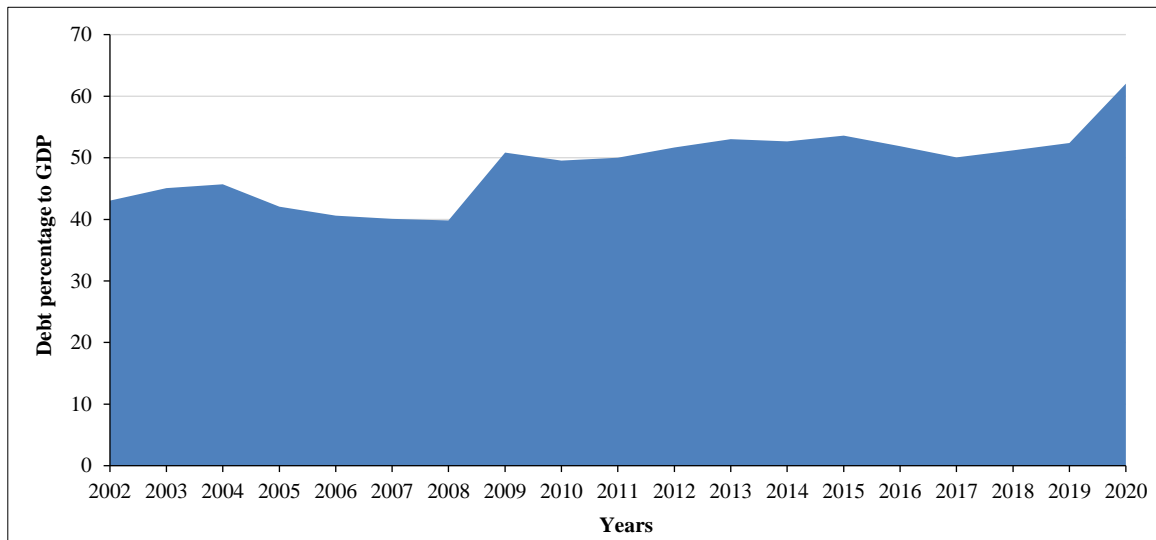

Figure 1. Total government debt (% of GDP) in Malaysia

1-2- Theoretical Background

Economic theory provides fertile ground for comprehending the intricate interplay between public debt and a nation's developmental trajectory. Three models are particularly pertinent to our study for exploring this relationship.

First, the two-gap model pioneered by Chenery and Strout in 1966 sheds light on two pivotal gaps that impede the progress of less-developed nations. The initial gap underscores the disparity between a country's savings (S) and the investment (I) necessary for growth. The second gap, commonly referred to as the trade gap, pertains to the imbalance between a nation's export (X) earnings and import (M) expenditures. This can result in borrowing as countries grapple with insufficient funds for essential imports. The model considers that internal factors such as savings and investment and external factors such as trade openness collectively influence a nation's debt accumulation and developmental trajectory.

Second, the debt overhang theory elucidates that excessive borrowing can hinder a country's economy by obstructing investments in vital sectors such as education, healthcare, and infrastructure, which are pivotal to growth [7]. When national debt reaches a burdensome level, allocating resources to service the existing debt limits the availability of funds for new projects, consequently decelerating economic advancement [8]. Furthermore, apprehensions about repayment may result in elevated interest rates, exacerbating the debt challenge. Essentially, the theory underscores that while borrowing can be advantageous, excessive debt can shackle a country's progress [9], akin to carrying a cumbersome burden on the path to economic development.

Third, crowding-out theory elucidates how extensive government borrowing and high public debt can affect an economy. When the government engages in substantial borrowing for its initiatives, it diminishes the pool of funds available for individuals and businesses to borrow, giving rise to what is known as "crowding out." As government borrowing escalates, it competes for funds, leading to increased interest rates. This, in turn, discourages business investments [10] and consumer spending [11]. This theory posits that significant government borrowing can limit the access of others to borrowing, ultimately resulting in elevated interest rates and sluggish economic growth.

In our study, we employ a two-gap model as a framework for delving into the factors influencing public debt dynamics. This differs from theories such as debt overhang and crowding out, which predominantly focus on the consequences of public debt on other variables. Our approach expands the two-gap model by introducing control variables such as FDI and environmental degradation. We strive for a comprehensive understanding of the elements that shape public debt dynamics within this framework.

The surge in public debt by countries has stimulated economic growth through infrastructure expansion, industrial development, trade promotion, and new investments, all of which carry environmental consequences [12, 13]. Addressing these environmental effects requires increased investments in green energy, climate change mitigation, ecological restoration, and sustainable development initiatives. This leads us to hypothesize that environmental pressure contributes to escalating public debt.

2- Literature Review

Global concerns surrounding public debt have prompted extensive research efforts to identify the factors driving its expansion and to comprehend its various consequences. Researchers have presented contrasting findings, as illustrated in an investigation conducted by Zafar and Butt [14]. Their study spanned an extensive 36-year period from 1972 to 2007 and integrated trade openness and GDP as central variables. Their results revealed a positive association between trade openness and public debt. This discovery emphasizes the complexity inherent in the dynamics of public debt and the intricate interactions among its influencing factors.

Kızılgöl & Ipek [15] examined various variables, including trade openness, terms of trade, budget deficits, FDI, exchange rates, and inflation, to scrutinize their influence on public debt. Their findings yielded intriguing outcomes, highlighting the statistically significant positive relationship between trade openness and public debt at the 1% level. By contrast, FDI has a negative effect on public debt levels. These results were corroborated by Bölükbaş [16] in a similar study conducted in Turkey that employed trade openness and exchange rates as independent variables, and affirmed the positive connection between trade openness and public debt. However, other researchers have observed a contrasting relationship between trade openness and public debt. For example, Brafu-Insaidoo et al. [17] investigated the effect of economic growth, domestic financial development, trade openness, and interest rates on public debt and found a negative association between trade openness and public debt in Ghana, aligning with the findings of Rodrik and Velasco [18]. This trend was further substantiated by Halebić & Moćević's [2] study in Bosnia, which examined the effects of budget deficit, trade openness, unemployment rate, and population on public debt levels.

Prior investigations by established researchers have frequently examined the relationship between gross domestic savings and public debt. For instance, Luke and Joanna examine the intricate relationship between savings and state debt in their 2008 study, spanning several countries in Latin America, the Caribbean, and sub-Saharan Africa. Their research incorporated gross domestic savings and capital stock as independent variables and public debt as the dependent variable from 1975 to 2004. The generalized least squares method was used for data analysis. Based on a two-gap model, their study revealed a negative correlation, indicating that savings hurt public debt. This discovery aligns with the findings of Sharif Chaudhry et al. [19], who extended their inquiry to include the Keynesian theory of consumption alongside the classical theory of savings, both of which are rooted in the loanable funds model. In their analysis of GDP and gross domestic savings against public debt, Sharif Chaudhry et al. [19] found that higher gross domestic savings led to reduced reliance on public debt. Furthermore, Akram [20] supports these findings by identifying a negative association between gross domestic savings and public debt in Pakistan, highlighting how inadequate gross domestic savings could result in budget deficits.

Other researchers argue that government investment is pivotal in shaping public debt dynamics. de Mendonça & Brito [21] conducted a study on 24 emerging markets using data spanning from 1996 to 2018. Their analysis, which included the GDP, inflation, and investment as variables, revealed a negative correlation between public debt and investment.

This finding aligns with those of prior studies by Trecroci and Salotti [22], Babu et al. [23], Abbas and Wizarat [24], and Alzahrani [25]. However, Jarju [4] found a statistically significant positive correlation between investment and state debt in Gambia at the 5% significance level. Jarju's analysis considers various variables, including GDP, trade openness, interest rates, exchange rates, and government effectiveness. Similarly, Were & Madete [3] examined government expenditure, trade openness, and investment in their study of Tanzania, revealing a positive association between investment and the magnitude of public debt and a similar relationship between trade openness and public debt.

In the realm of FDI and its implications for public debt, Sinha et al. [26] conducted an analysis incorporating variables such as current account balance, government expenditure, interest rates, GDP, inflation, and FDI. However, their findings revealed that these factors had no significant effect on public debt. By contrast, Swamy's [27] extensive investigation involving 148 countries revealed an inverse connection between FDI and public debt levels, a trend echoed by Kudla's [28] research, which emphasized how the absence of FDI can drive other sectors towards reliance on public debt for financing. Nonetheless, Jarju's [4] examination of Gambia presents a counternarrative as it identifies no substantial correlation between FDI and public debt. These divergent outcomes underscore the intricate and context-specific relationship between FDI and public debt, highlighting the need for a nuanced evaluation that considers specific regional and national variables.

A significant gap in previous research on public debt revolves around the overemphasis on macroeconomic factors, often neglecting other critical contributors to the escalation of public debt. One factor that has been overlooked is environmental degradation, which has not received sufficient attention as a potential driver of public debt. Although some prior studies, such as that of Zhao and Liu [29], have delved into the direct effect of public debt on CO_2 emissions, the inverse relationship wherein carbon dioxide emissions influence public debt remains largely unexplored. This gap underscores the pressing need for a more comprehensive investigation into how environmental factors, including carbon emissions, may interact with and shape public debt dynamics as an avenue of significant importance for future research in this domain. Therefore, it is reiterated that the current study distinguishes itself from previous research by addressing the inadequately explored relationship between environmental degradation, specifically carbon emissions, and the dynamics of public debt.

3- Research Methodology

In this study, we harnessed the power of the nonlinear autoregressive distributed lag (ARDL) methodology to delve into the intricate interconnections among trade openness, investment, savings, CO_2 emissions, and FDI, and their collective influence on the dynamics of public debt (PD). We subject all variables to logarithmic transformations to ensure the integrity of our analysis and mitigate potential data distribution challenges. Our data collection efforts spanned annual time-series data for the variables of interest, encompassing a significant time horizon for capturing long-term trends and dynamics. Our primary sources included reputable institutions such as the World Bank and the esteemed platform countryeconomy.com.

Utilizing the nonlinear ARDL (NARDL) model is rooted in its beneficial asymmetrical characteristics compared with the linear ARDL. The NARDL approach incorporates a dynamic error-correction model that addresses both temporal and spatial asymmetries, rendering it particularly advantageous in studies with limited datasets. This approach notably reduces the complexity of the equations required for cointegration analyses and effectively accommodates asymmetric nonlinearity. Notably, both nonlinear and conventional ARDL methodologies produce reliable and precise outcomes, even when handling variables of varying orders (I(0), I(1), or a combination thereof). Our analytical journey estimates the cointegration relationship using ordinary least squares (OLS) while judiciously selecting a suitable lag order, adhering to the principles of the NARDL methodology. It is crucial to highlight that the NARDL approach remains adaptable irrespective of the order of the data (I(0), I(1), or a combination thereof). Notably, both NARDL and ARDL methodologies exhibit particular proficiency when confronted with scenarios characterized by small sample sizes. The NARDL method also facilitates objective long-term approximations and rigorous econometric forecasting.

One of the distinctive strengths of the NARDL lies in its ability to seamlessly incorporate short-term adjustments within the framework of long-term equilibrium without compromising the integrity of long-run data. The dataset utilized for this research encompasses several critical variables: CO_2 emissions (*CO2*), proxied by total CO_2 emissions; savings, proxied by gross domestic savings (*GDS*) as a percentage of GDP; investment (*INV*), proxied by gross capital formation in current US dollars; trade openness (*TO*), proxied by net trade in goods and services in current US dollars; foreign direct investment (*FDI*), proxied by FDI net inflows in current US dollars; and public debt (*PD*), proxied by total annual public debt in ringgits. Our dataset spans 1980–2021 and all data were transformed into logarithms. Our research innovation relies on the application of the recently developed NARDL methodology introduced by Shin et al. [30]. This sophisticated model, equipped with its asymmetrical capabilities, paves the way for a robust and high-quality investigation and is formulated as follows in Equations 1 and 2:

$$\text{LNPD} = \beta_1 \text{LNTO}_t + \beta_2 \text{LNINV}_t + \beta_3 \text{LNGDS}_t + \beta_4 \text{LNFDI}_t + \beta_5 \text{LNCO2}_t + \varepsilon_t \tag{1}$$

where *LNTO* refers to the log of trade openness, *LNINV* refers to the log of investment, *LNGDS* refers to the log of Gross Domestic Savings, *LNFDI* refers to the log of Foreign Direct Investment, *LNCO2* refers to the log of Carbon Dioxide emissions, *LNPD* refers to the log of public debt, β_1, β_2, β_3, β_4, and β_5 refers to the parameters to determine the long run relationships between these variables, *t* is time period, ε_t is error term of residual at time "t".

In Equation 2, the variables (*LNTO, LNINV, LNGDS, LNFDI, LNCO2*, and *LNPD*) represent the logs of trade openness, investment, savings, FDI, CO₂ emissions, and public debt, respectively. ε is the error term. The parameters β_1, β_2, β_3, and β_5 determine the long-run relationships between these variables. To detect both short- and long-term asymmetric effects, we introduce an asymmetric ARDL model that uses negative and positive partial sum decompositions. Using stationarity criteria, the econometric model assesses the long-term relationship between the variables using ARDL and ECM/Granger causality. The sample variables were completely asymmetric. Linear regression works well for determining a straight line of causation between two variables, but fails miserably at capturing nonlinear behavior. To investigate this, Shin et al. [30] augmented the ARDL model to investigate the nonlinear connections between variables. Asymmetric ARDL, by contrast, uses a cointegration approach. This method is particularly effective in capturing abrupt shifts and structural fractures typically associated with asymmetries. CO₂ emissions are regressed against *LNGDP, LNFDI, LNPG*, and *LNCO2* in this study. The following explicit equation represents the unequal long-term link with public debt:

$$LNPD = \alpha_0 + \alpha_1 LNTO_t^+ + \alpha_2 LNTO_t^- + \alpha_3 LNINV_t^+ + \alpha_4 LNINV_t^- + \alpha_5 LNGDS_t^+ + \alpha_6 LNFDS_t^- + \alpha_7 LNFDI_t^+ + \alpha_8 LNFDI_t^- + \alpha_9 LNCO2_t^+ + \alpha_{10} LNCO2_t^- + \varepsilon_t \tag{2}$$

where $\alpha = \alpha_0$ to α_8 is a co-integrating vector to be estimated, and the partial sums of positive and negative fluctuations are represented as $LNTO_t^+$ to $LNCO2_t^-$, respectively.

Equations 4 to 11 correspond to the partial sums of the positive and negative changes in *LNTO, LNINV, LNGDS, LNFDI*, and *LNCO2* in public debt.

$$LNTO_t^+ = \sum_{i=1}^{t} \Delta LNTO_t^+ = \sum_{i=1}^{t} max \Delta LNTO_i, 0 \tag{3}$$

$$LNTO_t^- = \sum_{i=1}^{t} \Delta LNTO_t^- = \sum_{i=1}^{t} min \Delta LNTO_i, 0 \tag{4}$$

$$LNINV_t^+ = \sum_{i=1}^{t} \Delta LNINV_t^+ = \sum_{i=1}^{t} max \Delta LNINV_i, 0 \tag{5}$$

$$LNINV_t^- = \sum_{i=1}^{t} \Delta LNINV_t^- = \sum_{i=1}^{t} min \Delta LNINV_i, 0 \tag{6}$$

$$LNGDS_t^+ = \sum_{i=1}^{t} \Delta LNGDS_t^+ = \sum_{i=1}^{t} max \Delta LNGDS_i, 0 \tag{7}$$

$$LNGDS_t^- = \sum_{i=1}^{t} \Delta LNGDS_t^- = \sum_{i=1}^{t} min \Delta LNGDS_i, 0 \tag{8}$$

$$LNFDI_t^+ = \sum_{i=1}^{t} \Delta LNFDI_t^+ = \sum_{i=1}^{t} max \Delta LNFDI_i, 0 \tag{9}$$

$$LNFDI_t^- = \sum_{i=1}^{t} \Delta LNFDI_t^- = \sum_{i=1}^{t} min \Delta LNFDI_i, 0 \tag{10}$$

$$LNCO2_t^+ = \sum_{i=1}^{t} \Delta LNCO2_t^+ = \sum_{i=1}^{t} max \Delta LNCO2_i, 0 \tag{11}$$

$$LNPD_t^- = \sum_{i=1}^{t} \Delta LNPD_t^- = \sum_{i=1}^{t} min \Delta LNPD_i, 0 \tag{12}$$

Equations 3 to 12 delineate the negative and positive series, and by applying Equation 1, we deduce Equation 13, giving rise to the asymmetric model referred to as the ARDL, as shown below

$$\Delta LNPD_t = \beta_0 + \beta_1 LNPD_{t-1} + \beta_2 LNTO_{t-1}^+ + \beta_3 LNTO_{t-1}^- + \beta_4 LNINV_{t-1}^+ + \beta_5 LNINV_{t-1}^- + \beta_6 LNGDS_{t-1}^+ +$$
$$\beta_7 LNGDS_{t-1}^- + \beta_8 LNFDI_{t-1}^+ + \beta_9 LNFDI_{t-1}^- + \beta_{10} LNCO2_{t-1}^+ + \beta_{11} LNCO2_{t-1}^-$$

$$\sum_{i=1}^{m} \delta_{1i} \Delta LNPD2_{t-i} + \sum_{i=0}^{n} \delta_{2i} \Delta LNTO_{t-i}^+ + \sum_{i=0}^{0} \delta_{3i} \Delta LNTO_{t-i}^- + \sum_{i=0}^{p} \delta_{4i} \Delta LNINV_{t-i}^+ + \tag{13}$$
$$\sum_{i=0}^{q} \delta_{5i} \Delta LNINV_{t-i}^- + \sum_{i=0}^{r} \delta_{6i} \Delta LNGDS_{t-i}^+ + \sum_{i=0}^{s} \delta_{7i} \Delta LNGDS_{t-i}^- + \sum_{i=0}^{t} \delta_{8i} \Delta LNFDI_{t-i}^+ +$$
$$\sum_{i=0}^{u} \delta_{9i} \Delta LNFDI_{t-i}^- + \sum_{i=0}^{v} \delta_{8i} \Delta LNCO2_{t-i}^+ + \sum_{i=0}^{w} \delta_{9i} \Delta LNCO2_{t-i}^- + \mu_i$$

where the lag orders are denoted by (m to w), β_1 to β_{11} signify the enduring positive and negative influences of LNTO, LNINV, LNGDS, LNFDI, and LNCO2 on LNPD within the context of the asymmetrical ARDL model, which is represented by $\sum_{i=1}^{m} \delta_{1i}$ to $\sum_{i=1}^{w} \delta_{9i}$.

The asymmetric ARDL model proceeds through the prescribed steps to evaluate the short-term positive and negative associations among these variables. Initially, a stationarity test was conducted for all variables. Notably, the ARDL model can be employed, irrespective of whether the series is stationary at I(0) or I(1). A notable advantage of the ARDL approach, as Pesaran [31] underscore, is its adaptability to handle stationary series of different orders (I(0), I(1), or a combination), in contrast to the earlier cointegration approach of Engle and Granger [32], which necessitates uniform stationarity orders across all series. Thus, explicit stationarity tests are unnecessary when employing an ARDL model. However, it is important to note that cointegration values based on F-statistics may be unreliable when all series are stationary but of order I(2). To mitigate these issues, we ensure that the variables are stationary. The second stage involves applying the OLS technique to estimate Equation 1 with the additional use of the Schwarz Information Criterion (SIC) for model selection. The third step involves verifying the existence of co-integration through limit tests. Once cointegration was established, we implemented an asymmetric ARDL model. Moreover, we examined the cumulative effects of an asymmetric dynamic multiplier resulting from a 1% change in the variables.

$$LNTO_{t-1}^+, LNTO_{t-1}^-, LNINV_{t-1}^+, LNINV_{t-1}^-, LNGDS_{t-1}^+, LNGDS_{t-1}^-, LNFDI_{t-1}^+, LNFDI_{t-1}^-, LNCO2_{t-1}^+, LNCO2_{t-1}^- \qquad (14)$$

Similarly, given the circumstances,

$$S_h^+(LNTO) = \sum_{j=0}^{h} \frac{\partial lnPD_{t+1}}{\partial lnTO_{t-1}^+} \qquad (15)$$

$$S_h^-(LNTO) = \sum_{j=0}^{h} \frac{\partial lnPD_{t+1}}{\partial lnTO_{t-1}^-} \qquad (16)$$

$$S_h^+(LNINV) = \sum_{j=0}^{h} \frac{\partial lnPD_{t+1}}{\partial lnINV_{t-1}^+} \qquad (17)$$

$$S_h^-(LNINV) = \sum_{j=0}^{h} \frac{\partial lnPD_{2t+1}}{\partial lnINV_{t-1}^-} \qquad (18)$$

$$S_h^+(LNGDS) = \sum_{j=0}^{h} \frac{\partial lnPD_{t+1}}{\partial lnGDS_{t-1}^+} \qquad (19)$$

$$S_h^-(LNGDS) = \sum_{j=0}^{h} \frac{\partial lnPD_{t+1}}{\partial lnGDS_{t-1}^-} \qquad (20)$$

$$S_h^+(LNFDI) = \sum_{j=0}^{h} \frac{\partial lnPD_{t+1}}{\partial lnFDI_{t-1}^+} \qquad (21)$$

$$S_h^-(LNFDI) = \sum_{j=0}^{h} \frac{\partial lnPD_{t+1}}{\partial lnFDI_{t-1}^-} \qquad (22)$$

$$S_h^+(lnCO2) = \sum_{j=0}^{h} \frac{\partial lnPD_{t+1}}{\partial lnCO2_{t-1}^+} \qquad (23)$$

$$S_h^-(LNCO2) = \sum_{j=0}^{h} \frac{\partial lnPD_{t+1}}{\partial lnCO2_{t-1}^-} \qquad (24)$$

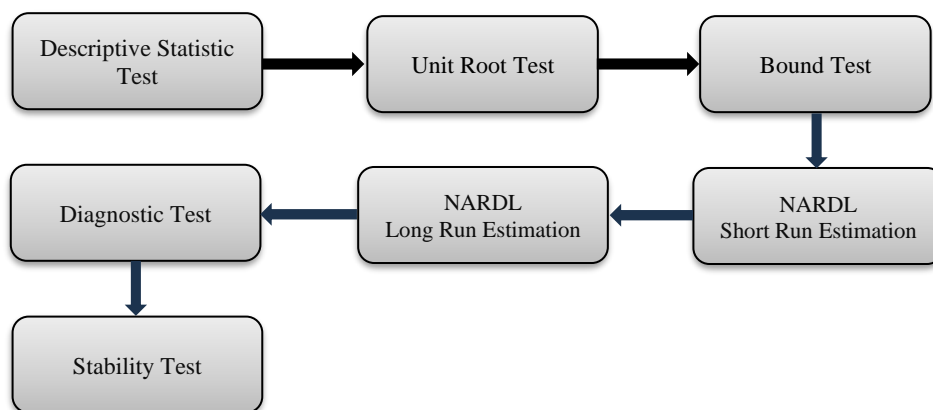Overall, the estimation process is implemented using the flows shown in Figure 2 as follows:

Figure 2. Estimation procedures

4- Results and Discussion

Table 1 presents the descriptive statistics for seven variables: *LNPD, LNTO, LNINV, LNGDS, LNCO2*, and *LNFDI*. The mean values provide insights into the typical levels; for instance, *LNPD*'s mean is approximately 18.9391. The medians, which are less sensitive to outliers, offer a middle-point reference: *LNTO's* median is approximately 23.5306. The maximum and minimum values indicate the data range; *LNFDI* reaches a maximum of 23.4393, whereas *LNTO* has a minimum of approximately -21.9711. Standard deviations signal variability, with *LNTO* displaying high variability

(approximately 16.8001). Skewness highlights distribution shape, with *LNTO* being left-skewed (-1.7285). The kurtosis indicates tail behavior, whereas *LNTO's* kurtosis of 4.0360 implies heavier tails. The Jarque-Bera test, employed to assess normality, clearly indicates a substantial departure from normality in the case of *LNTO*. This departure is underscored by a high-test statistic of 22.2493 and exceedingly low p-value of 0.0000. In summary, these statistics collectively provide a comprehensive understanding of the central tendencies, data ranges, variations, distributions, and normality, aiding analysts in data exploration and modeling. Moreover, consistent values between the mean and median signify that no outliers were detected.

Table 1. Descriptive statistics results

	LNPD	LNTO	LNINV	LNGDS	LNCO2	LNFDI
Mean	18.9391	15.5434	24.0562	3.6117	4.6951	21.8813
Median	18.6488	23.5306	24.0821	3.6033	4.8867	22.1242
Maximum	20.5949	24.6612	25.1746	3.8851	5.5843	23.4393
Minimum	16.9700	-21.9711	22.6983	3.2607	3.3362	18.5575
Std. Dev.	0.9694	16.8001	0.8102	0.1535	0.7555	1.1326
Skewness	0.1237	-1.7285	-0.1720	-0.2155	-0.4694	-0.8604
Kurtosis	2.0123	4.0360	1.7968	2.2834	1.7648	3.1866
Jarque-Bera	1.7711	22.2493	2.6752	1.1945	4.1120	5.1176
Probability	0.4125	0.0000	0.2625	0.5503	0.1280	0.0774

The unit root test results in Table 2 play a fundamental role in evaluating the stationarity of time-series data, which is a pivotal concept in time-series analysis. This significance arises from the fact that numerous statistical models rely on the assumption of stationarity, indicating that the statistical properties of the data remain consistent over time. Deviations from stationarity can yield misleading outcomes in statistical analyses. Examining the unit root test outcomes for the original (level) data revealed compelling insights. Specifically, variables such as *LNTO, LNFDI, LNINV, LNGDS,* and *LNCO2* indicate stationarity. *LNTO, LNFDI,* and *LNCO2* are stationary at I(0) and I(1). This indicates that the arrangement of the variables is mixed with stationarity. By contrast, the status of the *LNPD* appears to be less conclusive regarding stationarity. Nevertheless, when applying the first-difference transformation to these variables, a significant shift occurs; they all exhibit characteristics consistent with stationarity. This transformational shift is pivotal in time-series analysis as it aligns the data with the requisite stationarity assumption, thus rendering the ARDL approach appropriate and conducive for insightful modeling and interpretation.

Table 2. Unit root results

	Level		1st Difference	
Variable	**t-statistic**	**Prob***	**t-statistic**	**Prob***
LNPD	0.2596	0.973	-3.1071	0.0342
LNTO	-3.3436	0.0193	-9.3303	0.0000
LNFDI	-3.6443	0.009	-6.9459	0.0000
LNINV	-1.3149	0.6133	-5.2365	0.0001
LNGDS	-0.3714	0.9044	-5.3988	0.0001
LNCO2	-2.6575	0.0904	-4.3843	0.0012

Table 3 presents the results of the error correction term (ECT) and bound tests, which are commonly used in time-series analyses to investigate long-term equilibrium relationships and the presence of co-integration between variables. An ECT(-1) coefficient of -0.26018 represents the coefficient of the error correction term lagged by one period. This coefficient measures the speed at which the dependent variable (not specified in the table) adjusts towards its long-term equilibrium level after a deviation from equilibrium occurs. In this case, a coefficient of -0.26018 implies that the dependent variable adjusts by approximately 26.018% towards its equilibrium level in the subsequent period. The bound test assesses whether a cointegrating relationship exists among the variables in the model [33]. Cointegration indicates a long-term equilibrium relationship between variables, suggesting that they move together over an extended period. The test compares the F-statistic to critical values at various significance levels (10%, 5%, 2.5%, and 1%). The F-statistic in this test is 34.14284, which exceeds the critical values at all significance levels (10%, 5%, 2.5%, and 1%). This suggests a cointegrating relationship among the variables, indicating a long-term equilibrium relationship. The synthesis of these findings not only enhances the robustness of our time-series analysis, but also provides a comprehensive understanding of the interplay between variables over extended periods. The ECT and bounds tests collectively illuminate the intricacies of long-term equilibrium relationships and shed light on the persistence and interdependence of the variables under consideration.

Table 3. ECT and bound test results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
ECT(-1)*	-0.26018	0.010572	-24.6103	0
F-Bounds Test		**Null Hypothesis: No levels of relationship**		
Test Statistic	**Value**	**Signif.**	**I(0)**	**I(1)**
F-statistic	34.14284	10%	1.76	2.77
		5%	1.98	3.04
		2.5%	2.18	3.28
		1%	2.41	3.61

The analysis of short-term elasticities reported in Table 4 provides valuable insights into how changes in the independent variables influence the dependent variable, *LNPD*. These results stem from the application of the nonlinear ARDL method, where *LNPD* is the focal point of the investigation, along with a comprehensive suite of independent variables, including *LNTO_POS, LNTO_NEG, LNINV_POS, LNINV_NEG, LNGDS_POS, LNGDS_NEG, LNFDI_POS, LNFDI_NEG, LNCO2_POS, LNCO2_NEG*, and a constant term represented as C. Beginning with *LNTO_POS*, there is a 1% increase in *LNTO* to a modest -0.0012% reduction in *LNPD*, assuming all other factors remain constant. Notably, this coefficient is statistically significant at the 10% level. By contrast, when exploring *LNTO_NEG*, a 1% decrease in *LNTO* yields a marginal 0.0009% increase in *LNPD*, although this effect is not statistically significant. Shifting our attention to the *LNINV_POS*, a noteworthy finding emerges. A 1% increase in the LNINV results in a 0.1161% increase in the *LNPD*. However, this outcome is significant at the 10% level. *LNINV_NEG* has a substantial effect. A remarkable 1% increase in *LNINV* triggers a -0.1519% decline in *LNPD*, marking a statistically significant effect at the 1% level. The *LNGDS_POS* exhibits distinct patterns. A 1% increase in *LNGDS* is linked to a -0.1487% dip in *LNPD*. However, this result is not statistically significant. Conversely, a 1% reduction in the *LNGDS* corresponds to a 0.2218% increase in the *LNPD*. However, this effect remains statistically insignificant. The findings for the *LNFDI_POS* indicate a significant relationship. A 1% increase in *LNFDI* is associated with a -0.0673% decrease in *LNPD*, signifying statistical significance at the 1% level. Conversely, a 1% decrease in *LNFDI* results in a -0.0103% decrease in *LNPD*, although this effect does not attain statistical significance. Examining *LNCO2_POS*, the coefficient stands at -0.0100. This suggests that a 1% increase in *LNCO2* leads to a -0.0100% decrease in *LNPD*. However, it is essential to note that this effect is not statistically significant. Similarly, when considering *LNCO2_NEG*, a 1% decrease in *LNCO2* is tied to a -0.1865% decrease in *LNPD*. However, the difference is not statistically significant.

Table 4. Short-run elasticities results

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
LNTO_POS	-0.0012	0.0007	-1.8067	0.0839
LNTO_NEG	0.0009	0.0006	1.5426	0.1366
LNINV_POS	0.1161	0.0628	1.8492	0.0773
LNINV_NEG	-0.1519	0.0475	-3.1956	0.004
LNGDS_POS	-0.1487	0.1904	-0.7812	0.4427
LNGDS_NEG	0.2218	0.1540	1.4408	0.1631
LNFDI_POS	-0.0673	0.0192	-3.4994	0.0019
LNFDI_NEG	-0.0103	0.0094	-1.0954	0.2847
LNCO2_POS	-0.0100	0.1381	-0.0722	0.9431
LNCO2_NEG	-0.1865	0.3530	-0.5284	0.6023
C	4.8705	1.0598	4.5958	0.0001

The long-run elasticity results in Table 5 provide valuable insights into how the unspecified dependent variable responds to variations in the independent variables over an extended temporal horizon. Starting with *LNTO_POS*, the coefficient of -0.0045 implies that a 1% increase in *LNTO* results in a corresponding long-term decrease of -0.0045% in the unspecified dependent variable *LNPD*. Importantly, this effect is statistically significant at the 5% level. Conversely, *LNTO_NEG* exhibits an intriguing dynamic. The coefficient of 0.0090 suggests that a 1% decrease in *LNTO* leads to a long-term increase of 0.0090% in *LNPD*. Remarkably, this effect achieves high statistical significance at the 1% level. Shifting our focus to *LNINV_POS*, the coefficient of 0.4462 suggests that a 1% increase in *LNINV* corresponds to a long-term increase in *LNPD* of 0.4462 %. However, it is worth noting that this effect does not reach statistical significance.

However, *LNINV_NEG* indicates an opposing trend. With a coefficient of -0.5837, a 1% decrease in *LNINV* results in a long-term decrease of -0.5837% in *LNPD*. This effect is marginally significant at the 10% level, as supported by the t-statistic. Examining *LNGDS_POS*, a coefficient of -1.7985 signifies that a 1% increase in *LNGDS* is associated with a substantial long-term decrease of -1.7985% in *LNPD*. Importantly, this effect is not statistically significant. The *LNGDS_NEG* provides contrasting results. With a coefficient of 0.8526, a 1% decrease in the *LNGDS* leads to a long-term increase in the *LNPD* of 0.8526 %. Similar to the *LNGDS_POS*, this effect is not statistically significant. Moving forward, *LNFDI_POS* suggests that a 1% increase in *LNFDI* results in a long-term decrease of -0.2586% in *LNPD*. This effect is statistically significant at the 5% level, indicating its robustness. *LNFDI_NEG*, with a coefficient of -0.2633, indicates that a 1% decrease in *LNFDI* results in a long-term decrease of -0.2633% in *LNPD*. Importantly, this effect is statistically significant. Finally, *LNCO2_POS* exhibits a notable trend. The coefficient of 1.4254 suggests that a 1% increase in *LNCO2* leads to a substantial long-term increase of 1.4254% in *LNPD*. This effect is statistically significant. Conversely, the *LNCO2_NEG* shows the opposite outcome. Its coefficient of -0.7169 implies that a 1% decrease in *LNCO2* results in a long-term decrease of -0.7169% in *LNPD*. However, similar to other variables, this effect is not statistically significant.

Table 5. Long-run elasticities results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNTO_POS	-0.0045	0.0021	-2.1110	0.0459
LNTO_NEG	0.0090	0.0021	4.3382	0.0002
LNINV_POS	0.4462	0.2813	1.5863	0.1263
LNINV_NEG	-0.5837	0.2965	-1.9685	0.0612
LNGDS_POS	-1.7985	1.2017	-1.4966	0.1481
LNGDS_NEG	0.8526	0.7425	1.1483	0.2626
LNFDI_POS	-0.2586	0.1010	-2.5592	0.0175
LNFDI_NEG	-0.2633	0.0846	-3.1124	0.0049
LNCO2_POS	1.4254	0.3583	3.9786	0.0006
LNCO2_NEG	-0.7169	1.3797	-0.5196	0.6083
C	18.7195	0.3190	58.6818	0.0000

Diagnostic tests are crucial to evaluate the reliability and underlying assumptions of a model [34]. The results are presented in Table 6. The serial correlation test, with a test statistic of 1.5275 and probability of 0.2403, reveals no significant serial correlation, indicating that the model's residuals lack systematic relationships. Similarly, the heteroscedasticity test, which display a statistic of 1.5259 and a probability of 0.1758, fails to provide strong evidence of heteroscedasticity. This result implies that the variance in the residuals remains relatively stable. The Ramsey RESET test, presenting a statistic of 0.4038 and probability of 0.5317, confirms that the model is well specified and does not require additional nonlinear terms. Furthermore, the Jarque-Bera test, which shows a statistic of 0.2637 and probability of 0.8765, indicates that the residuals do not significantly deviate from a normal distribution, validating the assumption of normality within the model.

Table 6. Diagnostic test results

Test statistic	t-statistic	Prob.
Serial correlation	1.5275	0.2403
Heteroscedasticity	1.5259	0.1758
Ramsey RESET	0.4038	0.5317
Jarque-Bera	0.2637	0.8765

In summary, the diagnostic tests for the ARDL method collectively support the notion that the assumptions of the model are generally met, underscoring its reliability and suitability for further analysis.

Figure 3 displays the cumulative sum (CUSUM) and cumulative sum of squares (CUSUM of squares) tests. The CUSUM test is employed to detect shifts or changes in time-series data or model residuals. When the CUSUM values remain within the 5% significance level, it indicates that no significant deviations or structural changes were observed in the data, implying that the model remains stable and accurate. However, the CUSUM of squares test is a more robust version of the CUSUM test, which examines the squares of deviations. Similar to the CUSUM test, if the CUSUM of squares values remain within the 5% significance bound, the model performance remains stable, with no significant departures from the assumed stability conditions.
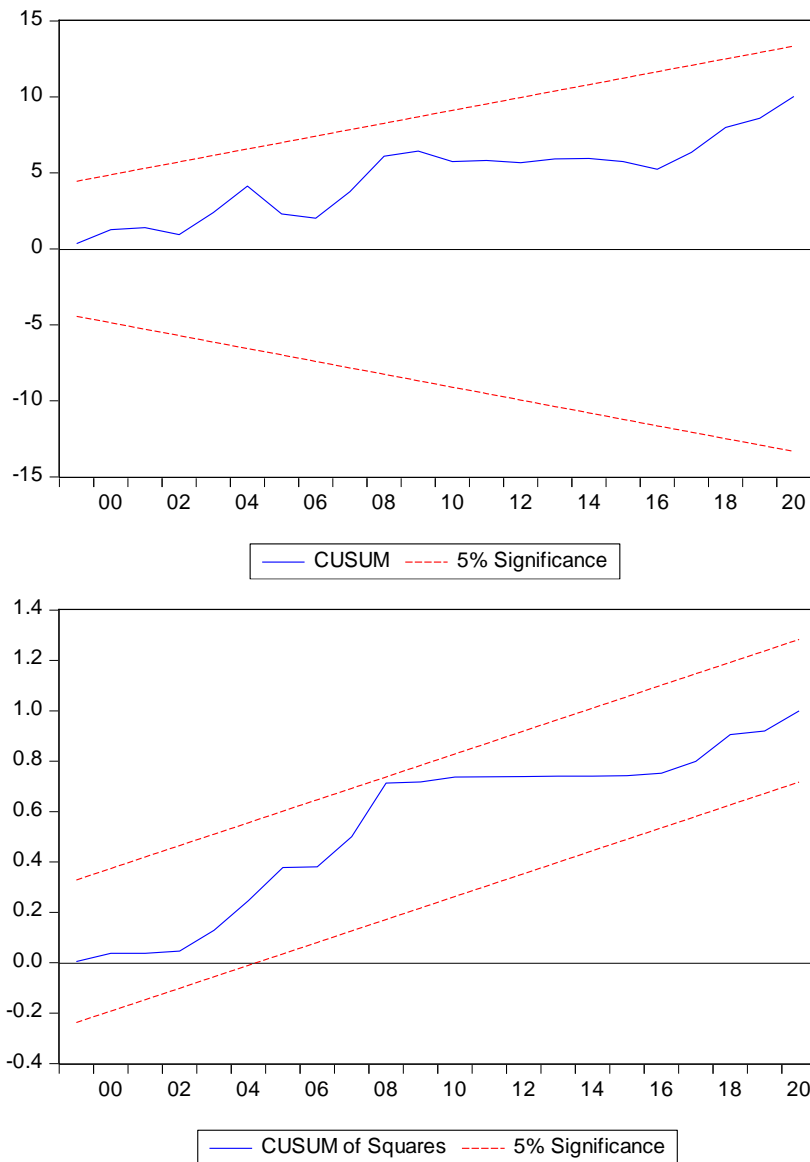
Figure 3. CUSUM and CUSUM of squares

5- Discussions

Recent research findings revealing a negative association between trade openness and public debt in Malaysia are intriguing and thought-provoking. Despite employing rigorous empirical analyses, the studies diverge in terms of geographical focus and specific variables under investigation. A Malaysian study employing the NARDL illuminates the negative relationship between trade openness and public debt. By contrast, Ibhagui's [35] research in sub-Saharan Africa emphasizes the interplay between external debt, trade openness, and current account dynamics. Both studies provide valuable insights into economic relationships, with Malaysian studies providing a unique perspective on Malaysia's context and its implications for public debt management. Ibhagui [35] delves into the adjustment processes of current account deficits in sub-Saharan Africa, emphasizing the role of external debt. Recognizing these distinctions enriches our understanding of how regional economic dynamics and the variables considered influence the outcomes of empirical analyses. Our discovery prompts a discussion about its implications, potential causes, and the broader economic context within which it operates. It implies that as Malaysia becomes more open to international trade, its public debt tends to decrease. This is noteworthy, given the increasing emphasis on globalization and trade liberalization to foster economic growth. As a country becomes more open to international trade, it often experiences an increase in export revenue [36]. This influx of funds can finance government expenditure, reducing the need for borrowing, and consequently, public debt. An open trade environment may encourage economic diversification. A diversified economy is less reliant on narrow revenue sources, reducing the fiscal burden and need to accumulate public debt.

Observing a positive relationship between investment and public debt in Malaysia is a complex and intriguing finding that warrants thorough examination. This result suggests that as investment levels increase, so does the country's public debt, as supported by Veiga and Veiga [37]. Comparing our study on public debt and investment in Malaysia with Veiga and Veiga's [37] research on municipal deficits and debt in Portuguese local governments, some notable differences and

similarities emerge. In our study on Malaysia, the finding that investment increases public debt suggests potential concerns regarding fiscal management. By contrast, Veiga and Veiga [37] focus on Portuguese local governments and identify a political budget cycle but find no evidence of strategic fiscal policy influencing subsequent governments. However, the political dimension in their study contrasts with our emphasis on investment. Moreover, the factors influencing indebtedness differ: in Malaysia, investment increases public debt, whereas in Portuguese local governments, greater support in the town hall, party similarity, higher unemployment rates, and specific economic indicators affect indebtedness. Understanding these variations underscores the importance of context-specific analysis when exploring the complex dynamics of public debt. In this discussion, we explore the significance of this result, consider potential explanations, and assess the implications for Malaysia's economic policies and prospects. Malaysia has invested heavily in infrastructure projects in recent years. Although these investments are vital for long-term economic growth, they often require substantial financing. Public debt may increase when the government borrows funds for these projects, resulting in a positive correlation between investment and public debt. Malaysia has been investing heavily in infrastructure projects in recent years. While these investments can be vital for long-term economic growth, they often require substantial financing. Public debt may increase when the government borrows funds for these projects, resulting in a positive correlation between investments and public debt.

The result indicating a negative relationship between high FDI and public debt in Malaysia in the long run is an important and intriguing finding. This finding suggests that a country's public debt decreases as its FDI levels increase. This result is similar to that reported by Kudla [28]. Our study on Malaysia and Kudla's [28] research on European Union (EU) countries delve into the dynamics of public debt, but differ in context, methodology, and key findings. In our study, employing the NARDL in the Malaysian context, higher FDI is associated with increased public debt. By contrast, Kudla focused on EU countries and analyzed the effect of fiscal variables on public debt dynamics. The methodology also varies, with our study using NARDL for a specific national context, whereas Kudla employs dynamic panel regressions across 27 EU countries for the 1995-2015 period. In terms of key determinants, our study identifies a positive relationship between FDI and public debt in Malaysia, whereas Kudla's findings for EU countries suggest that higher FDI stocks and greater general government expenditures contribute to lower primary balances. FDI often flows into productive sectors with the potential for high returns. These investments can contribute to economic growth, increase tax revenue, and reduce reliance on public debt to finance government operations. FDI stimulates economic growth by creating jobs, boosting productivity, and enhancing competitiveness [38, 39]. A growing economy can lead to higher government revenues and decreased public debt relative to GDP.

The assertion that CO_2 emissions are linked to increased public debt underscores the profound influence of environmental factors on a nation's fiscal well-being, an aspect overlooked in prior research. This connection highlights the potential economic ramifications of neglecting environmental concerns, particularly those related to carbon emissions, and the challenges associated with climate change. High CO_2 emissions are frequently correlated with pollution, leading to health issues and environmental degradation [40]. Addressing these problems often incurs substantial costs, exerts pressure on public budgets and potentially increases public debt [41]. The shift towards cleaner and more sustainable energy sources demands significant investments in technology and infrastructure. Governments may resort to borrowing to finance these transitions, contributing to an uptick in public debt. Additionally, the necessity of allocating resources for disaster insurance and risk-mitigation strategies in response to escalating CO_2 emissions has further compounded the burden on public debt.

6- Conclusions

This comprehensive study employs the NARDL method to examine the intricate dynamics between CO_2 emissions and public debt in Malaysia, spanning four decades, from 1980 to 2020. The multifaceted findings revealed several key relationships with important policy implications. First, it revealed an inverse correlation between trade openness and public debt in Malaysia. This revelation underscores international trade's pivotal role in shaping the nation's fiscal landscape. The evidence suggests that embracing trade liberalization, streamlining trade processes, and dismantling trade barriers can be pivotal strategies for harnessing the latent potential of trade openness, ultimately contributing to reduced public debt. A country like Malaysia can increase its export opportunities by reducing trade barriers and facilitating international trade. This can lead to higher revenues from exports, which, in turn, can contribute to government income through taxes and fees. The resulting boost in government revenue can reduce the need for borrowing, ultimately lowering public debt.

This study also highlights the positive connection between investments and public debt in Malaysia. This intricate relationship underscores the need for prudent debt-management strategies when leveraging investments for economic growth. Policymakers are encouraged to explore avenues for augmenting government revenues to offset the borrowing necessitated by investments. These avenues may involve enhancing tax collection, fostering economic diversification, and tightening fiscal discipline by curbing wasteful spending. This study also reveals the intriguing negative relationship between higher FDI and long-term public debt in Malaysia. This result suggests that Malaysia should continue to create an investor-friendly environment, attract foreign capital to bolster economic development, and decrease fiscal vulnerability.

However, the most pressing revelation is the study's confirmation of the positive relationship between CO_2 emissions and public debt. These findings underscore the urgent need to address environmental concerns. Policymakers must prioritize strategies to reduce CO_2 emissions, implement carbon pricing mechanisms to incentivize emission reduction, and promote the adoption of green technologies. Green technologies, such as renewable energy sources (e.g., wind, solar, and hydroelectric power), are characterized by minimal or zero carbon emissions during energy generation. This reduction in greenhouse gas emissions addresses climate change concerns and mitigates associated environmental and economic risks. These measures help mitigate the environmental risks associated with climate change and alleviate the fiscal burden on the government owing to environmental damage.

6-1- Limitations and Future Research

This study covers data from 1980 to 2020. Although this timeframe provides valuable insights, it may not capture recent developments or emerging trends in the relationship between CO_2 emissions and public debt. Future studies should extend the data period to assess contemporary dynamics. In addition, the accuracy and availability of data on CO_2 emissions, public debt, and other relevant variables may pose limitations. Variabilities in data sources, reporting methods, and data gaps may introduce uncertainty into the findings. This study explored the correlation between CO_2 emissions and public debt. Establishing causal relationships and identifying the mechanisms driving these connections require more in-depth research, including econometric modeling and causal inference techniques. This study focused on CO_2 emissions, public debt, trade openness, investment, and FDI. Other factors, such as government policies, geopolitical events, and global economic conditions, may influence public debt and environmental outcomes but are not accounted for in this study. These findings are specific to Malaysia, and may not be directly applicable to other countries with different economic structures, environmental policies, and levels of development. Future research should explore cross-country comparisons to identify broader trends.

7- Declarations

7-1- Author Contributions

Conceptualization, M.S.S., A.S., A.R.R., M.A.E., and E.L.; methodology, M.S.S., A.S., A.R.R., M.A.E., and E.L.; software, M.S.S., A.S., A.R.R., M.A.E., and E.L.; validation, M.S.S., A.R.R., M.A.E., and E.L.; formal analysis, M.S.S., A.S., A.R.R., M.A.E., and E.L.; investigation, M.S.S., A.R.R., M.A.E., and E.L.; resources, M.S.S., A.R.R., M.A.E., and E.L.; data curation, M.S.S.; writing—original draft preparation, M.S.S., A.S., A.R.R., and M.A.E.; writing—review and editing, M.S.S., A.S., A.R.R., M.A.E., and E.L.; visualization, M.S.S.; supervision, M.S.S.; project administration, M.S.S.; funding acquisition, M.A.E., All authors have read and agreed to the published version of the manuscript.

7-2- Data Availability Statement

The data for this study were sourced from the World Development Indicators (WDI) database available at: *https://data.worldbank.org*.

7-3- Funding

7-4- Institutional Review Board Statement

Not applicable.

7-5- Informed Consent Statement

Not applicable.

7-6- Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

8- References

[1] Matsuyama, K. (2023). Japan's Push to Boost Birth Rates Is Falling Short for Families. Bloomberg, New York, United States. Available online: https://www.bloomberg.com/news/newsletters/2023-03-06/japan-s-push-to-boost-birth-rates-is-falling-short (accessed on May 2024).

[2] Halebić, J., & Moćević, A. (2020). Analysis of Public Debt at Subnational Government Levels: Evidence from Cantons in the Federation of Bosnia and Herzegovina. South East European Journal of Economics and Business, 15(2), 109–123. doi:10.2478/jeb-2020-0019.

[3] Were, M., & Madete, L. (2022). The link between public debt and public investment in Tanzania. WIDER Working Paper. WIDER Working Paper 2022/155, 1-20. doi:10.35188/unu-wider/2022/288-1.

[4] Jarju, S. E. (2021). The Determinants of public debt in the Gambia. KDI Central Archives of Public Policy and Management, Sejong, Seoul, South Korea. Available online: https://archives.kdischool.ac.kr/handle/11125/42922 (accessed on April 2024).

[5] Hu, X., Zhong, A., Cao, Y., & Wang, W. (2024). The impact of air pollution on cost of debt: Evidence from corporate bond markets. Accounting & Finance. doi:10.1111/acfi.13257.

[6] Zandalinas, S. I., Fritschi, F. B., & Mittler, R. (2021). Global Warming, Climate Change, and Environmental Pollution: Recipe for a Multifactorial Stress Combination Disaster. Trends in Plant Science, 26(6), 588–599. doi:10.1016/j.tplants.2021.02.011.

[7] Diamond, D. W., & He, Z. (2014). A theory of debt maturity: The long and short of debt overhang. Journal of Finance, 69(2), 719–762. doi:10.1111/jofi.12118.

[8] Manasseh, C. O., Abada, F. C., Okiche, E. L., Okanya, O., Nwakoby, I. C., Offu, P., Ogbuagu, A. R., Okafor, C. O., Obidike, P. C., & Nwonye, N. G. (2022). External debt and economic growth in Sub-Saharan Africa: Does governance matter? PLOS ONE, 17(3), e0264082. doi:10.1371/journal.pone.0264082.

[9] Misra, S., Gupta, K., & Trivedi, P. (2023). Sub-national government debt sustainability in India: an empirical analysis. Macroeconomics and Finance in Emerging Market Economies, 16(1), 57–79. doi:10.1080/17520843.2021.1948171.

[10] Chen, C. J., Ruey-Shan Guo, Wang, S. H., & Lin, Y. H. (2022). Power distance diversification, ownership structure, and business group performance. Journal of Business Research, 151, 70–85. doi:10.1016/j.jbusres.2022.06.041.

[11] Dumitrescu, B. A., & Grecu, R. A. (2023). Impact of Financial Factors on the Economic Cycle Dynamics in Selected European Countries. Journal of Risk and Financial Management, 16(12), 492. doi:10.3390/jrfm16120492.

[12] Akam, D., Owolabi, O., & Nathaniel, S. P. (2021). Linking external debt and renewable energy to environmental sustainability in heavily indebted poor countries: new insights from advanced panel estimators. Environmental Science and Pollution Research, 28(46), 65300–65312. doi:10.1007/s11356-021-15191-9.

[13] Farooq, F., Aurang Zaib, Faheem, M., & Gardezi, M. A. (2023). Public debt and environment degradation in OIC countries: the moderating role of institutional quality. Environmental Science and Pollution Research, 30(19), 55354–55371. doi:10.1007/s11356-023-26061-x.

[14] Zafar, S., & Butt, M. S. (2008). Impact of trade liberalization on external debt burden: Econometric evidence from Pakistan. MPRA Paper No. 9548, 1-18.

[15] Kızılgöl, Ö.A., & İpek, E. (2014). An Empirical Evaluation of the Relationship between Trade Openness and External Debt: Turkish Case. International Econometric Review, 6(1), 42–58. doi:10.33818/ier.278030.

[16] Bölükbaş, M. (2016). The relationship between trade openness and external debt in Turkey: A Cointegration Analysis. Balkan and Near Eastern Journal of Social Sciences, 2(4), 43–48.

[17] Brafu-Insaidoo, W. G., Ahiakpor, F., Vera Ogeh, F., & William G, C. (2019). Macro-determinants of short-term foreign debt in Ghana. Cogent Economics & Finance, 7(1), 1630161. doi:10.1080/23322039.2019.1630161.

[18] Rodrik, D., & Velasco, A. (1999). Short-term capital flows. National bureau of economic research Cambridge, Cambridge, United States. Available online: https://www.nber.org/papers/w7364 (accessed on May 2024).

[19] Sharif Chaudhry, I., Malik, S., & Ramzan, M. (2009). Impact of Foreign Debt on Savings and Investment in Pakistan. Journal of Quality and Technology Management, V(2), 101–115.

[20] Akram, N. (2011). Impact of Public Debt on the Economic Growth of Pakistan. The Pakistan Development Review, 50(4II), 599–615. doi:10.30541/v50i4iipp.599-615.

[21] de Mendonça, H. F., & Brito, Y. (2021). The link between public debt and investment: an empirical assessment from emerging markets. Applied Economics, 53(50), 5864–5876. doi:10.1080/00036846.2021.1931008.

[22] Trecroci, C., & Salotti, S. (2012). Even Worse than You Thought: The Impact of Government Debt on Aggregate Investment and Productivity. SSRN Electronic Journal, 1-42. doi:10.2139/ssrn.2033107.

[23] Babu, J. O., Gisore, N., & Lawrence, K. (2018). Does Public Debt Crowd-Out Public Investment in East Africa Community? Research Journal, 2(4), 1-16.

[24] Abbas, S., & Wizarat, S. (2018). Military expenditure and external debt in South Asia: A panel data analysis. Peace Economics, Peace Science and Public Policy, 24(3), 20170045. doi:10.1515/peps-2017-0045.

[25] Alzahrani, A. A. (2018). The impact of government debt on macroeconomic indicators: evidence from G7 and ASEAN countries. Master Thesis, Eastern Illinois University, Charleston, United States.

[26] Sinha, P., Arora, V., & Bansal, V. (2011). Determinants of Public Debt for middle income and high-income group countries using Panel Data regression. MPRA Paper No. 32079, 1-28.

[27] Swamy, V. (2019). Debt and growth: Decomposing the cause-and-effect relationship. International Journal of Finance & Economics, 25(2), 141–156. doi:10.1002/ijfe.1729.

[28] Kudła, J. (2018). Determinants of Public Indebtedness in European Union Countries. e-Finance, 14(3), 76–86. doi:10.2478/fiqf-2018-0021.

[29] Zhao, T., & Liu, Z. (2022). Drivers of CO2 Emissions: A Debt Perspective. International Journal of Environmental Research and Public Health, 19(3), 1847. doi:10.3390/ijerph19031847.

[30] Shin, Y., Yu, B., Greenwood-Nimmo, M. (2014). Modelling Asymmetric Cointegration and Dynamic Multipliers in a Nonlinear ARDL Framework. Festschrift in Honor of Peter Schmidt. Springer, New York, United States. doi:10.1007/978-1-4899-8008-3_9.

[31] Pesaran, M. H. (2021). General diagnostic tests for cross-sectional dependence in panels. Empirical Economics, 60(1), 13–50. doi:10.1007/s00181-020-01875-7.

[32] Engle, R. F., & Granger, C. W. J. (1987). Co-Integration and Error Correction: Representation, Estimation, and Testing. Econometrica, 55(2), 251. doi:10.2307/1913236.

[33] Alimi, R. S. (2014). ARDL Bounds Testing Approach to Cointegration: A Re-Examination of Augmented Fisher Hypothesis in an Open Economy. Asian Journal of Economic Modelling, 2(2), 103–114. doi:10.18488/journal.8.2014.22.103.114.

[34] Bogduk, N. (2022). On understanding reliability for diagnostic tests. Interventional Pain Medicine, 1, 100124. doi:10.1016/j.inpm.2022.100124.

[35] Ibhagui, O. W. (2018). External debt and current account adjustments: The role of trade openness. Cogent Economics & Finance, 6(1), 1446247. doi:10.1080/23322039.2018.1446247.

[36] Malefane, M. R., & Odhiambo, N. M. (2018). Impact of Trade Openness on Economic Growth: Empirical Evidence from South Africa. International Economics/Economia Internazionale, 71(4), 387-416.

[37] Veiga, L. G., & Veiga, F. J. (2014). Determinants of Portuguese local governments' indebtedness. Working Paper, Braga, Portugal.

[38] Santos, E. (2023). FDI and Firm Productivity: A Comprehensive Review of Macroeconomic and Microeconomic Models. Economies, 11(6), 164. doi:10.3390/economies11060164.

[39] Chowdhury, T. S., Rahman, M. H., Majumder, S. C., & Esquivias, M. A. (2023). Significance of technological progress and capital formation to expand foreign direct investment in Bangladesh: Does money circulation matter? Cogent Economics & Finance, 11(2), 2279351. doi:10.1080/23322039.2023.2279351.

[40] Erdoğan, S., Yıldırım, D. Ç., & Gedikli, A. (2019). The Relationship Between CO_2 Emissions and Health Indicators: The Case of Turkey. Econometrics Letters, 6(1), 28–39.

[41] Majekodunmi, T. B., Shaari, M. S., Abidin, N. Z., & Esquivias, M. A. (2023). The environmental influence of national savings in D-8 countries: Empirical evidence using an ARDL model. Environmental Science and Pollution Research, 30(41), 94456–94473. doi:10.1007/s11356-023-28865-3.