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## Dynamic risk spillovers in European Stock Markets: a TVP-VAR Approach

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**Abstract.** *In this paper, we studied the propagation of risks in European capital markets based on 17 European stock market indices using the methodology proposed by Chatziantoniou et. al. (2021) of a TVP – VAR model and an approach to the levels of connection of variables. The study covers the period November 2001 – February 2025 and focuses on the returns and volatilities of stock market indices. We use a high frequency band (to measure the short term) and a low frequency (for the long term) to measure the level of connection. We observe that the level of interconnection of capital markets is high over the entire analyzed period, and risks propagate from Western European capital markets to Eastern European capital markets, both in terms of returns and volatility. In our opinion, this analysis contributes to understanding the dynamics of European capital markets and improving investors' portfolios.*

**Keywords:** Risk spillover, TVP-VAR, European capital markets, stock market indices, connectedness measures.

**JEL Classification:** G15, C32, C58, G01, F36.

## Introduction

The interconnection of global capital markets is one of the critical areas of research, especially for understanding how risk propagates across regions during periods of market stress. Risk spillovers—the transmission of volatility, uncertainty, and shocks from one capital market to another—have profound implications for market stability, portfolio management, and policy making. This study focuses on spillover dynamics between capital markets in Western and Eastern Europe, regions characterized by different levels of market maturity, economic development, and systemic integration.

Given the events that have taken place over the past 25 years, including the Great Recession of 2008–2009, the Sovereign Debt Crisis (or Euro crisis) of 2010–2012, the global COVID-19 pandemic of 2020, and the Russian-Ukrainian war that began in 2022, it is important to analyze the level of connectivity between European capital markets. Due to the visible differences between Western economies (classified as mature, developed economies) and Eastern economies (predominantly classified as developing economies), as well as European Union integration policies and the general trend toward globalization, the spread of financial risk effects is clearly a topic of interest to both capital market agents and legislative and supervisory bodies.

Therefore, in this paper, we decided to use a TVP-VAR (Time varying parameter – vector autoregression) econometric model designed by Diebold and Yilmaz (2014) and extended by Antonakakis et. al. (2020) to analyze the level of dynamic interconnection between Eastern and Western European capital markets (quantified by stock market indices with high capitalization levels for each region). Based on the literature, we have two expectations:

- 1) the level of interconnection has evolved positively over the last 25 years (i.e., it has grown relatively steadily over the period analyzed);
- 2) in times of financial/global crisis, the level of interconnection reaches its maximum values. The higher the level of interconnection, the greater the risk propagation effects (from an economic theory perspective).

The paper is structured as follows: Chapter I – Literature review, where we analyze the existing body of work on the present topic; Chapter II – Methodology, where we present the data and models used in the econometric analysis; Chapter III – Empirical results and discussions, where we present the estimates obtained and discuss them; the last chapter – Conclusions, recommendations, and limitations of the paper – in which we present the conclusions based on the above, along with the recommendations and limitations of the present study.

## 1. Specialized literature

The subject of analyzing the relationship between various capital markets (related to sovereign states) has always been of interest, both from the perspective of returns (ly rational agents seek to maximize their utility and wealth) and from the perspective of risk

(the same ly rational agents simultaneously seek to minimize possible losses). One of the main methods of analyzing the relationships between them is through stock market indices. Financial theory tells us that the price of a stock contains all the information necessary for rational agents to make the necessary decisions.

A number of studies have analyzed this relationship using VAR and VECM models. On the one hand, authors such as Friedman and Shachmurove (1997), Mylonidis and Kollias (2010), Guidi and Ugur (2014), and Tarță (2023) show that there is cointegration of European capital markets, using Granger cointegration (for the short term) and Johansen (for the long term). In most of these papers, the level of cointegration is weak between markets and, in general, they identify short-term cointegration more than long-term cointegration.

Other authors, including Égert and Kočenda (2007) and Dima Dan – Mihai (2024), show that this cointegration is not observed at the level of empirical data, using the same research methodology (Granger and Johansen cointegration). There are a number of reasons for this, ranging from the period of analysis (depending on when the study was conducted) to the frequency level taken into account (e.g., Guidi and Ugur (2014) use daily data, while Égert and Kočenda (2007) used intra-day data).

Despite the fact that stock market cointegration is either weak or non-existent, the studies presented above show that there are causal relationships—bidirectional, generally between the capital markets of Western European countries, and unidirectional, generally from Western European markets to Eastern European markets. One explanation for this is that the capitalist system based on the market economy has been in place for much longer in the mature economies of Western Europe than in Eastern Europe (which was under the communist regime – the centralized socialist system).

Given the purpose of this paper (to analyze the spillover effects of risk or "risk spillovers" on European stock markets), we present below those papers that have contributed to our understanding of this topic. de Araújo and Garcia (2013) use three econometric models in their paper: GARCH, EGARCH, and TARCH to analyze "risk spillover" between European stock indices (represented by DAX, CAC40, FTSE, etc.), US indices (S&P500) and Japanese indices (NIKKEI225) for the period January 30, 1998 - July 1, 2011. The data collected is daily, and the conclusions are that, in general, there are no risk spillover effects between Northern European stock exchanges (or they are very low, with contagion spreading over a few days), unlike their Southern partners (where contagion occurs over a longer period).

Another interesting analysis is that carried out between the effect of yield propagation between intra-EMU (European Monetary Market) countries and those outside the EMU. Authors Qarni and Gulzar (2020) analyze the period November 2009–December 2016, covering stock market indices (daily frequency) for 19 EMU member states and 9 non-EMU member states (but all part of the European Union). Using a TVP-VAR econometric model, the researchers show that the level of interconnection (connectivity) is higher in

EMU countries than in non-EMU countries. The direction of propagation is asymmetric, generally from EMU countries to non-EMU countries.

As mentioned, one of the events that had a strong impact on capital markets is the COVID-19 pandemic. Aslam et al. (2021) investigated the risk propagation effect (in the form of stock market volatility) in 12 Western European Union countries. The data is in the form of "intra-day" with a (high) frequency of 5 minutes for the period December 2019 – May 2020. Using the methodology proposed by Diebold and Yilmaz (2012), they estimate the volatility spillover effect (in gross and net terms) and show that there is a significant volatility spillover effect between the 12 stock markets, suggesting weak potential for diversification between them. The level of interconnection is also significantly high.

The Russian-Ukrainian war is another event that has implications for the capital market (considering the economic relations that the two states have with European countries – both EU and non-EU members). Therefore, economic researchers analyzed the geopolitical risk and how it propagates when the war was declared and started (effectively conducting an "event study").

Ciocîrlan and Nițoi (2023) investigate the geopolitical risk presented by the Russian-Ukrainian war, using a methodology developed by Baruník & Křehlík (2018) on 23 economies, 10 of which are Western European economies, 12 are Central and Eastern European (CEE) economies, and Russia. They use daily data for stock market indices (denominated in USD) for the period January 2015 – November 2022. The impact of the outbreak of war was moderate on the level of interconnection between the selected countries. Moreover, while the emerging EU countries showed a higher overall spillover effect, they returned to pre-war values relatively quickly, unlike countries outside the EU.

Another topic of interest to economists is the recent energy crisis (which arose as a result of the war between Russia and Ukraine). Since the European energy market tends to behave (recently speaking) like the capital market, economic researchers have applied econometric models to investigate the level of interconnection and spillover effect in this area.

Cevik & Zhao (2025) analyze the energy market in 24 European countries for the period 2014–2024. Using the econometric model proposed by Diebold and Yilmaz (2014), they observe that for the analyzed time interval, 73% of the variation in forecast errors is explained by "cross-variance shares" – which shows that the volatility spillover effect (and therefore risk) dominates the behavior of European energy markets.

In addition to all these academic works, the prevailing macroeconomic context at the European level must also be taken into account. Of the 44 countries in Europe, 27 are currently part of the European Union, and 20 of the 27 EU countries are part of the eurozone/EMU. Both the Maastricht Treaty (1993) and the Lisbon Treaty (2009) suggested and even recommended the integration of member states' markets as much as possible, with monetary union resulting in the single currency, the euro, being one of the most important moments for the cohesion of the European Union.

Considering the works presented above, we can extract the following research hypotheses to be tested in this study:

*H1*: The level of capital market interconnection tends to increase over time;

*H2*: The level of capital market interconnection peaks during periods of crisis and reaches its lowest point immediately after the end of the crisis;

*H3*: The propagation effect of stock market returns (calculated as the difference between daily stock market index values) tends to be unidirectional, from Western to Eastern European stock markets.

*H4*: The propagation effect of stock market volatility (calculated as the standard deviation of the difference between daily stock market index values as a 30-day rolling window) tends to be unidirectional, from Western to Eastern European stock markets.

## 2. Methodology

As a methodology used in this paper, we decided to analyze the collected data (namely, 17 stock indices related to the European space, these being AEX, ATH, BEL 20, BET, BUX, CAC, DAX, FMIB, HEX, IBEX, PX, SAX, SMI, SOFIX, UKX/FTSE 100, WIG 20, XU100/BIST 100), being of the "daily time series" type for the time interval November 2001 to February 2025 (totaling 5,971 observations), we use a TVP-VAR (time varying parameters – vector autoregression) econometric model.

The main work on which this type of econometric model is based is that of Koop and Korobilis (2014), who proposed using this TVP-VAR model instead of the rolling window VAR model, the latter being at that time the classic model for dynamic modeling of relationships between variables. The rolling window VAR model presents a number of problems in its application, including the arbitrary choice of size for the rolling window, loss of observations, and sensitivity of parameters to extreme values. The model proposed by Koop and Korobilis solves these problems.

Diebold and Yilmaz (2012, 2014) also proposed the use of a new methodology for calculating the level of connection between the various variables proposed for analysis. Based on these three papers, a new methodology was developed that uses both the concept of connection between variables proposed by Diebold and Yilmaz and the econometric modeling by TVP-VAR by Koop and Korobilis.

The two main papers introducing the new methodology are those by Baruník and Křehlík (2018) and Antonakakis et al (2020), respectively. Another econometric paper that improves the analysis and interpretation is that of Chatziantoniou et al (2021), which incorporates frequency bands into the TVP-VAR model (and into interconnection indices) to observe short-term (defined as 1–5), medium (5–Inf), and long (Total).

The econometric equation used in calculating the TVP-VAR model (as proposed in the aforementioned papers) has the following form:

$$x_t = \Phi_{1t}x_{t-1} + \Phi_{2t}x_{t-2} + \dots + \Phi_{pt}x_{t-p} + \varepsilon_t$$

$$\varepsilon_t \sim N(0, \Sigma_t) \quad (1)$$

where:

$x_t, x_{t-1}$  și  $\varepsilon_t$  are vectors of dimensions  $N \times 1$ ,

$\Sigma_t$  and  $\Phi_{it}$   $i = 1, \dots, p$  are  $N \times N$  matrices where the first represents the variance-covariance matrix that varies over time, and the second matrix illustrates the coefficients calculated for the "time-varying VAR" (this methodology is in line with that presented by Chatziantoniou et al (2021)).

After calculating the econometric model, we can calculate the measures of interconnection between variables (using GFEVD – "generalized forecast error variance decomposition"), which are:

- NPDC ("Net pairwise connectedness") shows us which of two variables influences the other more;
- TO ("Total direction connectedness TO others") shows us how much of the shock of one variable is transmitted to the other variables;
- FROM ("Total direction connectedness FROM others") shows us how much a variable receives from the shocks of the other variables;
- NET ("Net total directional connectedness") shows the difference between TO and FROM, which can be interpreted as the influence of that variable on the network of variables;
- TCI ("Total connectedness index") measures the level of interconnection at the variable network level – therefore, it measures the average impact that a variable has on all other variables.

For more details on the mathematical specifications of the TVP-VAR model and interconnection indices, I recommend reading the papers mentioned in this chapter, which provide an intuitive presentation of the econometric model and interconnection measures. In applying the model presented above, I used the R software with the "ConnectednessApproach" package, which is specifically designed to run TVP-VAR models and interconnectedness measures.

### 3. Empirical results and discussions

After collecting data for the 17 stock indices for the period November 2001 – February 2025, we proceeded to process them. Therefore, we applied the natural logarithm and first-order differentiation to obtain the daily returns of the stock indices.

The descriptive statistics for these can be seen below, with stock indices grouped according to the type of economy of the countries where the stock exchange is located (and the stock index is calculated).

**Table 1.** Descriptive statistics – market index returns for mature (Western) European economies

|              | AEX     | BEL_20  | CAC     | DAX     | FMIB    | FTSE_100   | HEX     | IBEX    | SMI     |
|--------------|---------|---------|---------|---------|---------|------------|---------|---------|---------|
| Mean         | 0.0001  | 0.00009 | 0.0001  | 0.00025 | 0.00003 | 0.00009    | 0.00003 | 0.00007 | 0.00012 |
| Median       | 0.0005  | 0.00038 | 0.00046 | 0.00069 | 0.0006  | 0.00034    | 0.00021 | 0.00051 | 0.00041 |
| Std. Dev.    | 0.013   | 0.012   | 0.0136  | 0.01394 | 0.01469 | 0.04924    | 0.01361 | 0.01386 | 0.01092 |
| Skewness     | -0.2085 | -0.4240 | -0.1970 | -0.1387 | -0.6264 | 0.18643    | -0.2962 | -0.3258 | -0.2715 |
| Kurtosis     | 10.971  | 13.1676 | 10.3187 | 9.77844 | 12.8632 | 2683.418   | 8.05706 | 12.3103 | 11.4947 |
| Jarque-Bera  | 15846   | 25890   | 1336    | 11447   | 24585   | 17,900,000 | 6448    | 21664   | 18020   |
| Probability  | 0       | 0       | 0.      | 0.      | 0.      | 0          | 0       | 0       | 0       |
| Observations | 5969    | 5969    | 5969    | 5969    | 5969    | 5969       | 5969    | 5969    | 5969    |

Source: Own calculations.

**Table 2.** Descriptive statistics – returns on emerging (Eastern) European market indices

|              | D_ATH    | D_BET    | D_BIST_100 | D_BUX    | D_PX     | D_SAX    | D_SOFIX  | D_WIG_20 |
|--------------|----------|----------|------------|----------|----------|----------|----------|----------|
| Mean         | -0.00009 | 0.0005   | 0.0007     | 0.00041  | 0.0002   | 0.00015  | 0.00038  | 0.00012  |
| Median       | 0.00016  | 0.00039  | 0.00069    | 0.00033  | 0.0004   | 0.000    | 0.00006  | 0.000    |
| Std. Dev.    | 0.017    | 0.01371  | 0.01768    | 0.01419  | 0.01237  | 0.01085  | 0.01118  | 0.01424  |
| Skewness     | -0.53352 | -0.37765 | -0.26849   | -0.41778 | -0.65127 | -0.80527 | -0.68253 | -0.36948 |
| Kurtosis     | 12.18278 | 16.6713  | 7.80758    | 11.68798 | 19.726   | 21.42304 | 16.58949 | 8.02778  |
| Jarque-Bera  | 21255    | 46627    | 5820       | 18946    | 70001    | 85059    | 46393    | 6423     |
| Probability  | 0        | 0        | 0          | 0.       | 0.       | 0        | 0        | 0        |
| Observations | 5969     | 5969     | 5969       | 5969     | 5969     | 5969     | 5969     | 5969     |

Source: Own calculations.

As can be seen, in general, the returns of emerging (eastern) economies in Europe tend to be higher on average than those of mature (western) economies. Here we note the exception of the ATH – Athens Composite Index, which show a negative return over the period, explained by the economic phenomena experienced by Greece (namely the Great Recession of 2007–2008, the Sovereign Debt Crisis of 2010–2012, and Greece's default in 2015).

For both Western and Eastern capital market returns, the skewness is predominantly negative, with the sole exception being the Anglo-Saxon capital market (represented by the FTSE 100 stock market index). This shows that there is a tendency to record lower-than-average returns—one explanation being the significant number of financial crises (and economic recessions) that have caused capital markets to lose significantly in each of them.

Tables 3 and 4 (in the appendix) present descriptive statistics for the volatilities of the market indices of mature (Western) European economies and emerging (Eastern) European economies, respectively. Volatilities were calculated using the rolling window methodology over a 30-day period based on previously calculated returns.

The two tables in the annexes show that in mature economies, stock market index volatility is around 0.01 (or 1%), while in emerging economies we see either values higher than 0.01 (as is the case with the ATH, BET, BIST\_100, PX, and WIG\_20 indices) or below 0.01 (as is the case with the SAX and SOFIX indices). Therefore, part of the reason for higher returns in the East versus the West is explained by the higher degree of volatility.

In Western European capital markets, the most volatile market is the Anglo-Saxon market, with an average value of approximately 1.32%. The least volatile of these is the Swiss market, with an average value of 0.96% over the period. Among Eastern European capital

markets, the most volatile are the Turkish (1.63%) and Greek (1.52%) markets. The least volatile Eastern European market is Bulgaria (0.91%).

Below, we will present and discuss the results obtained using the methodology presented in the previous chapter. Thus, in Tables 5, 6, and 7 (attached in the appendix), we can observe the levels of dynamic interconnection between the 17 stock indices—both overall and in the short term (coded "1-5") and in the long term (coded "5-Inf").

The tables are interpreted as follows: the column shows the spillover effect transmitted to other variables, and the row shows the spillover effect received from other variables. The NET row shows whether capital markets (represented by stock market indices) are net transmitters or net receivers.

According to Table 5, overall, the net transmitters are stock indices for Western European countries (or mature European economies), namely FTSE 100, AEX, BEL, CAC, DAX, FMIB, HEX, IBEX, and SMI. The French capital market is the net transmitter (with a CAC index value of 29.8), followed by the Dutch capital market through AEX (24.41) and the German capital market - DAX (23.54). The net recipients are the capital markets of Eastern European countries (or emerging European economies) represented by stock indices, namely ATH, BET, BIST 100, BUX, PX, SAX, SOFIX, and WIG 20. The Romanian capital market receives the most from the risk propagation effect, with a value of -24.39 for BET, followed by the Turkish capital market - BIST 100 (-23.22) and the Greek capital market - ATH (-22.77).

In the short term (Table 6), the trend observed at the total level continues (namely, Western European capital markets are net transmitters and Eastern European capital markets are net receivers). The net transmitters with the highest values are still CAC (20.78), AEX (17.7), and DAX (16.06). The net receivers with the lowest values are BIST 100 (-17.32), ATH (-15.86), and BET (-14.9), respectively. In the long term (Table 7), the trends observed previously are maintained, with the observation that the capital market where the propagation effects are most felt is the Romanian one, as observed by the value of the BET index (-9.45), followed by the Bulgarian capital market through SOFIX (-8.44) and the Greek capital market through ATH (-6.49).

The following three tables (Tables 7, 8, and 9) attached in the appendix show the level of interconnection between the 17 stock indices in terms of their volatility. In terms of volatility, we observe that, when calculated over the entire time interval, net transmitters and net receivers tend to be the same, with the sole exception being the WIG 20 stock index – corresponding to the Warsaw Stock Exchange in Poland. An economic explanation for this fact may be given by the interdependence between the German and Polish economies, which means that, from a volatility perspective, the Polish stock index follows the same trends as the volatility of the DAX index.

In the short term, we observe that the trend observed in short-term returns for stock indices is maintained, with the exception of the PX stock index (related to the Prague Stock Exchange, Czech Republic) – which is a net transmitter in this case (with a value of 0.08 >



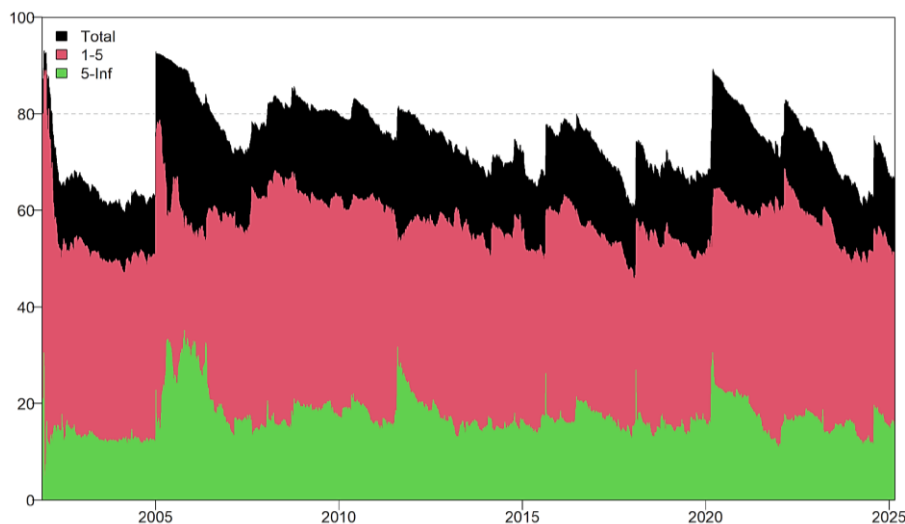
0), but with a value so close to 0, we can actually interpret that in the short term, the PX does not transmit or receive significant shocks from other stock indices. At the same time, the SMI acts in the short term as a net receiver of risk propagation (with a value of  $-0.53 < 0$ ). In the case of the Swiss stock index, it is a (relatively) weak receiver of the risk propagation effect from other stock indices, an economic explanation for this being the size of the Swiss economy (small) relative to its geographical neighbors (namely France, Austria, Germany, significantly larger economies).

In the long term, we again observe a change in the interconnection between the volatility of European stock indices and the long-term behaviour of European stock index returns. Thus, in terms of volatility, the WIG 20 index (in addition to other classic net transmitters, related to mature Western European economies) shows positive values of the NET index (for WIG 20  $\rightarrow 2.83 \gg 0$ ), thus also being a net transmitter of spillover effects. The main stock indices to which it transmits risk ("spillover") are BUX (6.88) and PX (6.14).

Based on the six tables presented above, we can say that our research hypotheses H3 and H4 are confirmed (to the extent of the available data and with the present methodology), namely that Western European stock indices transmit spillover risk to Eastern European stock indices, both in terms of daily returns and volatility.

Next, using the "ConnectednessApproach" package, we generated figures to observe how connectivity levels manifest themselves over the studied time interval (ergo, from a dynamic perspective). Thus, Figures 1 and 2 attached below represent the TCI ("Total Connectivity Index") connectivity index.

**Figure 1.** Total Dynamic Connectivity – stock index returns



**Source:** Own processing.

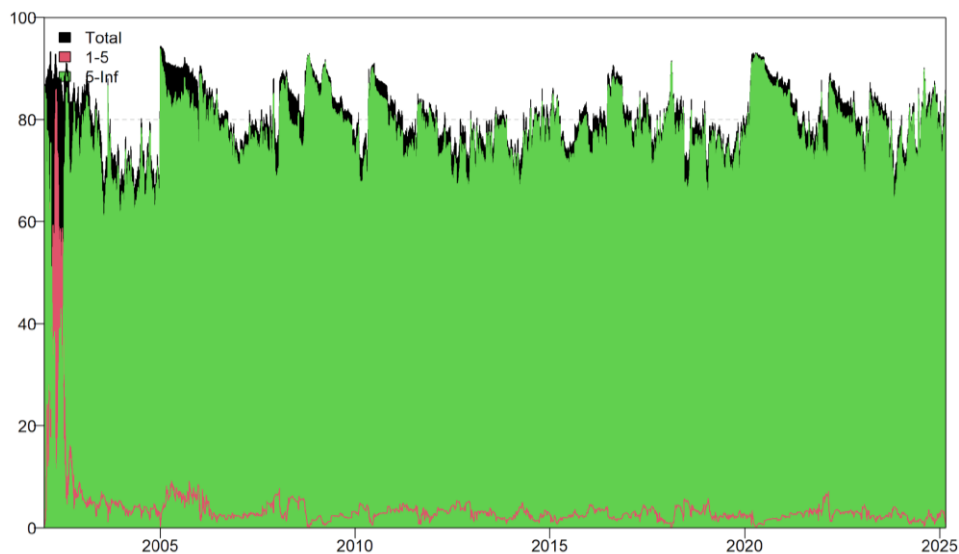
As can be seen in Figure 1, at the level of daily stock index returns, the connectivity level (on a scale of 0 to 100) has fluctuated between 70 and 90 over the last 24 years (with a

general average of around 78 for the entire time interval). Of the total value, around 20% of the connectivity level is explained by short-term yield movements, while most of the interconnection level is explained by long-term yield developments.

It can be seen that there are peaks reached throughout the analyzed period (in 2001, 2007–2008, 2012, and 2020–2021, respectively). The peaks coincide with moments of financial crisis (the years 2000–2001 being influenced by the global speculative "Dot com" bubble). At the same time, it can be seen that after each period of crisis, there is a decrease in the level of interconnection of capital markets (which is in line with economic logic – the financial market becomes a so-called "bearish market" – where investors seek to protect their investments and take refuge in safe assets, such as bonds or treasury bills rather than stocks and options).

We can also see that there is no upward or downward trend in capital markets in terms of their level of interconnection. Capital markets show a relatively high level of interconnection throughout the analysis period (from a yield perspective).

**Figure 2.** *Total Dynamic Connectivity – Stock Index Volatility*



**Source:** Own processing.

Figure 2 also shows the level of interconnection of stock indices (from the perspective of volatility this time) using the TCI index. Here we observe, unlike in the case of daily returns, that almost the entire level of interconnection is explained by long-term movements, while short-term volatilities had a significant impact in the early 2000s and then stabilized.

In terms of the level of connectivity of capital market volatilities, we observe that there are still a number of peaks (in the same periods as in the case of returns, namely 2000–2001, 2007–2012, here we have the combination at European level of the Great Recession with

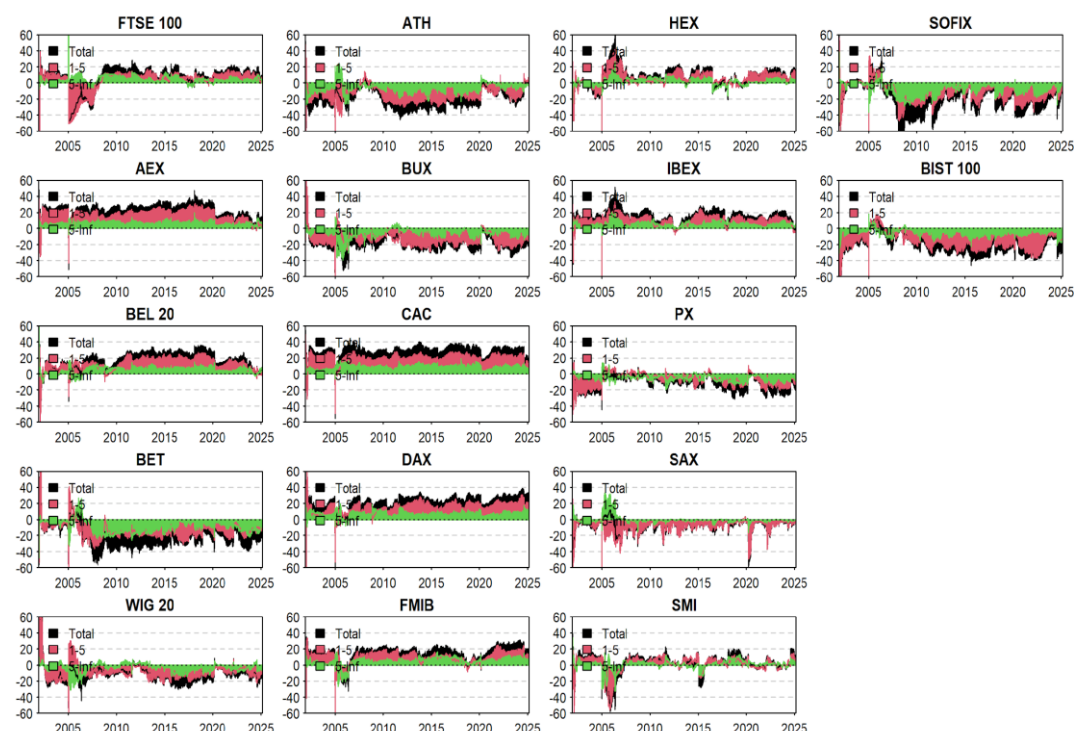
the Sovereign Debt Crisis and 2020–2021). Also, after each peak period, there is an immediate trough period (or moment), which is in line with our expectations.

An interpretation of the above figure from an economic perspective is provided by the concept of the rational agent (a concept that is prevalent in academic works in the economic and financial field). Given that agents active in the stock markets behave like rational investors, they monitor and adjust their investment portfolios based on long-term expectations of volatility, rather than analyzing short-term fluctuations. This does not mean that there are no agents who react in the short term (the red line representing the interconnection value due to short-term movements also shows peaks during periods of financial crisis/economic turmoil).

Based on these two figures, we can say that the first research hypothesis is rejected—because we do not have a clear trend of increase (or decrease) in the level of capital market interconnection over the time interval studied, and the second research hypothesis is confirmed in light of the maximum and minimum points observed in our analysis for the period 2001–2025.

To complete the analysis, we have generated a series of figures to observe how various stock indices influence each other over time (and proxies, European capital markets).

**Figure 3.** *NET Spillover – at the level of European stock market index returns*



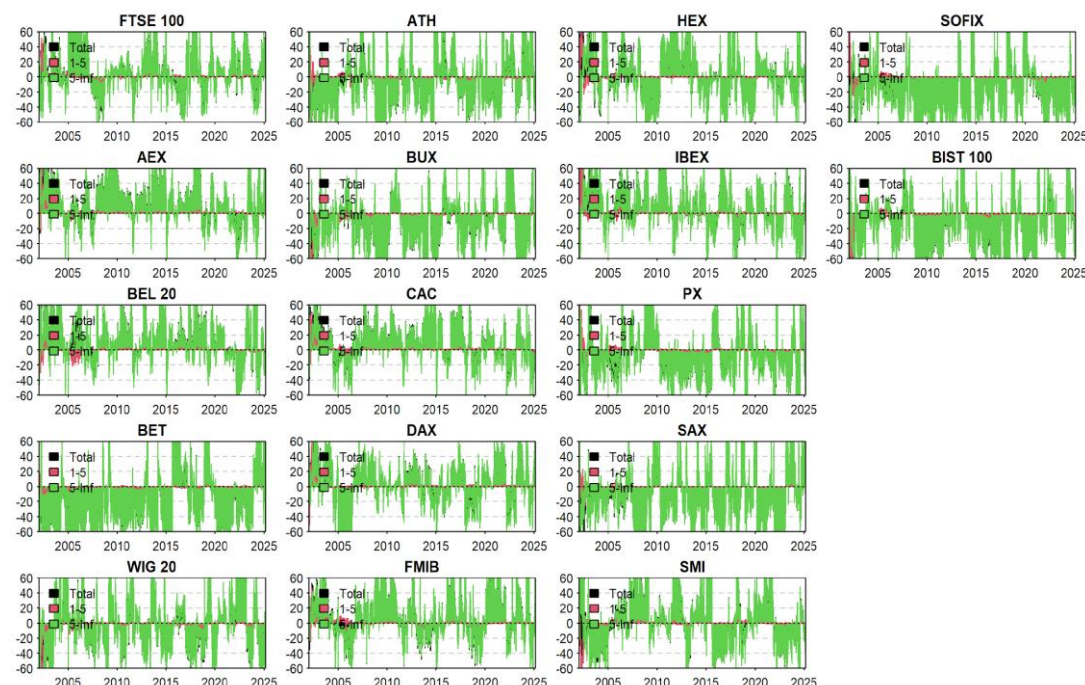
Source: Own calculations.

Figure 3 shows the evolution over time of the net risk spillover effect per stock market index (as daily returns). As can be seen in the tables above, for the capital markets of Western European economies, it can be seen that they tend to transmit their risk to other capital markets over the entire period. It is interesting to note that, in general, short-term movements tend to coincide with long-term movements, but there are also moments/periods of time when opposite trends can be observed.

For example, the FTSE 100 was clearly risk-seeking in the short term between 2005 and 2007, while in the long term, during the same period, it was clearly risk-transferring. Another interesting phenomenon can be observed in the SMI index, which was strongly risk-seeking between 2004 and 2006 (especially when calculated in the short term) and again in 2015.

From the perspective of the returns of Eastern European stock indices (emerging European economies), there is a general tendency among them to be net risk takers from other stock indices. As with Western stock indices, there is a tendency for short-term movements to be in tandem with long-term ones. We have cases such as SOFIX, where we can see that since 2007–2008, the Bulgarian capital market has continuously and systematically taken on the risks of other capital markets, reaching its peak values in 2007–2008. We also have cases such as the SAX index, related to the Slovak capital market, where short-term returns (and their associated spillover effect) explain most of the net negative value.

**Figure 4.** *NET Spillover - at the level of European stock market volatility*



**Source:** Own calculations.

Figure 4 shows the evolution over time of the net spillover effect, but at the level of European stock market volatility. As can be seen at first glance, short-term volatility is not significant for capital markets in general. At the level of Western European capital markets (mature economies), we observe that the trend is rather to be net transmitters than net receivers (although there are periods of time, specifically when there have been global or European economic and financial crises), during which they were also net receivers.

At the same time, capital markets tend to show fluctuations in the level of risk propagation over time, as is the case with the Spanish capital market (at the IBEX index level, we can see that after being a strong risk taker, it is immediately followed by a period of strong risk transmission, continuing at this pace after 2012). The same phenomenon can also be seen in the Finnish capital market (through the HEX stock index), where there are longer periods of time in which, from the perspective of volatility propagation, the market is a net transmitter or a net taker.

Eastern European capital markets (of emerging economies) tend to fluctuate significantly more than their neighbors, with a tendency to be more net receivers than net transmitters of the propagation effect (of risks), the clearest examples being BET, BIST 100, and SOFIX.

Another interesting observation is that of the 17 capital markets, the only one that was not net welcoming (ergo, was a net transmitter) during the COVID-19 pandemic was that of the Anglo-Saxon economy (the FTSE 100 stock index).

### **Conclusions, recommendations, and limitations of the paper**

The purpose of this paper was to investigate the risk propagation effect (from a dynamic perspective) of risks on European capital markets using the TVP-VAR methodology. To achieve the aim of the paper, we collected data from 17 European stock indices (to act as a proxy for capital markets) over the period November 2001 – February 2025 as daily time series. We transformed the data by applying the natural logarithm and first-order differentiation (to obtain daily returns) and calculated the 30-day volatility.

By applying the "ConnectednessApproach" package in R to the obtained returns and volatilities, we obtained a TVP-VAR model (Eng. "Time varying parameters – Vector Autoregression") model, based on which we were able to calculate the interconnection indices of European capital markets and observe whether the propagation comes from west to east, is bidirectional, or comes from east to west.

The results obtained and presented in the paper show that, over the period studied, the propagation of risks is predominantly from Western European capital markets (which are net transmitters) to Eastern European markets (which are net receivers). Moreover, these results are all the more relevant as the model applied shows us that, overall, capital markets are strongly interconnected and the level of interconnection increases in times of crisis (whether global or European).

Given what we've talked about in our analysis, the recommendation would be for capital market players to be aware that in times of economic crisis, markets tend not to isolate themselves but to become even more connected, so there's no greater protection from risk by investing in your own country (in the literature, this phenomenon is known as "home bias"). When investment portfolios are created, an analysis such as the one carried out in this paper can contribute significantly to identifying the main transmitters of risk to one market or another in order to develop hedging techniques against them.

The limitations of this paper are due to data availability, data frequency, and the geographical area chosen (a future paper could address the relationships between European capital markets and the US capital market, or between European and Asian capital markets).

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## Appendices

**Table 3.** *Descriptive statistics – volatility of market indices in mature (Western) European economies*

|             | VOL_AEX | VOL_BEL_20 | VOL_CAC | VOL_DAX | VOL_FMIB | VOL_HEX | VOL_FTSE_100 | VOL_IBEX | VOL_SMI |
|-------------|---------|------------|---------|---------|----------|---------|--------------|----------|---------|
| Mean        | 0.0113  | 0.0107     | 0.012   | 0.012   | 0.013    | 0.0121  | 0.0132       | 0.0123   | 0.0096  |
| Median      | 0.0094  | 0.0090     | 0.0101  | 0.0103  | 0.0115   | 0.0098  | 0.0081       | 0.0105   | 0.0080  |
| Std. Dev.   | 0.0069  | 0.006      | 0.0066  | 0.0067  | 0.0068   | 0.0062  | 0.0484       | 0.0065   | 0.0054  |
| Skewness    | 2.4719  | 2.4360     | 2.2005  | 2.1176  | 2.0206   | 1.5119  | 13.5515      | 2.1279   | 2.6812  |
| Kurtosis    | 10.802  | 11.2237    | 9.3502  | 8.4026  | 8.9863   | 5.1339  | 187.7234     | 9.3063   | 12.613  |
| Jarque-Bera | 21116   | 22612.76   | 14774   | 11664   | 12911    | 3390.1  | 8627186      | 14326    | 29991   |
| Prob        | 0       | 0          | 0       | 0       | 0        | 0       | 0            | 0        | 0       |
| Obs         | 5940    | 5940       | 5940    | 5940    | 5940     | 5940    | 5940         | 5940     | 5940    |

**Source:** Own calculations.

**Table 4.** *Descriptive statistics – volatility of market indices for emerging (eastern) European economies*

|             | VOL_ATH | VOL_BET | VOL_BIST_100 | VOL_BUX | VOL_PX | VOL_SAX | VOL_SOFIX | VOL_WIG_20 |
|-------------|---------|---------|--------------|---------|--------|---------|-----------|------------|
| Mean        | 0.015   | 0.0115  | 0.0163       | 0.01    | 0.01   | 0.0098  | 0.00914   | 0.013161   |
| Median      | 0.0131  | 0.0089  | 0.0146       | 0.01    | 0.0089 | 0.0093  | 0.0073    | 0.011894   |
| Std. Dev.   | 0.0082  | 0.0074  | 0.0066       | 0.0064  | 0.006  | 0.0045  | 0.00595   | 0.005426   |
| Skewness    | 1.7293  | 2.1145  | 1.381804     | 2.8278  | 3.8232 | 1.4434  | 2.35199   | 2.085144   |
| Kurtosis    | 6.9572  | 8.6821  | 5.160489     | 15.095  | 26.658 | 6.8943  | 10.1710   | 9.545644   |
| Jarque-Bera | 6836    | 12417   | 3045.547     | 44125   | 1530   | 5816.2  | 18203.9   | 14,908.6   |
| Prob        | 0       | 0       | 0            | 0       | 0      | 0       | 0         | 0          |
| Obs         | 5940    | 5940    | 5940         | 5940    | 5940   | 5940    | 5940      | 5940       |

**Source:** Own calculation.



**Table 5.** *Yield spillover index – total*

|          | FTSE 100.<br>Total | AEX.<br>Total | BEL 20<br>Total | BET.<br>Total | WIG 20.<br>Total | ATH.<br>Total | BUX.<br>Total | CAC.<br>Total | DAX.<br>Total | FMIB.<br>Total | HEX.<br>Total | IBEX.<br>Total | PX.<br>Total | SAX.<br>Total | SMI.<br>Total | SOFIX.<br>Total | BIST 100<br>Total | FROM.<br>Total |
|----------|--------------------|---------------|-----------------|---------------|------------------|---------------|---------------|---------------|---------------|----------------|---------------|----------------|--------------|---------------|---------------|-----------------|-------------------|----------------|
| FTSE 100 | 16.17              | 9.31          | 8.05            | 2.03          | 3.82             | 2.82          | 2.87          | 9.43          | 8.31          | 7.45           | 7.13          | 7.65           | 3.53         | 0.62          | 7.41          | 1.09            | 2.32              | 83.83          |
| AEX      | 8.03               | 12.26         | 8.92            | 2.05          | 4.02             | 3.13          | 2.96          | 10.3          | 9.55          | 8.36           | 7.5           | 8.05           | 3.71         | 0.48          | 7.49          | 0.89            | 2.3               | 87.74          |
| BEL 20   | 7.41               | 9.46          | 13.01           | 2.02          | 3.77             | 3.36          | 3.05          | 9.74          | 8.94          | 8.39           | 7.34          | 8.44           | 4.06         | 0.49          | 7.29          | 0.95            | 2.28              | 86.99          |
| BET      | 4.21               | 4.83          | 4.65            | 39.93         | 3.5              | 3.1           | 3.38          | 4.79          | 4.59          | 4.08           | 4.69          | 4.21           | 4.54         | 1.03          | 4.07          | 2.1             | 2.28              | 60.07          |
| WIG 20   | 5.57               | 6.55          | 5.89            | 2.35          | 22.6             | 3.7           | 5.92          | 6.73          | 6.77          | 5.98           | 6.1           | 6              | 5.42         | 0.71          | 5.21          | 1.06            | 3.43              | 77.4           |
| ATH      | 4.81               | 6.09          | 6.2             | 2.58          | 4.43             | 27.04         | 3.54          | 6.45          | 6.29          | 6.32           | 5.41          | 6.31           | 5.16         | 0.55          | 4.86          | 1.08            | 2.89              | 72.96          |
| BUX      | 4.84               | 5.78          | 5.65            | 2.57          | 6.99             | 3.6           | 27.04         | 6.03          | 5.93          | 5.4            | 5.35          | 5.28           | 6.07         | 0.4           | 4.67          | 1.08            | 3.23              | 72.96          |
| CAC      | 7.75               | 9.85          | 8.82            | 1.98          | 3.92             | 3.16          | 3             | 11.72         | 9.83          | 8.95           | 7.49          | 8.78           | 3.72         | 0.5           | 7.33          | 0.92            | 2.28              | 88.28          |
| DAX      | 7.32               | 9.66          | 8.59            | 1.95          | 4.09             | 3.21          | 3.06          | 10.41         | 12.44         | 8.86           | 7.43          | 8.4            | 3.65         | 0.5           | 7.2           | 0.8             | 2.37              | 87.56          |
| FMIB     | 6.95               | 8.98          | 8.59            | 1.86          | 3.9              | 3.4           | 3.04          | 10.04         | 9.37          | 13.17          | 6.92          | 9.7            | 4.02         | 0.48          | 6.54          | 0.86            | 2.18              | 86.83          |
| HEX      | 7.14               | 8.83          | 8.18            | 2.23          | 4.38             | 3.31          | 3.22          | 9.22          | 8.71          | 7.6            | 14.68         | 7.61           | 4.05         | 0.6           | 6.66          | 1.16            | 2.41              | 85.32          |
| IBEX     | 7.1                | 8.69          | 8.65            | 1.98          | 3.89             | 3.37          | 2.97          | 9.91          | 8.94          | 9.75           | 6.98          | 13.4           | 4.08         | 0.55          | 6.46          | 0.94            | 2.34              | 86.6           |
| PX       | 5.08               | 6.23          | 6.63            | 3.08          | 5.63             | 4.36          | 5.15          | 6.59          | 6.09          | 6.31           | 5.85          | 6.46           | 22.7         | 0.58          | 4.79          | 1.45            | 3.02              | 77.32          |
| SAX      | 1                  | 1.06          | 1.12            | 1.42          | 1.36             | 1.03          | 0.9           | 1.16          | 1.15          | 0.9            | 1.57          | 1.27           | 1.14         | 80.81         | 0.95          | 1.79            | 1.28              | 19.19          |
| SMI      | 7.86               | 9.12          | 8.37            | 2.25          | 3.96             | 3.06          | 2.98          | 9.28          | 8.67          | 7.42           | 6.93          | 7.28           | 3.49         | 0.65          | 15.56         | 1.04            | 2.08              | 84.44          |
| SOFIX    | 2.76               | 2.75          | 2.82            | 3.3           | 2.14             | 2.17          | 1.95          | 2.9           | 2.84          | 2.51           | 3.25          | 2.79           | 3.08         | 1.32          | 2.41          | 59.16           | 1.87              | 40.84          |
| BIST 100 | 4.51               | 4.98          | 4.66            | 2.02          | 4.85             | 3.37          | 3.83          | 5.1           | 5.1           | 4.21           | 4.58          | 4.78           | 4.03         | 0.85          | 3.6           | 1.28            | 38.25             | 61.75          |
| TO       | 92.33              | 112.1         | 105.8           | 35.68         | 64.66            | 50.1          | 51.83         | 118.1         | 111.1         | 102.56         | 94.53         | 103            | 63.8         | 10.41         | 86.93         | 18.56           | 38.54             | 1260.1         |
| Inc. Own | 108.5              | 124.4         | 118.81          | 75.61         | 87.26            | 77.2          | 78.87         | 129.8         | 123.5         | 115.73         | 109.2         | 116.39         | 86.4         | 91.22         | 102.5         | 77.72           | 76.78             | cTCI/TCI       |
| Net      | 8.5                | 24.41         | 18.81           | -24.39        | -12.74           | -22.77        | -21.13        | 29.8          | 23.54         | 15.7           | 9.2           | 16.39          | -13.6        | -8.78         | 2.48          | -22.28          | -23.22            | 78.76/74.12    |
| NPDC     | 10                 | 15            | 13              | 2             | 7                | 5             | 4             | 16            | 14            | 12             | 9             | 11             | 6            | 0             | 8             | 1               | 3                 |                |

**Source:** Own calculations.

**Table 6.** *Yield spillover index – short term*

|             | FTSE<br>100.1-5 | AEX.<br>1-5 | BEL<br>20.1-5 | BET.<br>1-5 | WIG<br>20.1-5 | ATH.<br>1-5 | BUX.<br>1-5 | CAC.<br>1-5 | DAX.<br>1-5 | FMIB.<br>1-5 | HEX.<br>1-5 | IBEX.<br>1-5 | PX.<br>1-5 | SAX.1<br>-5 | SMI.<br>1-5 | SOFIX.<br>1-5 | BIST<br>100.1-5 | FROM.<br>1-5 |
|-------------|-----------------|-------------|---------------|-------------|---------------|-------------|-------------|-------------|-------------|--------------|-------------|--------------|------------|-------------|-------------|---------------|-----------------|--------------|
| FTSE<br>100 | 13.4            | 7.47        | 6.3           | 1.6         | 3.05          | 2.26        | 2.33        | 7.59        | 6.65        | 5.99         | 5.77        | 6.15         | 2.84       | 0.55        | 5.93        | 0.94          | 1.9             | 67.47        |
| AEX         | 6.35            | 9.67        | 6.95          | 1.59        | 3.17          | 2.41        | 2.34        | 8.11        | 7.5         | 6.6          | 5.89        | 6.3          | 2.88       | 0.34        | 5.94        | 0.65          | 1.77            | 68.77        |
| BEL 20      | 5.81            | 7.36        | 10.13         | 1.54        | 2.94          | 2.56        | 2.39        | 7.6         | 6.96        | 6.56         | 5.72        | 6.53         | 3.14       | 0.34        | 5.71        | 0.68          | 1.76            | 67.6         |
| BET         | 2.94            | 3.36        | 3.21          | 30.87       | 2.5           | 2.24        | 2.44        | 3.36        | 3.2         | 2.82         | 3.34        | 2.98         | 3.36       | 0.78        | 2.81        | 1.6           | 1.56            | 42.49        |
| WIG 20      | 4.2             | 4.96        | 4.43          | 1.76        | 18.07         | 2.84        | 4.7         | 5.1         | 5.15        | 4.6          | 4.61        | 4.49         | 4.22       | 0.49        | 4.01        | 0.73          | 2.58            | 58.91        |
| ATH         | 3.54            | 4.48        | 4.54          | 2.01        | 3.3           | 21.02       | 2.67        | 4.78        | 4.61        | 4.64         | 4.03        | 4.62         | 3.95       | 0.42        | 3.6         | 0.82          | 2.18            | 54.19        |
| BUX         | 3.68            | 4.35        | 4.25          | 1.96        | 5.38          | 2.69        | 21.51       | 4.55        | 4.45        | 4.1          | 4.03        | 3.96         | 4.61       | 0.32        | 3.57        | 0.76          | 2.41            | 55.09        |
| CAC         | 6.22            | 7.89        | 7.02          | 1.57        | 3.15          | 2.49        | 2.41        | 9.41        | 7.86        | 7.18         | 5.99        | 6.99         | 2.96       | 0.36        | 5.9         | 0.7           | 1.79            | 70.47        |
| DAX         | 5.86            | 7.68        | 6.78          | 1.51        | 3.24          | 2.51        | 2.43        | 8.29        | 9.93        | 7.09         | 5.89        | 6.66         | 2.86       | 0.36        | 5.8         | 0.65          | 1.84            | 69.47        |
| FMIB        | 5.57            | 7.15        | 6.81          | 1.43        | 3.1           | 2.64        | 2.4         | 8.01        | 7.45        | 10.61        | 5.5         | 7.7          | 3.17       | 0.33        | 5.28        | 0.63          | 1.67            | 68.82        |
| HEX         | 5.52            | 6.79        | 6.26          | 1.7         | 3.46          | 2.54        | 2.54        | 7.1         | 6.7         | 5.89         | 11.56       | 5.84         | 3.14       | 0.44        | 5.18        | 0.84          | 1.84            | 65.79        |
| IBEX        | 5.63            | 6.85        | 6.8           | 1.52        | 3.07          | 2.62        | 2.3         | 7.85        | 7.06        | 7.73         | 5.48        | 10.59        | 3.22       | 0.39        | 5.13        | 0.69          | 1.81            | 68.18        |
| PX          | 3.78            | 4.57        | 4.83          | 2.32        | 4.25          | 3.34        | 3.94        | 4.84        | 4.46        | 4.68         | 4.32        | 4.74         | 18         | 0.42        | 3.55        | 1.09          | 2.26            | 57.39        |
| SAX         | 0.87            | 0.91        | 0.99          | 1.25        | 1.18          | 0.85        | 0.77        | 1.01        | 0.99        | 0.87         | 1.4         | 1.11         | 1.01       | 68.4        | 0.8         | 1.55          | 1.1             | 16.65        |
| SMI         | 6.1             | 7.1         | 6.46          | 1.79        | 3.1           | 2.35        | 2.33        | 7.27        | 6.7         | 5.8          | 5.42        | 5.69         | 2.72       | 0.53        | 12.43       | 0.84          | 1.62            | 65.92        |
| SOFIX       | 1.85            | 1.81        | 1.88          | 2.39        | 1.52          | 1.44        | 1.38        | 1.95        | 1.92        | 1.7          | 2.17        | 1.84         | 2.13       | 0.99        | 1.68        | 45.78         | 1.26            | 27.92        |
| BIST 100    | 3.41            | 3.73        | 3.48          | 1.55        | 3.74          | 2.56        | 3           | 3.84        | 3.83        | 3.2          | 3.4         | 3.58         | 3.08       | 0.6         | 2.74        | 0.91          | 30.67           | 46.66        |
| TO          | 71.43           | 86.47       | 81.06         | 27.56       | 50.15         | 38.33       | 40.43       | 91.25       | 85.52       | 79.44        | 72.97       | 79.17        | 49.3       | 7.69        | 67.62       | 14.08         | 29.3            | 971.82       |
| Inc. Own    | 84.83           | 96.15       | 91.19         | 58.43       | 68.22         | 59.35       | 61.94       | 100.7       | 95.45       | 90.04        | 84.53       | 89.76        | 67.3       | 76.09       | 80.06       | 59.87         | 60.01           | cTCI/TCI     |
| Net         | 3.96            | 17.7        | 13.46         | -14.9       | -8.76         | -15.86      | -14.67      | 20.78       | 16.05       | 10.61        | 7.18        | 10.99        | -8.1       | -8.96       | 1.71        | -13.84        | -17.32          | 61/57        |
| NPDC        | 9               | 15          | 13            | 2           | 7             | 5           | 4           | 16          | 14          | 12           | 10          | 11           | 6          | 0           | 8           | 1             | 3               |              |

**Source:** Own calculations.

**Table 7.** *Yield spillover index – long term*

|             | FTSE<br>100.5-Inf | AEX.<br>5-Inf | BEL<br>20.5-Inf | BET.<br>5-Inf | WIG<br>20.5-Inf | ATH.<br>5-Inf | BUX.<br>5-Inf | CAC.<br>5-Inf | DAX.<br>5-Inf | FMIB.<br>5-Inf | HEX.<br>5-Inf | IBEX.<br>5-Inf | PX.<br>5-Inf | SAX.<br>5-Inf | SMI.<br>5-Inf | SOFIX.<br>5-Inf | BIST<br>100.5-Inf | FROM.<br>5-Inf |
|-------------|-------------------|---------------|-----------------|---------------|-----------------|---------------|---------------|---------------|---------------|----------------|---------------|----------------|--------------|---------------|---------------|-----------------|-------------------|----------------|
| FTSE<br>100 | 2.77              | 1.84          | 1.67            | 0.37          | 0.77            | 0.57          | 0.54          | 1.84          | 1.66          | 1.45           | 1.36          | 1.5            | 0.6          | 0.08          | 1.47          | 0.15            | 0.42              | 16.36          |
| AEX         | 1.68              | 2.59          | 1.97            | 0.46          | 0.86            | 0.72          | 0.62          | 2.19          | 2.05          | 1.76           | 1.61          | 1.75           | 0.83         | 0.14          | 1.55          | 0.24            | 0.53              | 18.96          |
| BEL 20      | 1.6               | 2.09          | 2.88            | 0.4           | 0.8             | 0.8           | 0.6           | 2.15          | 1.98          | 1.8            | 1.62          | 1.91           | 0.92         | 0.15          | 1.59          | 0.27            | 0.52              | 19.39          |
| BET         | 1.26              | 1.46          | 1.44            | 9.06          | 1               | 0.89          | 0.94          | 1.42          | 1.39          | 1.27           | 1.34          | 1.23           | 1.18         | 0.26          | 1.26          | 0.5             | 0.71              | 17.58          |
| WIG 20      | 1.33              | 1.58          | 1.46            | 0.59          | 4.53            | 0.86          | 1.22          | 1.63          | 1.62          | 1.39           | 1.5           | 1.5            | 1.2          | 0.2           | 1.2           | 0.3             | 0.85              | 18.49          |
| ATH         | 1.27              | 1.62          | 1.66            | 0.57          | 1.14            | 6.02          | 0.87          | 1.66          | 1.68          | 1.67           | 1.38          | 1.69           | 1.21         | 0.12          | 1.26          | 0.26            | 0.71              | 18.76          |
| BUX         | 1.16              | 1.42          | 1.4             | 0.6           | 1.61            | 0.91          | 5.5           | 1.48          | 1.48          | 1.3            | 1.31          | 1.32           | 1.46         | 0.1           | 1.1           | 0.32            | 0.82              | 17.87          |
| CAC         | 1.54              | 1.96          | 1.8             | 0.41          | 0.77            | 0.6           | 0.5           | 2.31          | 1.97          | 1.77           | 1.5           | 1.79           | 0.76         | 0.13          | 1.4           | 0.22            | 0.49              | 17.8           |
| DAX         | 1.46              | 1.98          | 1.8             | 0.4           | 0.85            | 0.7           | 0.6           | 2.11          | 2.51          | 1.7            | 1.54          | 1.74           | 0.78         | 0.14          | 1.4           | 0.23            | 0.53              | 18.09          |
| FMIB        | 1.39              | 1.84          | 1.79            | 0.44          | 0.8             | 0.76          | 0.6           | 2.03          | 1.92          | 2.56           | 1.42          | 2              | 0.84         | 0.15          | 1.26          | 0.23            | 0.51              | 18.01          |
| HEX         | 1.62              | 2.03          | 1.93            | 0.53          | 0.92            | 0.76          | 0.68          | 2.12          | 2.01          | 1.71           | 3.11          | 1.77           | 0.91         | 0.19          | 1.47          | 0.31            | 0.57              | 19.53          |
| IBEX        | 1.46              | 1.84          | 1.85            | 0.46          | 0.82            | 0.75          | 0.64          | 2.06          | 1.89          | 2.01           | 1.5           | 2.8            | 0.87         | 0.16          | 1.33          | 0.25            | 0.53              | 18.43          |
| PX          | 1.3               | 1.66          | 1.8             | 0.7           | 1.3             | 1.02          | 1.2           | 1.76          | 1.63          | 1.64           | 1.53          | 1.72           | 4.7          | 0.15          | 1.24          | 0.36            | 0.76              | 19.92          |
| SAX         | 0.13              | 0.15          | 0.14            | 0.17          | 0.17            | 0.18          | 0.13          | 0.15          | 0.16          | 0.12           | 0.17          | 0.16           | 0.13         | 12.41         | 0.15          | 0.25            | 0.19              | 2.54           |
| SMI         | 1.69              | 2.02          | 1.91            | 0.45          | 0.86            | 0.71          | 0.66          | 2.01          | 1.95          | 1.62           | 1.51          | 1.59           | 0.78         | 0.11          | 3.12          | 0.2             | 0.46              | 18.53          |
| SOFIX       | 0.91              | 0.93          | 0.94            | 0.91          | 0.62            | 0.73          | 0.56          | 0.95          | 0.92          | 0.81           | 1.08          | 0.95           | 0.95         | 0.32          | 0.73          | 13.38           | 0.61              | 12.92          |
| BIST 100    | 1.1               | 1.25          | 1.1             | 0.4           | 1.1             | 0.82          | 0.83          | 1.26          | 1.27          | 1.01           | 1.18          | 1.2            | 0.95         | 0.2           | 0.86          | 0.36            | 7.58              | September 15   |
| TO          | 20.9              | 25.67         | 24.73           | 8.13          | 14.51           | 11.86         | 11.41         | 26.83         | 25.57         | 23.13          | 21.56         | 23.83          | 14.5         | 2.72          | 19.3          | 4.48            | 9.2               | 288.27         |
| Inc. Own    | 23.67             | 28.26         | 27.62           | 17.18         | 19.04           | 17.88         | 16.93         | 29.14         | 28.08         | 25.69          | 24.67         | 26.63          | 19.2         | 15.1          | 22.43         | 17.85           | 16.78             | cTCI/TCI       |
| Net         | 4.54              | 6.71          | 5.35            | -9.45         | -3.98           | -6.91         | -6.46         | 9.02          | 7.48          | 5.12           | 2.03          | 5.4            | -5.47        | 0.18          | 0.77          | -8.44           | -5.9              | 18/17          |
| NPDC        | 10                | 14            | 10              | 1             | 6               | 5             | 3             | 16            | 15            | 12             | 8             | 11             | 5            | 10            | 8             | 0               | 2                 |                |

**Source:** Own calculations.

**Table 8. Volatility spillover index - total**

|          | FTSE<br>100.Total | AEX.<br>Total | BEL<br>20Total | BET.<br>Total | WIG 20.<br>Total | ATH.<br>Total | BUX.<br>Total | CAC.<br>Total | DAX.<br>Total | FMIB.<br>Total | HEX.<br>Total | IBEX.<br>Total | PX.<br>Total | SAX.<br>Total | SMI.<br>Total | SOFIX.<br>Total | BIST<br>100Total | FROM.<br>Total |
|----------|-------------------|---------------|----------------|---------------|------------------|---------------|---------------|---------------|---------------|----------------|---------------|----------------|--------------|---------------|---------------|-----------------|------------------|----------------|
| FTSE 100 | 20.51             | 7.47          | 6.5            | 3.16          | 4.96             | 3.7           | 3.47          | 6.48          | 5.81          | 5.88           | 6.21          | 6.13           | 4.15         | 2.69          | 6.74          | 2.93            | 3.18             | 79.49          |
| AEX      | 7.79              | 11.96         | 8.44           | 2.65          | 4.68             | 3.8           | 3.46          | 8.97          | 7.98          | 7.37           | 7.09          | 6.97           | 4.25         | 2.13          | 7.58          | 2.34            | 2.52             | 88.04          |
| BEL 20   | 7.32              | 9.15          | 13.07          | 2.77          | 4.76             | 4.27          | 3.33          | 8.4           | 6.95          | 7.59           | 6.44          | 7.21           | 4.51         | 2.13          | 7.09          | 2.36            | 2.67             | 86.93          |
| BET      | 6.47              | 4.27          | 4.86           | 24.22         | 4.85             | 4.88          | 4.62          | 3.9           | 3.66          | 4.62           | 5.82          | 4.48           | 4.96         | 3.7           | 5.3           | 4.13            | 5.25             | 75.78          |
| WIG 20   | 6.04              | 6.43          | 5.98           | 3.34          | 21.58            | 4.72          | 4.97          | 5.14          | 5.1           | 5.31           | 5.77          | 5.3            | 5.3          | 2.56          | 5.87          | 2.99            | 3.57             | 78.42          |
| ATH      | 4.82              | 5.28          | 6.1            | 4.13          | 5.14             | 23.43         | 4.03          | 4.85          | 4.33          | 6.07           | 4.5           | 5.97           | 5.33         | 3.06          | 5.72          | 3.27            | 3.95             | 76.57          |
| BUX      | 5.73              | 5.61          | 5.41           | 3.55          | 7.14             | 4.24          | 21.11         | 4.9           | 4.53          | 5.37           | 5.6           | 5.45           | 6.1          | 3.43          | 5.18          | 3.25            | 3.37             | 78.89          |
| CAC      | 7.42              | 9.31          | 8.38           | 2.82          | 4.33             | 3.79          | 3.36          | 10.96         | 8.83          | 8.56           | 6.55          | 8              | 3.99         | 2.06          | 7.1           | 2.16            | 2.37             | 89.04          |
| DAX      | 7.24              | 9.2           | 7.64           | 2.7           | 4.81             | 3.76          | 3.64          | 9.04          | 11.35         | 7.87           | 6.79          | 7.41           | 4.23         | 2.15          | 7.33          | 2.26            | 2.57             | 88.65          |
| FMIB     | 6.74              | 8.08          | 7.81           | 2.81          | 4.64             | 4.21          | 3.52          | 8.76          | 8.17          | 13.46          | 5.87          | 8.91           | 4.15         | 2.07          | 5.97          | 2.48            | 2.33             | 86.54          |
| HEX      | 6.58              | 8.23          | 7.19           | 2.83          | 4.92             | 4.09          | 3.88          | 7.55          | 7.01          | 6.73           | 14.41         | 6.64           | 4.45         | 2.7           | 6.89          | 2.95            | 2.95             | 85.59          |
| IBEX     | 6.71              | 7.67          | 7.8            | 2.63          | 4.41             | 4.29          | 3.5           | 8.62          | 7.5           | 9.29           | 6.09          | 13.28          | 4.5          | 2.17          | 6.24          | 2.45            | 2.79             | 86.72          |
| PX       | 5.83              | 5.43          | 5.88           | 3.93          | 6.32             | 5.08          | 6.25          | 5.04          | 4.44          | 5.48           | 6.52          | 5.68           | 17.4         | 4.03          | 5.35          | 3.57            | 3.81             | 82.64          |
| SAX      | 3.67              | 3.42          | 4.28           | 2.83          | 3.46             | 3.59          | 3.24          | 3.34          | 3.41          | 3.7            | 3.97          | 4.08           | 3.4          | 42.07         | 4.15          | 3.88            | 3.5              | 57.93          |
| SMI      | 7.38              | 8.51          | 7.85           | 2.88          | 4.95             | 3.96          | 3.61          | 7.38          | 6.82          | 6.55           | 6.7           | 6.22           | 4.45         | 2.25          | 14.75         | 2.64            | 3.1              | 85.25          |
| SOFIX    | 4.77              | 3.89          | 4.21           | 4.44          | 4.89             | 4.32          | 4.97          | 3.66          | 3.69          | 4.44           | 5.04          | 4.55           | 4.99         | 4.95          | 3.95          | 28.5            | 4.75             | 71.5           |
| BIST 100 | 4.93              | 4.58          | 4.53           | 3.03          | 5.19             | 4.81          | 4.76          | 4.03          | 3.63          | 4.34           | 4.92          | 4.86           | 4.51         | 3.29          | 5.21          | 3.64            | 29.73            | 70.27          |
| TO       | 99.44             | 106.5         | 102.94         | 50.49         | 79.46            | 67.51         | 64.66         | 100.1         | 91.85         | 99.16          | 93.91         | 97.87          | 73.3         | 45.36         | 95.67         | 47.31           | 52.69            | 1368.2         |
| Inc. Own | 119.95            | 118.5         | 116            | 74.71         | 101.04           | 90.94         | 85.78         | 111.0         | 103.2         | 112.62         | 108.3         | 111.14         | 90.7         | 87.4          | 110.4         | 75.81           | 82.42            | cTCI/TCI       |
| Net      | 19.95             | 18.5          | 16             | -25.3         | 1.04             | -9.06         | -14.22        | 11.03         | 3.2           | 12.62          | 8.32          | 11.14          | -9.32        | -12.56        | 10.42         | -24.19          | -17.58           | 85/80          |
| NPDC     | 16                | 15            | 13             | 1             | 7                | 5             | 4             | 14            | 11            | 11             | 8             | 9              | 4            | 4             | 11            | 0               | 3                |                |

**Source:** Own calculations.

**Table 9.** *Volatility spillover index – short term*

|             | FTSE<br>100.1-5 | AEX.<br>1-5 | BEL<br>20.1-5 | BET.<br>1-5 | WIG<br>20.1-5 | ATH.<br>1-5 | BUX.<br>1-5 | CAC.<br>1-5 | DAX.<br>1-5 | FMIB.<br>1-5 | HEX.<br>1-5 | IBEX.<br>1-5 | PX.<br>1-5 | SAX.<br>1-5 | SMI.<br>1-5 | SOFIX.<br>1-5 | BIST<br>100.1-5 | FROM.<br>1-5 |
|-------------|-----------------|-------------|---------------|-------------|---------------|-------------|-------------|-------------|-------------|--------------|-------------|--------------|------------|-------------|-------------|---------------|-----------------|--------------|
| FTSE<br>100 | 1.68            | 0.45        | 0.36          | 0.05        | 0.13          | 0.12        | 0.11        | 0.46        | 0.39        | 0.35         | 0.31        | 0.39         | 0.17       | 0.06        | 0.          | 0.1           | 0.08            | 3.83         |
| AEX         | 0.45            | 0.91        | 0.56          | 0.06        | 0.17          | 0.15        | 0.13        | 0.72        | 0.61        | 0.56         | 0.45        | 0.56         | 0.23       | 0.09        | 0.38        | 0.14          | 0.09            | 5.37         |
| BEL 20      | 0.4             | 0.67        | 1.06          | 0.06        | 0.2           | 0.          | 0.1         | 0.65        | 0.5         | 0.5          | 0.43        | 0.55         | 0.2        | 0.12        | 0.41        | 0.13          | 0.13            | 5.39         |
| BET         | 0.08            | 0.11        | 0.11          | 2.1         | 0.09          | 0.1         | 0.09        | 0.12        | 0.12        | 0.11         | 0.09        | 0.13         | 0.14       | 0.05        | 0.09        | 0.1           | 0.07            | 1.62         |
| WIG 20      | 0.2             | 0.38        | 0.33          | 0.1         | 2.07          | 0.17        | 0.2         | 0.36        | 0.37        | 0.32         | 0.34        | 0.37         | 0.3        | 0.1         | 0.2         | 0.1           | 0.1             | 4.17         |
| ATH         | 0.17            | 0.23        | 0.24          | 0.1         | 0.1           | 1.97        | 0.1         | 0.2         | 0.2         | 0.2          | 0.2         | 0.3          | 0.2        | 0.05        | 0.17        | 0.1           | 0.1             | 2.83         |
| BUX         | 0.2             | 0.3         | 0.26          | 0.09        | 0.26          | 0.1         | 1.89        | 0.3         | 0.2         | 0.29         | 0.31        | 0.3          | 0.3        | 0.12        | 0.21        | 0.18          | 0.16            | 3.8          |
| CAC         | 0.46            | 0.72        | 0.55          | 0.06        | 0.15          | 0.16        | 0.13        | 0.95        | 0.7         | 0.6          | 0.47        | 0.6          | 0.2        | 0.09        | 0.38        | 0.14          | 0.08            | 5.63         |
| DAX         | 0.43            | 0.68        | 0.49          | 0.07        | 0.15          | 0.14        | 0.12        | 0.78        | 1.02        | 0.65         | 0.48        | 0.65         | 0.25       | 0.08        | 0.36        | 0.15          | 0.06            | 5.53         |
| FMIB        | 0.41            | 0.63        | 0.54          | 0.06        | 0.15          | 0.16        | 0.13        | 0.76        | 0.67        | 1.13         | 0.44        | 0.76         | 0.24       | 0.08        | 0.32        | 0.16          | 0.07            | 5.57         |
| HEX         | 0.35            | 0.57        | 0.42          | 0.05        | 0.16          | 0.18        | 0.15        | 0.6         | 0.56        | 0.48         | 1.39        | 0.6          | 0.32       | 0.11        | 0.33        | 0.18          | 0.09            | 5.17         |
| IBEX        | 0.43            | 0.65        | 0.53          | 0.07        | 0.16          | 0.21        | 0.16        | 0.77        | 0.67        | 0.75         | 0.54        | 1.22         | 0.31       | 0.12        | 0.36        | 0.2           | 0.09            | 6.01         |
| PX          | 0.2             | 0.31        | 0.25          | 0.1         | 0.1           | 0.2         | 0.1         | 0.3         | 0.3         | 0.2          | 0.3         | 0.3          | 1.4        | 0.08        | 0.19        | 0.17          | 0.11            | 3.6          |
| SAX         | 0.1             | 0.1         | 0.1           | 0.04        | 0.07          | 0.08        | 0.09        | 0.17        | 0.16        | 0.16         | 0.18        | 0.21         | 0.12       | 3.87        | 0.09        | 0.13          | 0.07            | 2            |
| SMI         | 0.38            | 0.53        | 0.42          | 0.06        | 0.15          | 0.16        | 0.14        | 0.54        | 0.47        | 0.41         | 0.39        | 0.46         | 0.21       | 0.09        | 1.09        | 0.14          | 0.09            | 4.63         |
| SOFIX       | 0.21            | 0.23        | 0.15          | 0.11        | 0.08          | 0.11        | 0.11        | 0.24        | 0.23        | 0.23         | 0.24        | 0.28         | 0.19       | 0.09        | 0.11        | 2.21          | 0.05            | 2.67         |
| BIST 100    | 0.15            | 0.2         | 0.1           | 0.07        | 0.1           | 0.1         | 0.16        | 0.19        | 0.17        | 0.16         | 0.19        | 0.22         | 0.2        | 0.07        | 0.15        | 0.1           | 2.4             | 2.5          |
| TO          | 4.7             | 6.85        | 5.53          | 1.14        | 2.37          | 2.48        | 2.27        | 7.22        | 6.4         | 6.2          | 5.44        | 6.87         | 3.67       | 1.38        | 4.1         | 2.24          | 1.47            | 70.35        |
| Inc. Own    | 6.41            | 7.76        | 6.6           | 3.2         | 4.43          | 4.44        | 4.16        | 8.17        | 7.42        | 7.33         | 6.83        | 8.08         | 5.16       | 5.25        | 5.19        | 4.45          | 3.93            | cTCI/TCI     |
| Net         | 0.89            | 1.49        | 0.14          | -0.48       | -1.8          | -0.36       | -1.54       | 1.59        | 0.87        | 0.6          | 0.27        | 0.86         | 0.08       | -0.63       | -0.53       | -0.43         | -1.06           | 4.40         |
| NPDC        | 15              | 15          | 10            | 4           | 1             | 6           | 1           | 15          | 13          | 10           | 10          | 12           | 8          | 3           | 6           | 5             | 2               |              |

**Source:** Own calculations.

**Table 10.** *Volatility spillover index – long term*

|          | FTSE<br>100.5-Inf | AEX.<br>5-Inf | BEL<br>20.5-Inf | BET.<br>5-Inf | WIG<br>20.5-Inf | ATH.<br>5-Inf | BUX.<br>5-Inf | CAC.<br>5-Inf | DAX.<br>5-Inf | FMIB.<br>5-Inf | HEX.<br>5-Inf | IBEX.<br>5-Inf | PX.<br>5-Inf | SAX.<br>5-Inf | SMI.<br>5-Inf | SOFIX.<br>5-Inf | BIST<br>100.5-Inf | FROM.<br>5-Inf |
|----------|-------------------|---------------|-----------------|---------------|-----------------|---------------|---------------|---------------|---------------|----------------|---------------|----------------|--------------|---------------|---------------|-----------------|-------------------|----------------|
| FTSE 100 | 18.83             | 7.02          | 6.19            | 3.11          | 4.82            | 3.58          | 3.35          | 6.03          | 5.42          | 5.52           | 5.9           | 5.74           | 3.98         | 2.63          | 6.44          | 2.82            | 3.11              | 75.66          |
| AEX      | 7.34              | 11.05         | 7.88            | 2.6           | 4.51            | 3.65          | 3.33          | 8.25          | 7.37          | 6.81           | 6.64          | 6.4            | 4.03         | 2.03          | 7.2           | 2.2             | 2.43              | 82.67          |
| BEL 20   | 6.91              | 8.48          | 12.01           | 2.71          | 4.55            | 4.07          | 3.15          | 7.74          | 6.46          | 7.05           | 6.01          | 6.66           | 4.28         | 2.02          | 6.67          | 2.23            | 2.54              | 81.54          |
| BET      | 6.39              | 4.16          | 4.75            | 22.12         | 4.76            | 4.77          | 4.53          | 3.78          | 3.54          | 4.52           | 5.73          | 4.36           | 4.82         | 3.65          | 5.2           | 4.03            | 5.18              | 74.16          |
| WIG 20   | 5.78              | 6.05          | 5.65            | 3.24          | 19.51           | 4.55          | 4.71          | 4.78          | 4.72          | 4.98           | 5.42          | 4.93           | 5.05         | 2.47          | 5.62          | 2.85            | 3.44              | 74.26          |
| ATH      | 4.65              | 5.05          | 5.87            | 4.03          | 5.02            | 21.46         | 3.91          | 4.61          | 4.13          | 5.83           | 4.29          | 5.67           | 5.1          | 3.01          | 5.55          | 3.18            | 3.8               | 73.74          |
| BUX      | 5.52              | 5.31          | 5.15            | 3.45          | 6.88            | 4.07          | 19.22         | 4.61          | 4.25          | 5.09           | 5.32          | 5.09           | 5.77         | 3.31          | 4.97          | 3.06            | 3.21              | 75.08          |
| CAC      | 6.96              | 8.59          | 7.83            | 2.75          | 4.19            | 3.64          | 3.23          | 10.01         | 8.12          | 7.89           | 6.08          | 7.34           | 3.77         | 1.98          | 6.72          | 2.02            | 2.29              | 83.41          |
| DAX      | 6.8               | 8.52          | 7.15            | 2.64          | 4.66            | 3.62          | 3.53          | 8.26          | 10.33         | 7.23           | 6.31          | 6.76           | 3.98         | 2.07          | 6.98          | 2.11            | 2.51              | 83.12          |
| FMIB     | 6.33              | 7.45          | 7.28            | 2.75          | 4.49            | 4.05          | 3.38          | 8             | 7.5           | 12.34          | 5.43          | 8.16           | 3.92         | 1.99          | 5.65          | 2.32            | 2.26              | 80.97          |
| HEX      | 6.23              | 7.66          | 6.77            | 2.78          | 4.76            | 3.91          | 3.74          | 6.95          | 6.45          | 6.24           | 13.02         | 6.02           | 4.13         | 2.59          | 6.56          | 2.77            | 2.86              | 80.43          |
| IBEX     | 6.28              | 7.02          | 7.27            | 2.56          | 4.25            | 4.07          | 3.38          | 7.85          | 6.83          | 8.54           | 5.55          | 12.06          | 4.19         | 2.06          | 5.88          | 2.25            | 2.7               | 80.71          |
| PX       | 5.61              | 5.12          | 5.63            | 3.83          | 6.14            | 4.88          | 6.08          | 4.73          | 4.14          | 5.19           | 6.18          | 5.31           | 15.9         | 3.95          | 5.16          | 3.4             | 3.7               | 79.04          |
| SAX      | 3.56              | 3.24          | 4.13            | 2.78          | 3.39            | 3.51          | 3.15          | 3.18          | 3.25          | 3.54           | 3.78          | 3.87           | 3.27         | 38.2          | 4.06          | 3.75            | 3.43              | 55.92          |
| SMI      | 7                 | 7.99          | 7.43            | 2.81          | 4.8             | 3.8           | 3.47          | 6.84          | 6.35          | 6.14           | 6.31          | 5.76           | 4.24         | 2.16          | 13.66         | 2.51            | 3.01              | 80.62          |
| SOFIX    | 4.56              | 3.66          | 4.06            | 4.34          | 4.82            | 4.21          | 4.85          | 3.42          | 3.46          | 4.2            | 4.8           | 4.2            | 4.79         | 4.85          | 3.83          | 26.3            | 4.7               | 68.82          |
| BIST 100 | 4.7               | 4.3           | 4.36            | 2.96          | 5.04            | 4.66          | 4.61          | 3.84          | 3.45          | 4.17           | 4.73          | 4.63           | 4.31         | 3.22          | 5.06          | 3.54            | 27.27             | 67.74          |
| TO       | 94.71             | 99.69         | 97.4            | 49.35         | 77.09           | 65.03         | 62.4          | 92.86         | 85.45         | 92.95          | 88.47         | 91             | 69.6         | 43.99         | 91.57         | 45.06           | 51.22             | 1297.9         |
| Inc.Own  | 113.54            | 110.7         | 109.41          | 71.46         | 96.6            | 86.49         | 81.62         | 102.9         | 95.78         | 105.29         | 101.5         | 103.06         | 85.5         | 82.19         | 105.2         | 71.36           | 78.5              | cTCI/TCI       |
| Net      | 19.06             | 17.02         | 15.86           | -24.8         | 2.83            | -8.71         | -12.69        | 9.45          | 2.33          | 11.99          | 8.05          | 10.29          | -9.4         | -11.94        | 10.95         | -23.76          | -16.52            | 81.12/76.35    |
| NPDC     | 16                | 15            | 14              | 1             | 7               | 5             | 4             | 13            | 11            | 11             | 8             | 9              | 4            | 4             | 11            | 0               | 3                 |                |

**Source:** Own calculations.

## Co-movement and causality among exchange rates: a wavelet analysis

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**Abstract.** *This paper investigates the dynamic co-movement and causality among the daily returns of four currency pairs: USD/INR, EUR/INR, GBP/INR, and JPY/INR, covering the period from 2000 to 2024. Using Wavelet Power Spectrum (WPS) and Wavelet Coherence Analysis (WCA), we explore the relationships and causal dynamics between these currency pairs across various time scales. Our findings reveal significant coherence among the currency pairs from 2008 to 2019, likely influenced by global events such as the 2008 financial crisis. The findings also reveal that the majority of the pairs exhibit positive and strong co-movement across different scales. Finally, bidirectional causality is observed between USD and EUR, while the other pairs exhibit either unidirectional causality or independent movements.*

**Keywords:** co-movement, causality, exchange rates, returns, wavelet analysis.

**JEL Classification:** C10, C58, F31, G11, G15.

## 1. Introduction

Foreign exchange rate co-movement is a crucial concept in international finance. It has sparked growing interest among investors and financial analysts due to its significant implications for global trade and investment. In currency markets, understanding co-movement is essential for optimizing portfolio diversification strategies in both domestic and international settings. Much like stock markets, foreign exchange markets exhibit interconnected dynamics that influence asset allocation and risk management. The effective co-movement between currency pairs increases the ability to predict exchange rate trends, playing a critical role in risk management and expected returns. Currency markets have become highly integrated, forming complex relationships across regions and time frames. This interconnectedness allows investors to adjust their strategies based on currency fluctuations and global economic conditions. Technological advancements have accelerated this integration, providing real-time data flows that drive periods of both synchronized and independent movement in currency markets. However, the inherent volatility of exchange rates and the scarcity of reliable information make it difficult for investors to anticipate market movements with certainty. Despite increasing focus on financial markets, co-movement in exchange rates has received relatively limited attention, with only a handful of studies addressing this topic (Kuşkaya et al., 2022; Kumar et al., 2016; Yang et al., 2016; Nikkinen et al., 2011). This presents an exciting opportunity to explore exchange rate co-movement, particularly in the time-frequency domain, given the limited existing literature in this area.

On the econometric side, most previous studies have relied on traditional methods, such as correlation coefficients (Negro et al., 2004), co-integration techniques, and error correction models (Arouri et al., 2013). Other approaches, like the copula model (Nguyen et al., 2013; Samarakoon, 2011) and ARCH/GARCH frameworks (Hammoudeh et al., 2015; Ito et al., 1994; Mensi et al., 2016; Theodossiou et al., 1993), have been applied to investigate stock market co-movement. While these models have proven useful, they often produce mixed results and are not well-suited to capturing co-movement across multiple time frequencies, which is an important concern for portfolio managers (Hkiri et al., 2014). Additionally, long-term co-integration may not be enough to understand the complexities of exchange rate dynamics, especially when short-term fluctuations and broader time-frequency interactions are considered. As a result, predicting the dynamic co-movement and causality in foreign exchange markets remains a complex yet vital task for financial practitioners and researchers. Unlike traditional approaches, co-integration examines long-term equilibrium relationships between exchange rates, which are influenced by a wide range of complex and interconnected economic and political factors. Exchange rates are also categorized by noise and non-stationarity, making them difficult to forecast using classical statistical methods. As Daubechies (1990) suggested, wavelet transform or wavelet analysis is an effective tool for analysing time series with non-stationary properties across different frequencies. One of the important strengths of wavelet analysis is its ability to examine relationships between variables from both time and frequency perspectives simultaneously. This allows the separation of currency movements into various frequency components, enabling a more detailed study of their dynamics. Building on this approach, in this paper, we examine the dynamic co-movement and causality in daily returns of USD/INR,



EUR/INR, GBP/INR, and JPY/INR currency pairs using the wavelet coherence approach. This study is expected to contribute to the existing literature by exploring the relatively under-researched area of co-movement and causality in exchange rates. Applying the wavelet coherence approach, to analyse the time-frequency dynamics of exchange rate co-movement.

The structure of this study is outlined as follows: Section 2 describes the methodology employed and details the dataset used for wavelet analysis. Section 3 presents the empirical results and discussion of the key findings. Lastly, Section 4 provides a summary of the main findings and concludes the study.

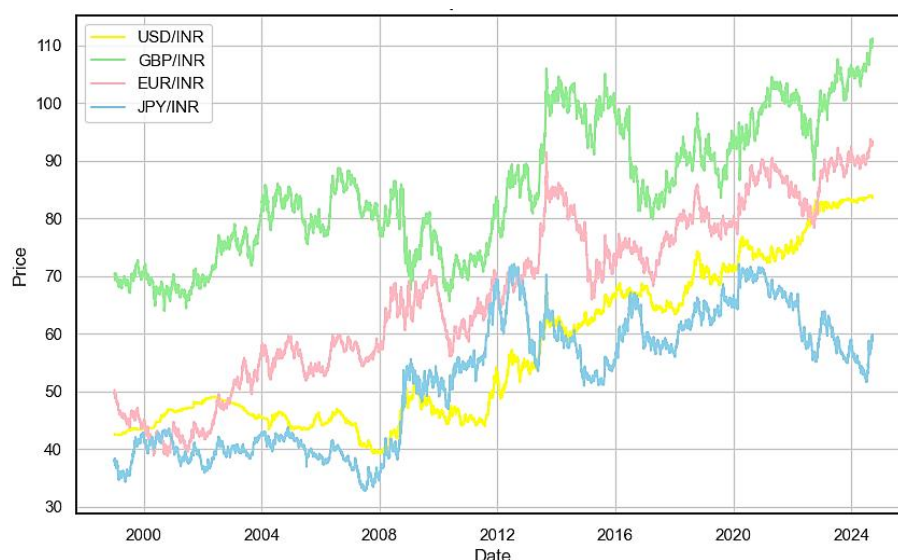
## 2. Research Methodology

This section presents the theoretical framework, empirical methodology, and the data used in the study, followed by an explanation of the wavelet analysis process. We start by describing the data.

### 2.1. Data

This study investigates the dynamic co-movement and causality in the daily returns of selected currency pairs using the wavelet coherence approach. The dataset includes daily exchange rates of four major currency pairs, namely USD/INR, EUR/INR, GBP/INR, and JPY/INR, covering the period from 1 April 1999 to 20 September 2024. This time frame spans 6222 daily observations and was selected based on data availability from the Reserve Bank of India (RBI). The exchange rate data are sourced entirely from the official website of the RBI ([rbi.org.in](http://rbi.org.in)).

**Figure 1.** *Daily time series of exchange rates*



**Source:** Developed by the author(s).

The dataset consists of daily exchange rates between the Indian Rupee (INR) and the US Dollar (USD), Euro (EUR), British Pound (GBP), and Japanese Yen (JPY). These currency pairs are chosen due to their significance in India's foreign trade, investment flows, and overall economic interactions. They represent India's primary economic partners and have a major influence on its foreign exchange market and the value of the INR. Figure 1 shows the daily exchange rate trends of all the selected currency pairs over the study period. Consequently, this study is expected to provide insights into how global economic trends and bilateral relationships impact India's exchange rate dynamics.

## 2.2. Data Transformation

To analyse the currency returns, we computed the daily returns using the first differences of the natural logarithms of exchange rates. The returns formula is expressed as:

$$R_t = \log \left( \frac{P_t}{P_{t-1}} \right) \times 100$$

where  $R_t$  represents the currency returns on day  $t$ , while  $P_t$  and  $P_{t-1}$  represent the exchange rate levels at time  $t$  and  $t-1$ , respectively. The returns are expressed as percentages by multiplying the logarithmic differences by 100. This method allows us to normalize the data and ensure comparability across the different currency pairs.

## 2.3. Wavelet Analysis

The Wavelet methodology is a mathematical approach increasingly used in various fields, including economics and finance, for modeling time series data. Unlike the traditional Fourier Analysis, which cannot capture time-dependent changes in a signal, the wavelet transform offers the advantage of representing a signal in both time and frequency domains (Caraiani 2012). Wavelets are oscillating functions that decay over time, making them effective filters for decomposing signals into different resolution levels. This process, known as multi-resolution decomposition, allows the analysis of both large and small features in a time series, with each level corresponding to a specific time scale. The application of wavelets is particularly useful for non-stationary phenomena – those that exhibit time-varying characteristics and do not maintain a constant mean or variance. In addition to its frequency and time domain features, this emerging method addresses econometric synergy by overcoming issues related to error terms and structural breaks (Antonakakis et al., 2017; Yang et al., 2017). This versatility has led to their widespread use in disciplines such as geophysics, medicine, statistics, economics, and finance. Ftiti et al. (2016) emphasized some benefits of wavelets, including their ability to decompose data into different frequency components, which made it easier to identify seasonality, structural changes, volatility clusters, and local and global dynamics Nini et al., (2023). However, Dibal et al. (2018) pointed out drawbacks such as redundancy, high computational demand, and imperfect signal reconstruction.

This study attempts to examine the co-movement among USD/INR, EUR/INR, GBP/INR, and JPY/INR currency pairs to understand their linkages across different time horizons (short, medium, and long-term). The wavelet coherency method, as proposed by Grinsted et al. (2004), allows for decomposing these relationships into time-frequency components.

It can be applied in both bivariate and multivariate analyses to explore covariation and causal relationships across different scales over time. Similar to the Pearson Bivariate Correlation Coefficient, wavelet coherence measures the degree of co-movement in the time-frequency domain between two time series (Singh et al. 2022).

#### 2.4. The Continuous Wavelet Transform (CWT)

The CWT is a multiresolution analysis technique that focuses on the dilation and contraction of wavelet functions (Sahabuddin et al., 2022). The wavelet technique decomposes return series into time-scale components while capturing the variability and structure of stochastic processes at each scale. A wavelet is a small wave that can be stretched or compressed to extract frequency components from a complex signal (Bouri et al. 2020).

The mother wavelet, which generates these smaller waves, is defined by time and scale  $s$  as:

$$\psi_{\tau,s}(t) = \frac{1}{\sqrt{s}} \psi\left(\frac{t - \tau}{s}\right)$$

Here,  $\tau$ ,  $s$ , and  $1/\sqrt{s}$  represent the translation parameter, dilation parameter, and normalization factor, respectively.  $\psi_{\tau,s}(t)$  are elementary functions derived from the wavelet transform of a time series, obtained from a time-localized mother wavelet  $\psi(t)$ .

To analyse wavelet coherence among USD/INR, EUR/INR, GBP/INR, and JPY/INR currency pairs, the Morlet Wavelet is applied (Morlet et al. 1982). This wavelet comprises both smooth (father) and detailed (mother) functions within the wavelet family and provides an optimal balance between time and frequency localization. Grinsted et al. (2004) noted that the Fourier period for the Morlet wavelet closely matches the scale used:

$$\psi^M(t) = \frac{1}{\pi^{1/4}} e^{i\omega_0 t} e^{-t^2/2}$$

In this context,  $\pi^{1/4}$  preserves wavelet energy within a band while maintaining the central frequency. The term  $\omega_0$  refers to the localizations that balance time and frequency. Also,  $e^{-t^2/2}$  represents the Gaussian envelope, while  $e^{i\omega_0 t}$  denotes a complex analytic wavelet.

#### 2.5. Wavelet Power Spectrum

Wavelet analysis can use either continuous (CWT) or discrete wavelet transforms (DWT). The CWT has advantage of flexibility in wavelet selection based on data length and its redundancy. The CWT of a discrete-time series  $x(t)$ , where  $t = 0, 1, \dots, n$ , with respect to  $\psi(t)$ , is given by:

$$W_x(\tau, s) = \frac{1}{\sqrt{s}} \int_{-\infty}^{+\infty} x(t) \psi^* \left( \frac{t - \tau}{s} \right) dt$$

Here,  $*$  represents the complex conjugate. The wavelet power spectrum (WPS) measures the relative contribution of each time and scale to a time series' variance, represented as  $|W_x(\tau, s)|^2$ . The WPS was used in this paper to analyse the behavior of the time series.

Wavelet transform preserves the energy of a time series, making it useful for power spectrum analysis. The total variance is calculated by integrating across both time ( $\tau$ ) and scale ( $s$ ), and is expressed as:

$$\sigma_x^2 = \frac{1}{C_\psi} \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} |W_x(\tau, s)|^2 \frac{d\tau ds}{s^2}$$

As stated above, the cross-wavelet spectrum is notable for revealing co-movement between two series in both frequency and time. Through analysing the contour plot of the wavelet cross-spectrum, one can identify the time-frequency regions where the series co-move and assess the variation in co-movement over time and frequency.

## 2.6. Wavelet Coherence

The cross-wavelet power identifies areas of strong shared power between two time series in the time-frequency domain. The wavelet squared coherence between the two series is defined as:

$$R_{xy}^2(\tau, s) = \frac{|S(s^{-1}W_{xy}(\tau, s))|^2}{S(s^{-1}|W_x(\tau, s)|^2) \cdot S(s^{-1}|W_y(\tau, s)|^2)}$$

The term  $R_{xy}^2(\tau, s)$  is a measure of contemporaneous correlations between  $x(t)$  and  $y(t)$  at each time point and frequency. The function  $S(\cdot)$  is a smoothing parameter for scale and time. The value of  $R_{xy}^2(\tau, s)$  ranges from zero (indicating no co-movement) to one (indicating high co-movement), reflecting a scale-specific squared correlation between the two series. The wavelet coherence framework helps the analysis of lead-lag relationships between series, overcoming the limitation of squared coherence in distinguishing between positive and negative correlations. Phase differences, which span the entire time frame for frequency band functions, provide clear idea into these lead-lag relationships. They are represented by arrows that indicate positive or negative correlations in both frequency and time domains. According to Webster et al., (1999) and Bloomfield (2013), the phase relationship between  $x(t)$  and  $y(t)$  is expressed as:

$$\phi_{xy}(\tau, s) = \tan^{-1} \frac{\Im\{W_{xy}(\tau, s)\}}{\Re\{W_{xy}(\tau, s)\}}, \phi_{x,y} \in [-\pi, \pi]$$

In this context, the parameters  $\Im$  and  $\Re$  represent the imaginary and real parts of the smoothed power spectrum, respectively. A zero-degree phase difference indicates synchronization between  $x(t)$  with  $y(t)$  at a specific time-frequency. In wavelet coherence plots,  $\phi_{xy}(\tau, s)$  is demonstrated with arrows – rightward, leftward, upward, and downward – within statistically significant areas. A rightward arrow suggests that  $x(t)$  and  $y(t)$  are in phase and positively associated, while a leftward arrow indicates they are out of phase and negatively associated, with minimal time lag. An upward arrow signifies that the first series leads the second by  $\pi/2$ , and a downward arrow indicates the opposite.

The results of wavelet coherence are generally presented in a chart where time and frequency (or scale) are plotted on the respective axes. The degree of association (co-

movement) between the two analysed time series is represented by a color gradient. Warmer colors, such as red, indicate strong co-movements, while cooler colors, like blue, signify weak co-movements. Areas located outside the black line, known as the cone of influence, indicate that the estimates of wavelet coefficients are statistically insignificant at the 5% significance level and are therefore not considered in the analysis.

### 3. Empirical results and Discussion

In this section, we begin with preliminary statistical analysis, which includes descriptive statistics for each series, normality tests, serial correlation tests, and graphical representations, as detailed in Subsection 3.1.

#### 3.1. Preliminary Analysis

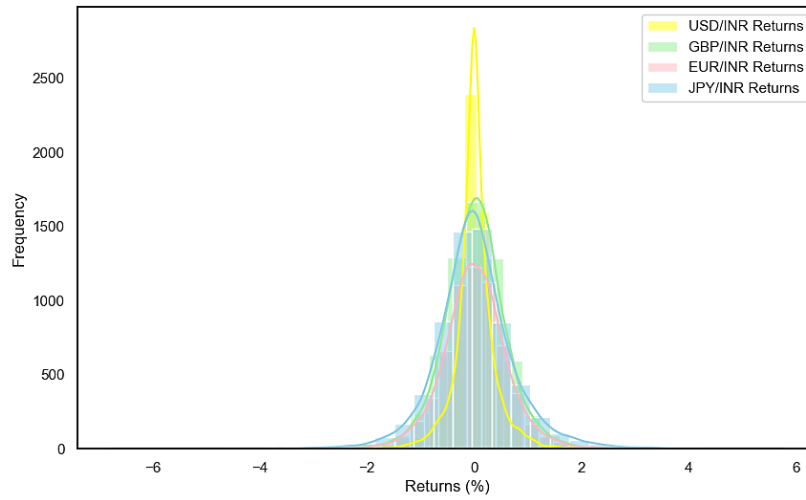
**Table 1.** Summary statistics for the return series of currency pairs

|                                  | USD/INR             | GBP/INR             | EUR/INR            | JPY/INR            |
|----------------------------------|---------------------|---------------------|--------------------|--------------------|
| <b>Descriptive statistics:</b>   |                     |                     |                    |                    |
| Mean                             | 0.0109              | 0.0074              | 0.0099             | 0.0073             |
| Standard Deviation               | 0.3858              | 0.6104              | 0.6146             | 0.7557             |
| Minimum                          | -0.1409             | -0.3325             | -0.3446            | -0.3978            |
| Maximum                          | 0.1562              | 0.3471              | 0.3547             | 0.3776             |
| Skewness                         | 4.0200              | 3.6789              | 4.1545             | 5.7640             |
| Kurtosis                         | 0.2094              | -0.5519             | 0.0529             | 0.3035             |
| <b>Normality tests:</b>          |                     |                     |                    |                    |
| Jarque-Bera test                 | 18174.13<br>(0.000) | 12629.12<br>(0.000) | 1754.12<br>(0.000) | 4228.04<br>(0.000) |
| Shapiro-Wilk test                | 0.8986<br>(0.000)   | 0.9552<br>(0.000)   | 0.9779<br>(0.000)  | 0.9564<br>(0.000)  |
| Kolmogorov-Smirnov test          | 0.2579<br>(0.000)   | 0.1521<br>(0.000)   | 0.1439<br>(0.000)  | 0.1147<br>(0.000)  |
| <b>Serial correlation tests:</b> |                     |                     |                    |                    |
| Ljung-Box test                   | 45.75<br>(0.000)    | 23.70<br>(0.0084)   | 19.71<br>(0.0321)  | 17.24<br>(0.0691)  |
| Breusch-Godfrey test             | 44.40<br>(0.000)    | 23.22<br>(0.00995)  | 19.98<br>(0.02945) | 17.24<br>(0.06925) |

**Note:** The values in the parentheses are p-values.

**Source:** Author(s) calculation.

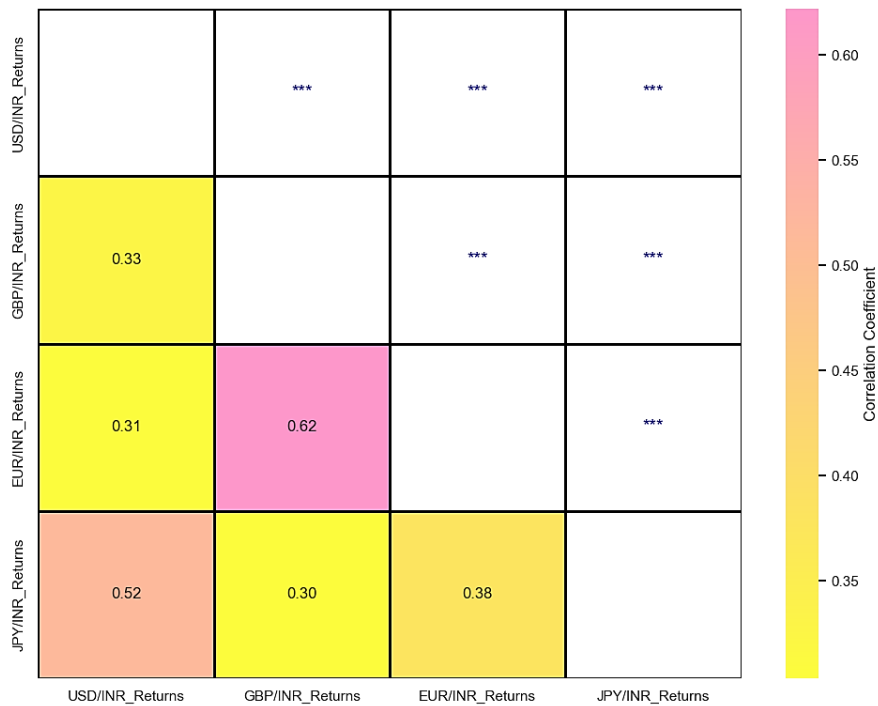
We start by presenting summary statistics for the return series of each currency pair. Table 1 summarizes the daily return statistics for four currencies, namely USD, EUR, GBP, and JPY, relative to the INR. Among these, the USD/INR pair stands out with the highest average return and the lowest volatility, indicating both favorable and stable performance compared to the others. The JPY shows the lowest average daily returns among the currencies. Additionally, JPY returns are the most volatile within the group, with a standard deviation of 0.76%. All currency pairs are positively skewed, representing a longer tail on the right side of the distribution. On the other hand, only GBP/INR has a negative kurtosis value, indicating a flatter distribution. The hypothesis of normality of the unconditional distribution for all currency pairs are rejected, confirming the presence of outliers and non-standard behaviors in each series. This can also be seen in Figure 2. With the exception of JPY/INR, all the other pairs show strong autocorrelation in both the return series and the squared return series.

**Figure 2.** *Distribution of returns series of currency pairs*

**Source:** Developed by the author(s).

### 3.2. Unconditional Correlation Analysis

Figure 3 presents the pairwise correlations across the returns of the currencies considered.

**Figure 3.** *Unconditional correlation matrix*

**Source:** Developed by the author(s).

All currency pairs show positive, significant, and moderate correlations with one another. The highest association is observed between EUR/INR and GBP/INR at 62%, followed by JPY/INR and USD/INR at 52%, among others.

### 3.3. Non-Stationarity Tests

The results of the unit root tests for the return series of the currency pairs, using the Augmented Dickey-Fuller (ADF) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests, are presented in Table 2. For all the currency pairs, highly significant negative statistics with p-values below the significance level are shown by the ADF test results. In contrast, relatively low KPSS test statistics with p-values greater than 5% are observed. Together, these results confirm that the return series for all currency pairs are stationary, as the absence of a unit root is suggested by both tests.

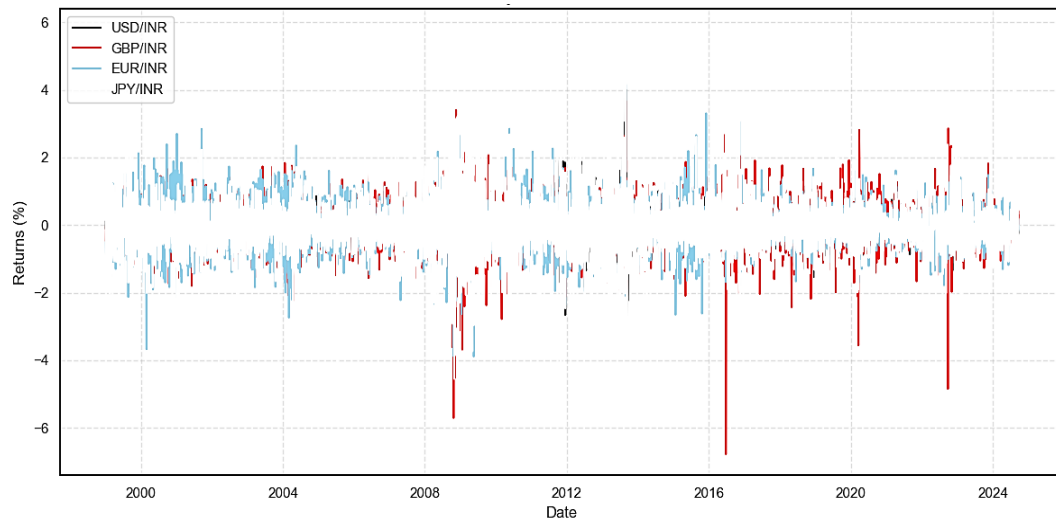
Furthermore, the time-series plot of the returns in Figure 4 provides additional visual confirmation of the absence of a unit root, reinforcing the stationarity of the data.

**Table 2.** Unit root test for the return series of currency pairs

| Currency | Augmented Dickey-Fuller (ADF) test |         | Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test |         |
|----------|------------------------------------|---------|-----------------------------------------------|---------|
|          | Statistic                          | p-value | Statistic                                     | p-value |
| USD/INR  | -14.2430                           | 0.0000  | 0.1258                                        | 0.1000  |
| GBP/INR  | -17.6173                           | 0.0000  | 0.0361                                        | 0.1000  |
| EUR/INR  | -26.5274                           | 0.0000  | 0.0419                                        | 0.1000  |
| JPY/INR  | -81.4603                           | 0.0000  | 0.0706                                        | 0.1000  |

**Source:** Author(s) calculation.

**Figure 4.** Daily returns series of currency pairs



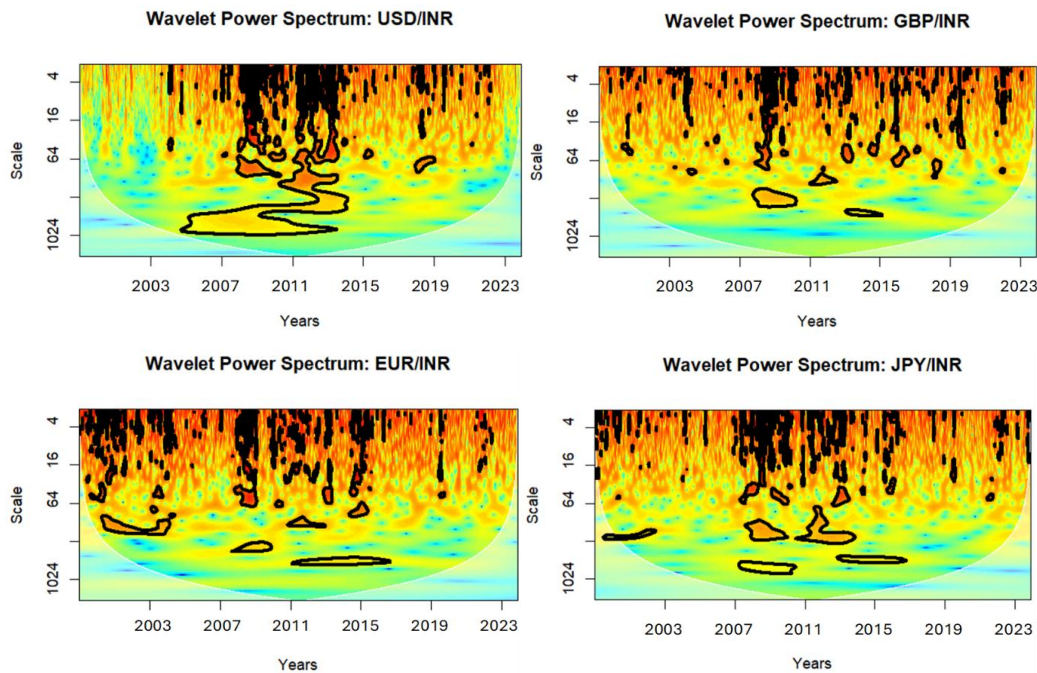
**Source:** Developed by the author(s).

### 3.4. Wavelet Power Spectrum

Figure 5 demonstrates the wavelet power spectrum for USD/INR, EUR/INR, GBP/INR, and JPY/INR returns from 2000 to 2024. The scale represents different frequencies, with lower values (4-16) representing short-term fluctuations and higher values (1024) corresponding to long-term variations. Orange areas indicate high power and strong volatility, while light blue/green areas signify low power, reflecting periods of stability.

For the USD/INR series, the early period from 2000 to 2004 displays a relatively stable market, with mostly blue/green regions reflecting minimal volatility. However, volatility begins to rise around 2005, peaking between 2009 and 2013 (where noticeable short-term fluctuations dominate the spectrum). A more turbulent period follows from 2019 to 2021, with significant medium- and long-term volatility, especially between 64-16 scales. By 2022 and 2023, volatility diminishes, though some medium-term instability remains.

**Figure 5.** *Wavelet power spectrum*



**Source:** Developed by the author(s).

Turning to GBP/INR, long-term fluctuations become more significant during 2008-2015. The shorter and medium-term volatility, on the other hand, is a consistent feature across the entire time frame. The EUR/INR series demonstrates clear instability from 2000 to 2005, where volatility peaks at low and medium frequencies. Between 2008 and 2017, volatility becomes more widespread, influencing the entire frequency spectrum, indicating continuous market disturbances during this time. Lastly, the JPY/INR series reveals significant market fluctuations from 2007 to 2017, with high volatility across all

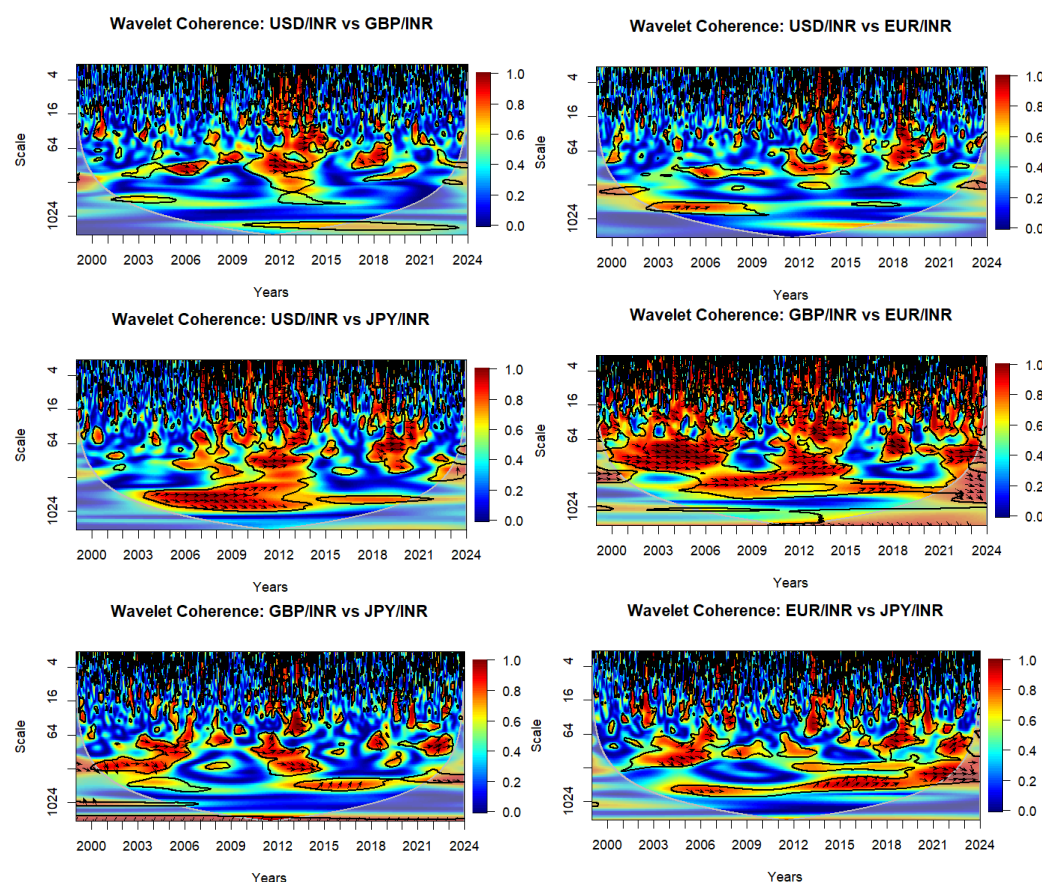


frequencies. Notable short-term fluctuations appear in 2019 and 2023, while the early period (2000-2002) experiences both short- and medium-term volatility.

### 3.5. Wavelet Coherence Approach

The wavelet coherence approach is applied to capture the causal relationship between the return series of selected currency pairs. Figure 6 present the results from the wavelet coherence and phase difference between each time series pair. This shows the co-movement of these four currency pairs in the time-frequency space. The x-axis represents time (in days), and the y-axis represents the frequency domain. The analysis considers five frequency bands, namely 1–4 days (short-term relationship), 4–16 days, 16–64 days, 64–256 days (medium-term relationship), and 256–1024 days (long-term relationship). The color gradient on the right is coherence, with dark blue indicating low power and dark red indicating high power (close to one). The arrows represent the phase relationship, show the direction of influence or lead-lag dynamics between two currencies.

**Figure 6.** *Wavelet coherence dynamic.*



**Source:** Developed by the author(s).

From 2008 to 2019, high coherence across all scales is observed for most pairs, likely due to global events like the 2008 financial crisis. Lions' share arrows point right or up-right, indicating positive relationships during those periods. The wavelet coherence shows up arrows in 2002 and 2004, suggesting that USD/INR positively influenced GBP/INR in the medium term. Between 2000-2005, the return series did not move consistently together, except for occasional coherence above 16 days, indicating a weak long-term association. USD/INR and EUR/INR had a strong positive relationship from 2009 to 2016 and again from 2019 to 2021, mainly across short and medium scales. A similar pattern is noted from 2004 to 2006, but only over the long term. However, overall long-term coherence is weak, except during 2004-2006. A strong connection between USD/INR and JPY/INR is observed from 2003 to 2014, with multi-scale coherence from 2010 to 2014. The return series of GBP/INR and EUR/INR show positive and stronger co-movement across all scales from the beginning to the end of the period. In contrast, GBP/INR and JPY/INR exhibit medium to long-term negative association during 2000-2005 and 2012-2014, but a positive association from 2015-2017 and 2021-2023. Similarly, EUR/INR and JPY/INR display negative association in the medium to long term between 2003-2008 and 2020-2024.

### 3.6. Wavelet-Based Decomposition Granger Causality Analysis

In this study, wavelet-based decomposed Granger Causality tests are used to verify the robustness of the Continuous Wavelet Transform (CWT) and Wavelet Coherence (WC) analysis results. The tests are applied to twelve currency return pairs, and the results are presented in Figure 7.

The results show a combination of bidirectional and unidirectional causality across the

**Figure 7.** Granger causality test results



**Source:** Developed by the author(s).

currency pairs, with some pairs moving independently. Only USD and EUR have bidirectional causality between each other, indicating that changes in both currency pairs can influence one another. There is no significant causality in either direction between USD-JPY and GBP-EUR, suggesting that these currency pairs move independently. USD-GBP, GBP-JPY, and JPY-EUR show unidirectional causality, implying that the past movements in USD, GBP, and JPY can predict GBP, JPY, and EUR, respectively, but not vice versa.

#### 4. Summary and conclusions

In this study, an attempt has been made to analyse the co-movement of major currency pairs (USD, EUR, GBP, JPY) against the INR from 2000 to 2024 using wavelet power spectrum and coherence across short, medium, and long-term frequencies. The findings reveal dynamic changes in volatility over time and across scales. The USD experienced stable periods in the early 2000s, with sensitive volatility during 2009-2013 and 2019-2021. The GBP showed consistent medium-term volatility, while the EUR faced market instability from 2000-2005, with extensive volatility from 2008-2017. On the other hand, the JPY displayed significant fluctuations from 2007-2017, with notable short-term volatility in 2019 and 2023.

The results of the coherence analysis indicate strong relationships between several pairs, particularly during global events like the 2008 financial crisis. The USD showed positive coherence with the GBP in the medium term, while USD and EUR exhibited strong connections during 2009-2016 and 2019-2021. GBP and EUR maintained positive co-movements throughout the period, while GBP and JPY, as well as EUR and JPY, demonstrated negative associations at times. Bidirectional causality was found only between USD and EUR, while other pairs exhibited unidirectional or independent movements. Overall, the analysis emphasizes evolving co-movement dynamics influenced by both global and currency-specific factors.

Our results reveal dynamic co-movements among major currencies, offering key insights for portfolio managers and international investors with exposure to INR. These findings are also significant for Indian banks and import-export firms seeking to hedge against fluctuations in USD, EUR, GBP, and JPY.

Given India's large trade potential with major economies, the identified co-movement patterns suggest limited benefits from currency diversification over monthly, quarterly, and semi-annual horizons. However, international investors may still find opportunities for gains at shorter intervals, such as intraweek, weekly, and fortnightly periods, where lower correlations among currencies are observed. This highlights the need for a nuanced approach to currency diversification and risk management in the Indian market. There is significant potential for further research on exploring the relationships among currency returns using advanced techniques, such as artificial intelligence and machine learning models, which have been applied in market prediction.

In particular, deep learning strategies employing neural networks could be instrumental in measuring co-movements among the variables considered. Additionally, future studies could explore different currencies, especially where data scarcity has made this type of research limited.

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## **Financial development and economic growth in emerging economies: the mediating role of entrepreneurship**

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**Abstract.** *The purpose of this study is to explore the mediating role of entrepreneurship between financial development and economic growth. Using data from 29 emerging economies (2006–2022) and Structural Equation Modelling (SEM) to assess both the direct and indirect influence of the financial sector on growth through entrepreneurial activity. The findings indicate that financial development enhances growth when channelled through entrepreneurship, while its direct effect turns negative without this mediation. Entrepreneurship also has a direct positive impact on growth. These findings reveal the importance of promoting entrepreneurial activity to strengthen financial systems, human capital, institutional quality, and inclusive growth.*

**Keywords:** financial development, economic growth, entrepreneurship, emerging economies, Structural Equation Modelling (SEM).

**JEL Classification:** O16, O47, L26, C39, O57.

## 1. Introduction

(Schumpeter J., 1911) is widely acknowledged as one of the earliest economists to emphasise the pivotal role of the financial sector in fostering economic growth. He particularly underlined the contribution of financial intermediaries in stimulating innovation and entrepreneurship by facilitating access to financial resources for firms and individuals seeking to develop new ideas. The nexus between financial development, entrepreneurship, and economic growth has since attracted considerable attention across macroeconomics, development studies, and financial policy research. A large body of literature argues that a well-functioning financial system enhances economic performance by efficiently allocating resources, reducing transaction costs, and encouraging investment and innovation (King and Levine, 1993; Levine, 2005). Furthermore, entrepreneurship is increasingly recognised as a key driver of productivity gains and sustained long-term growth (Ács et al., 2005; Wong, Ho and Autio, 2005). However, recent studies extend the analysis beyond these separate relationships by examining whether entrepreneurship operates as a mediating factor within the transmission pathway connecting financial development and economic growth (Khyareh, 2023; (Cumba et al., 2024)). Despite mounting interest, this mediation channel remains underexplored at the global level, creating a pressing research gap.

To address this gap, this study empirically investigates the relationship between financial development, entrepreneurship, and economic growth, examining both the direct and indirect effects of the financial sector through entrepreneurship across 29 emerging economies over the period 2006–2022.

To this end, we employed structural equation modelling (SEM) — a multivariate statistical technique for testing hypotheses about the influences of sets of variables on other variables, as noted by (Hayashi, Bentler and Yuan, 2011). This approach enables the simultaneous estimation of multiple dependent relationships, including both direct and indirect (mediated) effects. To preview our main results, we find a statistically significant and positive direct impact of financial development on entrepreneurship, but it has a statistically and negative direct impact on economic growth, however it's indirect effect through entrepreneurship is statistically and positively significant. Additionally, entrepreneurship has a statistically significant and positive direct impact on growth. Our model demonstrates a good overall fit; thus, it is suitable for interpretation. Additionally, we've found that our results support the notion that the entrepreneurship-financial development nexus is conditional on institutional conditions, confirming the findings of (Dutta and Meierriecks, 2021).

This study contributes to the existing literature by providing empirical evidence on the mediating role of entrepreneurship in the nexus between financial development and economic growth within emerging economies. Unlike much of the previous research, which primarily focuses on the direct impact of financial development on growth or examines only the direct role of entrepreneurship, this study adopts a broader perspective. It also integrates key macroeconomic and institutional control variables, thereby offering a more comprehensive evaluation of how financial development influences growth.



The remainder of this paper is structured as follows: Section 2 reviews the relevant literature on the links between financial development, entrepreneurship, and economic growth. Section 3 describes the data and outlines the empirical methodology. Section 4 presents the main findings along with the model's goodness-of-fit results, and Section 5 concludes the study.

## 2. Literature review

The early theoretical foundations regarding the role of financial development in economic growth originate from two contrasting schools of thought. The Keynesian perspective, represented by Joan Robinson, asserts that “where enterprise leads, finance follows” (Joan Robinson, 1952), suggesting that financial development is largely reactive and evolves in response to the demands of the real sector. In this view, economic expansion generates financing needs, and the financial system adjusts accordingly. Conversely, (Schumpeter J., 1911) argues that financial intermediaries play an active role in promoting growth by facilitating innovation and directing capital toward its most productive uses, thereby triggering a long-standing debate on the contribution of financial development to the process of economic growth.

Building on this perspective, (King and Levine, 1993) and (Levine, 2005) argue that a well-functioning financial system enhances economic performance by efficiently allocating resources, reducing transaction costs, and facilitating investment and innovation. Subsequent empirical research has largely validated these conclusions. For instance, (Oluitan, 2012), using a panel of 30 African countries over the period 1970–2005, found evidence of bidirectional causality between financial development and economic growth. Similarly, (Herwartz and Walle, 2014) and Pradhan et al. (2018) confirmed the positive relationship between financial development and economic growth. Furthermore, (Quito et al., 2025) highlight that the impact of financial development differs across developed and developing economies. Drawing on a sample of 76 countries covering 1980–2019, their findings reveal that in developing countries, financial institutions—particularly banks—play a significant role in supporting economic growth, whereas in developed economies, stock market-oriented financial development contributes more substantially to growth.

In Schumpeter's analysis of growth, innovation is considered the primary driving force for economic progress. The financial sector, in this regard, promotes innovation by providing financial support to firms and entrepreneurs seeking to innovate. Therefore, the Schumpeterian view of finance and growth highlights the significant impact of financial intermediaries on productivity growth and technological change. Based on this perspective, the financial intermediary sector alters the path of economic progress (Levine and Loayza, 2000).

In this context, an increasing number of studies provide evidence of a positive relationship between financial development and entrepreneurial activity. (Dutta and Meierrieks, 2021) demonstrate that financial deepening increases entrepreneurship globally, especially in institutional contexts that provide property rights protection and regulatory efficiency.

Their panel analysis of 136 countries underscores the critical role of governance quality in conditioning this relationship. (Ajide and Ojeyinka, 2022) also find that the relationship becomes significant only once financial systems pass a certain development threshold, which wasn't the case for the 20 selected countries in Africa—below which financial access remains inadequate for entrepreneurial growth.

The type of financial instrument available is equally important. Beck et al. (2005, 2008) show that diverse financing sources—bank loans, venture capital, microfinance, and crowdfunding—differentially affect entrepreneurial outcomes. This aligns with (Prokopenko et al., 2025), who argue that sustainable and inclusive entrepreneurial ecosystems rely on flexible financial systems capable of serving both early-stage and high-growth ventures. Their study stresses that beyond structural banking reforms, policymakers must enhance digital finance, financial literacy, and funding equity.

Moreover, financial systems do not just fund business ideas but also foster innovation and then growth by reducing liquidity constraints and information asymmetries. Banks, for instance, enhance the quality of information about projects and facilitate resource allocation in the economy (John H. Boyd and Edward C. Prescott, 1986). Additionally, (Allen and Gale, 2000) argue that a competitive environment between banks and stock markets fosters innovation, reduces the cost of financial resources, and stimulates economic growth (Beck and Levine, 2002).

Although the direct relationship between finance and entrepreneurship, and between entrepreneurship and growth, are well-documented, few studies explore the effect of entrepreneurship as a mediator in the transmission mechanism linking finance to growth. (Khyareh, 2023) and (Cumba et al., 2024)) offer rare empirical tests of this hypothesis.

(Khyareh, 2023) used a panel of 42 countries that participated in the Global Entrepreneurship Monitor (GEM) spanning from 2001 to 2018, utilising the two-step Generalized Moment Method. He has identified that the combined effect of entrepreneurship and financial development on economic growth is largely positive, suggesting that financial development can amplify the positive effect of entrepreneurship on economic growth.

Moreover, Cumba et al. (2024), using panel GMM estimation on African countries, found that entrepreneurship partially mediates the relationship between financial support and GDP growth. Their results suggest that up to 40% of finance's growth-enhancing effects operate indirectly through entrepreneurial activity. Hence, the existing literature reveals a significant research gap: the mediation role of entrepreneurship in the finance–growth nexus is under-theorised, poorly quantified, and highly context-dependent. Addressing this gap is crucial for both theory building and evidence-based policy.

Drawing upon the insights from prior literature, the following hypotheses are formulated:

$H_1$  : Well-developed financial systems have a direct and positive effect on economic growth.

$H_2$  : Financial development exerts a positive influence on the level of entrepreneurial activity.

$H_3$  : Entrepreneurial activity has a positive and significant impact on economic growth.

$H_4$  : The relationship between financial development and economic growth is mediated by entrepreneurship.

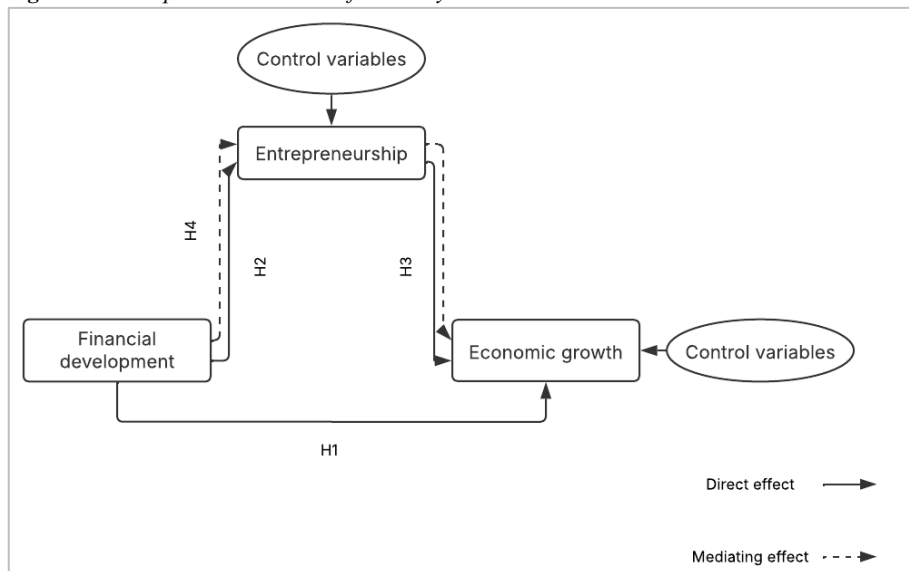
As presented in the hypotheses, Figure 1 illustrates the conceptual framework of this study, highlighting how entrepreneurship functions as a mediating variable in the relationship between financial development and economic growth.

### 3. Data and methodology

#### 3.1. Description and sources of model variables

The primary objective of this study is to investigate the role of entrepreneurship as a mediating factor in the transmission mechanism through which financial development influences economic growth. To achieve this, the analysis relies on data from 29 emerging economies, classified according to the International Monetary Fund (IMF) based on income levels, covering the period 2006–2022. The majority of the data were obtained from the World Bank's World Development Indicators (WDI, 2023).

**Figure 1.** *Conceptual Framework of the study*



**Source:** Authors' illustration.

### **3.1.1. The dependent variable**

The study uses economic growth (EG) as the dependent variable, measured by the annual percentage change in GDP per capita. The growth rate of GDP per capita is considered a more accurate indicator of economic performance compared to overall GDP growth, as it better reflects improvements in living standards. An increase in aggregate GDP does not necessarily imply better welfare for the population, since various demographic and structural factors may influence this relationship. For instance, when population growth outpaces production growth, per capita output may decline, even if total GDP rises. Therefore, GDP per capita is adopted as a more reliable measure of economic growth. The data for this variable were obtained from the World Bank's World Development Indicators (WDI).

### **3.1.2. The key explanatory variable**

For financial development (FD), the study employs domestic credit to the private sector (expressed as a percentage of GDP) as a proxy indicator. This measure reflects the degree to which financial institutions, particularly banks, allocate resources to the private sector, which represents a core function of a well-developed financial system (King and Levine, 1993; Levine, 2005).

### **3.1.3. The key mediating variable**

For the mediating variable, entrepreneurship (ENTR), the study employs new business density—measured as the number of newly registered firms per 1,000 individuals aged 15–64—as a proxy indicator. This metric offers a clear and quantifiable measure of the intensity of entrepreneurial activity within an economy, capturing the extent to which new businesses are being established, which represents a fundamental dimension of entrepreneurship.

### **3.1.4. Control variables**

Based on the literature review presented, it is crucial to incorporate institutional quality as a control variable, alongside human capital and employment levels in the mediating equation. Specifically, government efficiency (GE) and the rule of law (RL) are utilised as proxies for institutional quality; school enrolment (tertiary, % gross) serves as a proxy for human capital (HC), while the employment-to-population ratio for those aged 15 and over (total, %) is used to represent the level of employment (EMP).

In the economic growth equation, and in line with the endogenous growth theory, the model controls for human capital (HC), capital accumulation (GCF), and other key macroeconomic indicators, including inflation (CPI) and trade openness (OP). Capital accumulation is proxied by gross capital formation (as a percentage of GDP), inflation is measured by the annual percentage change in consumer prices, and trade openness is captured by the trade-to-GDP ratio.

### 3.2. Methodology framework

The primary objective of this study is to investigate the mediating role of entrepreneurship in the relationship between financial development and economic growth. Specifically, it seeks to determine whether financial development affects economic growth indirectly through entrepreneurial activity. To achieve this, the study applies Structural Equation Modelling (SEM), a statistical technique particularly suitable for estimating simultaneous direct, indirect, and total effects within a theoretically structured framework.

SEM is a multivariate analytical approach that combines the features of multiple regression and path analysis, enabling researchers to examine complex causal relationships among observed variables. As explained by Kline (2023) “SEM is a comprehensive statistical approach to testing hypotheses about relations among observed and latent variables.” While SEM was originally designed for models involving latent constructs, it can also be effectively applied to frameworks that rely exclusively on observed variables, which is the case in this study.

The use of SEM is particularly appropriate for this research as it enables the simultaneous estimation of the effects of financial development on economic growth, both directly and indirectly through entrepreneurship. Unlike traditional regression methods, SEM facilitates the evaluation of mediating pathways within a single, unified framework, thereby providing greater analytical power, precision, and interpretability.

The model used in this study consists of two structural equations:

- Entrepreneurship Equation (Financial Development → Entrepreneurship)

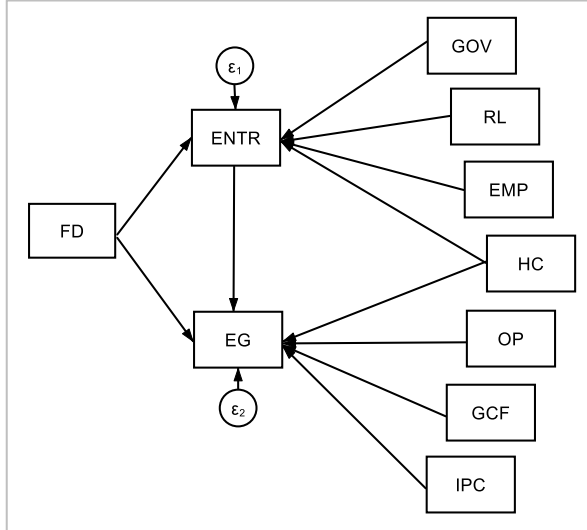
$$ENTR_{it} = \alpha_{0i} + \alpha_{1i}FD_{it} + \alpha_{2i}GOV_{it} + \alpha_{3i}RL_{it} + \alpha_{4i}HC_{it} + \alpha_{5i}EMP_{it} + \varepsilon_{1it}$$

This equation captures how financial development and institutional/human factors influence entrepreneurial activity.

- Economic Growth Equation (Financial Development → Entrepreneurship → Economic Growth)

$$EG_{it} = \beta_{0i} + \beta_{1i}FD_{it} + \beta_{2i}ENTR_{it} + \beta_{3i}HC_{it} + \beta_{4i}GCF_{it} + \beta_{5i}OP_{it} + \beta_{6i}CPI_{it} + \varepsilon_{2it}$$

The second structural equation examines how both financial development (FD) and entrepreneurship (ENTR) contribute to economic growth (EG), while controlling for other macroeconomic variables, including human capital (HC), gross capital formation (GCF), trade openness (OP), and an innovation proxy (IPC). The estimation and interpretation of the proposed model (Figure 2) are carried out following the guidelines outlined by Kang & Ahn (2021) for reporting Structural Equation Modelling results.

**Figure 2.** *Structural equation model*

Source: Authors' illustration.

#### 4. Results and discussion

As a first step, we examine the coefficient correlation matrix. (Table 1) to assess the relationships between observed variables and to identify potential issues such as multicollinearity or unexpected signs.

**Table 1.** *Coefficient correlation matrix*

| Variables | EG      | ENTR    | FD      | RL      | EMP    | HC      | OP      | GOV     | GCF    | IPC    |
|-----------|---------|---------|---------|---------|--------|---------|---------|---------|--------|--------|
| EG        | 1.0000  |         |         |         |        |         |         |         |        |        |
| ENTR      | 0.1046  | 1.0000  |         |         |        |         |         |         |        |        |
| FD        | -0.1178 | 0.4379  | 1.0000  |         |        |         |         |         |        |        |
| RL        | 0.0114  | 0.3886  | 0.6222  | 1.0000  |        |         |         |         |        |        |
| EMP       | 0.1627  | -0.0091 | -0.0143 | 0.0605  | 1.0000 |         |         |         |        |        |
| HC        | 0.0757  | 0.2620  | -0.1394 | -0.2905 | 0.1926 | 1.0000  |         |         |        |        |
| OP        | 0.1481  | 0.2302  | 0.3308  | 0.3877  | 0.3662 | 0.2821  | 1.0000  |         |        |        |
| GOV       | 0.0146  | 0.2897  | 0.6224  | 0.7931  | 0.2421 | -0.2598 | 0.4202  | 1.0000  |        |        |
| GCF       | 0.5025  | 0.0313  | -0.0758 | 0.0040  | 0.0712 | 0.0048  | 0.1143  | -0.0260 | 1.0000 |        |
| IPC       | 0.0673  | -0.0954 | -0.2466 | -0.2914 | 0.0305 | 0.1747  | -0.0264 | -0.3758 | 0.0309 | 1.0000 |

Source: Authors' own elaboration.

Economic growth (EG) exhibits the strongest correlation with gross capital formation (GCF) ( $r=0.50$ ), followed by moderate positive correlations with trade openness (OP) ( $r=0.15$ ) and employment ( $r=0.16$ ), which aligns with the expectations of standard macroeconomic theory.

Entrepreneurship (ENTR), used as a proxy for innovation, shows moderate positive correlations with financial development (FD) ( $r=0.44$ ), rule of law ( $r=0.39$ ), and government efficiency ( $r=0.29$ ), underscoring the importance of institutional quality and

financial environments in fostering innovative activity. Furthermore, institutional variables, specifically rule of law and government efficiency, are highly correlated ( $r=0.79$ ), suggesting the potential presence of multicollinearity and highlighting the need for diagnostic tests. Overall, these correlations provide empirical support for the hypothesised relationships in the structural model and justify the inclusion of institutional and macroeconomic control variables in the analysis.

**Table 2.** *VIF test to asses multicollinearity*

| Variable | VIF  | 1/VIF    |
|----------|------|----------|
| GOV      | 3.74 | 0.267278 |
| RL       | 3.46 | 0.289153 |
| FD       | 2.04 | 0.490656 |
| HC       | 1.78 | 0.560561 |
| OP       | 1.77 | 0.563517 |
| ENTR     | 1.62 | 0.617087 |
| EMP      | 1.35 | 0.740246 |
| IPC      | 1.21 | 0.829741 |
| GCF      | 1.05 | 0.956629 |
| Mean VIF | 2.00 |          |

**Source:** Authors' own elaboration.

To evaluate the presence of multicollinearity among the explanatory variables, a Variance Inflation Factor (VIF) test was performed (Table 2). The results indicate that all VIF values are below the commonly accepted threshold of 5, with the highest values observed for government efficiency ( $VIF=3.74$ ) and rule of law ( $VIF=3.46$ ). These relatively elevated values are consistent with their strong correlation ( $r=0.79$ ), yet they remain within acceptable limits. The mean VIF is 2.00, indicating that multicollinearity is not a significant concern in the model and is unlikely to distort coefficient estimates or standard errors.

Table 3 presents the estimation results of the structural model. In the entrepreneurship equation (Financial Development  $\rightarrow$  Entrepreneurship), financial development—measured by domestic credit to the private sector—has a positive and statistically significant effect on entrepreneurship. Specifically, a 1% increase in financial development is associated with a 3.82% increase in entrepreneurial activity. In addition, both human capital (HC) and the rule of law exert positive effects on entrepreneurship, with impacts estimated at 5.07% and 101.63%, respectively.

In the economic growth equation (Financial Development  $\rightarrow$  Entrepreneurship  $\rightarrow$  Economic Growth), entrepreneurship emerges as a significant driver of growth: a 1% increase in entrepreneurship corresponds to a 28.63% rise in the economic growth rate. Furthermore, gross capital formation (GCF) and trade openness (OP) exhibit positive and statistically significant effects on growth, estimated at 14.22% and 1.37%, respectively. Conversely, financial development shows a negative association with economic growth, as a 1% increase in financial development leads to a 3.22% decline in the growth rate.

**Table 1.** *Estimates of Structural Model.*

| Dependent Variable | Independent Variable | Coefficient | Std. Error | z-value | p-value |
|--------------------|----------------------|-------------|------------|---------|---------|
| ENTR               | FD                   | 0.0382***   | 0.0051     | 7.47    | 0.000   |
|                    | HC                   | 0.0507***   | 0.0057     | 8.85    | 0.000   |
|                    | EMP                  | -0.0192     | 0.0121     | -1.58   | 0.113   |
|                    | RL                   | 1.0163***   | 0.3381     | 3.01    | 0.003   |
|                    | GOV                  | -0.1474     | 0.3686     | -0.40   | 0.689   |
|                    | Constant             | -0.1974     | 0.7082     | -0.28   | 0.780   |
| EG                 | ENTR                 | 0.2863***   | 0.0844     | 3.39    | 0.001   |
|                    | FD                   | -0.0322***  | 0.0088     | -3.66   | 0.000   |
|                    | GCF                  | 0.1422***   | 0.0117     | 12.11   | 0.000   |
|                    | OP                   | 0.0137**    | 0.0064     | 2.15    | 0.032   |
|                    | HC                   | -0.0066     | 0.0111     | -0.59   | 0.553   |
|                    | IPC                  | 0.0268      | 0.0360     | 0.74    | 0.457   |
|                    | Constant             | 1.6810***   | 0.7081     | 2.37    | 0.018   |

LR test of model vs. saturated:  $\chi^2(6) = 10.34$  Prob >  $\chi^2 = 0.1109$

**Note:** \*\*\*, \*\* and \* denotes the significance at 1%, 5% and 10% significance level respectively.

Although financial development (FD) exhibits a negative direct effect on economic growth (EG), the results reported in Table 4 indicate that FD exerts a statistically significant and positive indirect effect on growth through entrepreneurship (ENTR), thereby confirming the mediating role of entrepreneurship. Specifically, a 1% increase in the indirect effect of FD via ENTR is associated with a 1.09% rise in EG. However, since the total effect of FD on EG remains negative, the findings suggest that, in emerging economies, the financial sector should channel a greater share of investment towards entrepreneurial activities in order to enhance its positive contribution to economic growth.

Similarly, while human capital (HC) exhibits a negative direct effect on growth, its indirect effect through entrepreneurship is significantly positive. A 1% increase in this indirect effect results in a 1.45% rise in economic growth. This indicates that entrepreneurship enhances the productivity of human capital, transforming it into a positive driver of growth.

The rule of law also exerts a significant and positive indirect effect on economic growth through its influence on entrepreneurship. A stronger institutional framework enhances entrepreneurial activity, which subsequently contributes to higher levels of economic performance. These findings underscore the critical role of robust regulatory and institutional systems in promoting entrepreneurship and, consequently, supporting sustainable long-term economic development.

**Table 4.** *Mediating Effects of Structural Model*

| Endogenous Variable | Exploratory Variable | Direct Effect       | Indirect Effect   | Total Effect       |
|---------------------|----------------------|---------------------|-------------------|--------------------|
| ENTR                | FD                   | 0.0382 (0.0051)***  | –                 | 0.0382 (0.0051)*** |
|                     | HC                   | 0.0507 (0.0057)***  | –                 | 0.0507 (0.0057)*** |
|                     | EMP                  | -0.0192 (0.0121)    | –                 | -0.0192 (0.0121)   |
|                     | RL                   | 1.0163 (0.3381)**   | –                 | 1.0163 (0.3381)**  |
|                     | GOV                  | -0.1474 (0.3686)    | –                 | -0.1474 (0.3686)   |
| EG                  | ENTR                 | 0.2863 (0.0844)***  | –                 | 0.2863 (0.0844)*** |
|                     | FD                   | -0.0322 (0.0088)*** | 0.0109 (0.0035)** | -0.0212 (0.0079)** |
|                     | HC                   | -0.0066 (0.0111)    | 0.0145 (0.0046)** | 0.0079 (0.0103)    |



| Endogenous Variable | Exploratory Variable | Direct Effect      | Indirect Effect   | Total Effect       |
|---------------------|----------------------|--------------------|-------------------|--------------------|
|                     | EMP                  | –                  | –0.0055 (0.0038)  | –0.0055 (0.0038)   |
|                     | RL                   | –                  | 0.2910 (0.1287)** | 0.2910 (0.1287)**  |
|                     | GOV                  | –                  | –0.0422 (0.1062)  | –0.0422 (0.1062)   |
|                     | GCF                  | 0.1422 (0.0117)*** | –                 | 0.1422 (0.0117)*** |
|                     | OP                   | 0.0137 (0.0064)**  | –                 | 0.0137 (0.0064)**  |
|                     | IPC                  | 0.0268 (0.0360)    | –                 | 0.0268 (0.0360)    |

**Note:** \*\*\*, \*\* and \* denotes the significance at 1%, 5% and 10% significance level respectively.

The results of the structural equation model (SEM) estimation (Table 5) indicate that the proposed model provides a good overall fit to the data. The Chi-square statistic is  $\chi^2(6)=10.344$  with a p-value of 0.111. Since the p-value exceeds the conventional significance threshold of 0.05, the null hypothesis—that the model fits as well as the saturated model—cannot be rejected. This suggests that the proposed model adequately reproduces the observed covariance matrix.

The Root Mean Square Error of Approximation (RMSEA) is 0.038, with a 90% confidence interval ranging from 0.000 to 0.077. The associated p-close value of 0.640 provides strong evidence in favour of the hypothesis that the population RMSEA is less than or equal to 0.05, indicating a close model fit.

The incremental fit indices also confirm the adequacy of the model. The Comparative Fit Index (CFI) equals 0.987, and the Tucker–Lewis Index (TLI) equals 0.962. Both values exceed the conventional benchmark of 0.95, demonstrating an excellent improvement over the null (independence) model.

Finally, the Coefficient of Determination (CD) is 0.508, indicating that the model explains approximately 51% of the variance in the endogenous variables, providing further support for the robustness of the proposed framework.

**Table 2.** *Goodness of Fit Indices*

| Model           | $\chi^2$ | df | RMSEA | SRMR | CFI   | TLI   | CD    |
|-----------------|----------|----|-------|------|-------|-------|-------|
| Final SEM Model | 10.344   | 6  | 0.038 | –    | 0.987 | 0.962 | 0.508 |

**Note:** SRMR is not reported because of missing values.

## 5. Conclusions and Policy implications

The findings of this study reveal that financial development (FD) exerts a negative direct effect on economic growth (EG) but demonstrates a positive and statistically significant indirect effect through entrepreneurial activity (ENTR), thereby confirming the mediating role of entrepreneurship. Specifically, a 1% increase in FD leads to a 3.82% rise in ENTR, which subsequently contributes to a 1.09% increase in EG. Similarly, human capital (HC) shows a negative and statistically insignificant direct effect on growth but exhibits a significant positive indirect impact via ENTR, where a 1% increase in HC along the indirect pathway raises EG by approximately 1.45%. Moreover, the rule of law (RL) also has a significant positive indirect effect on growth through its influence on entrepreneurship.

Importantly, entrepreneurship itself emerges as a key driver of growth: a 1% increase in ENTR results in a 28.63% rise in EG. In addition, gross capital formation (GCF) and trade openness (OP) contribute positively to economic growth, with estimated effects of 14.22% and 1.37%, respectively.

These findings imply that emerging economies must reorient their development strategies to develop their financial sector, strengthen human capital, and improve institutional quality—always with a clear focus on entrepreneurship. Rather than simply expanding overall credit, financial institutions should introduce dedicated credit lines for start-ups and small businesses, featuring lighter collateral requirements and grace periods tailored to the cash-flow realities of early-stage firms. At the same time, the emergence of fintech innovations and digital lending platforms presents a significant opportunity to reduce transaction costs, expand financial inclusion, and facilitate the creation of peer-to-peer lending networks. To encourage the flow of risk-tolerant capital into entrepreneurial ventures, governments could implement matching-grant programs and offer tax incentives targeted at venture-capital funds that focus on high-growth potential sectors. Additionally, the alignment of education and skills development with market needs. Embedding entrepreneurship modules into secondary and tertiary curricula—alongside incubator programmes and mentorship from seasoned entrepreneurs—will equip students with both the mindset and practical know-how to launch viable ventures. Lifelong learning initiatives, supported by public–private partnerships, can certify in-demand technical, managerial, and digital competencies, while innovation clusters that link universities and industry can channel cutting-edge research into commercial applications. Finally, the rule of law must be strengthened to reduce uncertainty and lower the cost of doing business. Simplifying business registration through one-stop digital portals; modernising land and asset registries; and introducing fast-track commercial courts will protect property and enforce contracts more efficiently. Transparent e-procurement systems and open-budget platforms, coupled with rigorous audit regimes, can curb corruption and build investor confidence. In this context, a robust regulatory framework not only directly fosters entrepreneurship but also enhances the indirect effects of financial development and human capital on economic growth. Regarding the hypothesis testing, the results lead to the rejection of  $H_1$ , indicating that strengthened financial systems do not exert a direct positive effect on growth. Conversely,  $H_2$ ,  $H_3$ , and  $H_4$  are supported: financial development positively influences entrepreneurial activity; entrepreneurship has a significant positive impact on economic growth; and the relationship between financial development and growth is partially mediated by entrepreneurship. By illuminating these mechanisms, our research contributes both theoretically and practically. It demonstrates that entrepreneurship is the vital conduit through which financial and institutional resources are converted into economic performance. For policymakers in emerging economies, this means shifting from a narrow focus on credit expansion to a broader, entrepreneurship-driven development agenda—one that harnesses the productivity of human capital and institutional reforms to create sustainable, long-term growth.

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## House prices and macroprudential policy in the Romanian economy: evidence from a BVAR analysis

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**Abstract.** *The study examines the determinants of Romania's house price growth cycle over the period 2005Q1-2024Q4. A Bayesian VAR with six variables is employed, namely real house prices, GDP, inflation, construction, macroprudential policy and monetary policy. The results are derived from variance decomposition and impulse response analyses under two shock identification methods. The findings suggest shifting contributions from house price idiosyncratic factors, inflation, GDP, and policy instruments, with notable differences between the roles of monetary and macroprudential measures. Under Cholesky identification, monetary policy exerted significant influence, whereas under sign restrictions, macroprudential policy emerged as a key driver, underscoring contrasting roles of policy instruments across episodes.*

**Keywords:** house prices, real estate, macroprudential policy, monetary policy, BVAR.

**JEL Classification:** R38, E32, E52, G28, C11, C32.

## 1. Introduction

Residential real estate (RRE) markets are an important component of the modern economy. A large part of the wealth of households are given by their holdings of RRE. Changes in house prices affect the households' ability to consume and invest. Household consumption is impacted mainly through the wealth channel and through borrowing against RRE collateral. Household investment is impacted as RRE properties are an important investment vehicle for households to place their deposits. These effects can have non-negligible macroeconomic effects (ESRB, 2014).

Besides the macroeconomic effects, house prices have substantial implications for the stability of the financial system. Financial institutions, especially banks, are directly interested in the state of the real estate markets. First of all, a large proportion of households financing is done through the pledging of housing collateral. Thus, lenders have a direct stake in the evolution of real estate. A negative shock that would bring a series of defaults, would leave the lenders in a position to recuperate the loan by selling the collateral. Often, this implies a loss for the lender. If the phenomenon is generalized, it can put substantial stretch on the solvency of credit institutions.

Real estate has been at the center of numerous financial crisis (ESRB, 2015), but most recently it has been in the forefront of the Great Financial Crisis of 2007-2009 (GFC). A mortgage credit boom financed the large scale acquisition of housing and drove up the prices to an unsustainable level. When the bubble burst, the losses did not only affect banks, but the whole financial system as the mortgages have been sold through securitization to other financial institutions. The effects trickled down from the financial system to the real economy, causing one of the deepest global recessions in modern history.

The repercussions of the financial crisis prompted policy makers to come up with solutions to avoid such a financial crisis to ever happen. This led to the creation of a dedicated set of instruments called macroprudential policy. In terms of real estate, the main macroprudential instruments are capital buffers and borrower-based measures. Capital buffers are designed to increase the equity of banks in times of systemic risk, acting as a stabilizer that can absorb eventual losses and not dry up credit during downturns. The EU legislation contain the following instruments: countercyclical capital buffer (CCyB), systemic risk buffer (SyRB), systemically important institution buffer (G-SII/O-SII) and capital conservation buffer (CCoB). Out of these, only the first two can target real estate risks. Borrower based measures act as limits to the amount of borrowing that households can take. The instruments used here are: loan-to-value (LTV), debt-to-income (DTI), debt-service-to-income (DSTI), amortization requirements, maturity limits. Both type of measures have been extensively used in Europe, including in Romania (Aliman et al., 2024)

Romanian authorities were proactive in using macroprudential instruments. Even before the GFC, BBMs were in place in the form of LTV and DSTI limits. Those measures were recalibrated after the outcome of the GFC has passed. Additionally, the National Committee for Macroprudential Oversight (NCMO), the designated national macroprudential authority, disposed the activation of all the types of macroprudential buffers existing in EU legislation. Given this uptake of measures, it is natural to inquire

how the measures have impacted the RRE cycle over the years and how can it influence it in the future. This article sets out to give an answer to these questions.

## 2. Literature review

House price determinants are a topic that was intensively studied in the economic literature. So far, there have been 3 different main approaches to tackle this subject: (i) asset pricing models, (ii) hedonic models, (iii) macroeconomic determinants models.

Asset pricing models consider that the price of a house can be determined in a similar way to the price of any asset, and should be computed using the discounted cash flows given by potential income that the house can generate. The income is usually given by rents or approximated user costs. Piazzesi et al. (2007) models housing as both consumption and investment, showing that time-varying composition risk explains cross-sectional variation in asset returns and links housing to broader asset pricing dynamics. Weenen (2004) applies asset pricing models to U.K. housing, using price-to-rent ratios to assess overvaluation and risk premia, finding evidence of misalignment with fundamentals and time-varying expected returns.

Hedonic models determine the price of individual houses based on granular characteristics, such as number of rooms, quality of neighborhood, number of floors etc. Chau and Chin (2003) provide a systematic review of global housing hedonic studies, summarizing commonly used attributes (locational, structural, neighborhood) and methodological lessons. Zilișteanu et al. (2019) investigates factors influencing dwelling sale prices in Bucharest using a hedonic OLS model, finding that most housing attributes, including room count, surface area, comfort, and amenities, positively affect property prices.

Macroeconomic determinants studies use models that look at the aggregate house prices and how this relates to various macroeconomic factors, such as GDP, interest rate, credit growth etc. Most studies compromise of both demand side and supply side factors. There are authors that compute multiple country-level panels and some that compute only national level, regional level or even city level studies. The present study falls into the strand of literature that uses a national view.

On an international level, Adam and Fuss (2010) report that a 1% boost in economic activity raises house prices by 0.6%, while construction costs and interest rates play lesser roles, indicating slower-than-expected equilibrium adjustment. Melecky and Paksi (2024) analyze European country data, revealing strong influence from demand-side factors and a notable impact of financial sector development on housing prices.

At a regional level, Belke and Keil (2018) conduct panel analysis on housing prices across almost 100 German cities, identifying effects from construction levels, housing supply, rental prices, market size, and local infrastructure conditions. At city level, Eichholtz et al. (2015) examine 350 years of Amsterdam housing data, observing that during downturns, fundamentals dominate expectations, while in boom phases, price momentum plays a more prominent role.

In the context of the Romanian market, Chiriluș (2023) develops a multiple linear regression model to predict Romanian apartment auction prices, providing useful insights for analysts, improving investment efficiency, and offering long-term economic value, despite limitations in market scope and forecasting precision. Cosmulese and Zhavoronok (2024) show that the Ukraine war significantly impacted Romania's real estate market. Ukrainian migration raised urban housing prices and rental demand, while higher mortgage rates reduced affordability. GDP growth positively influenced prices, highlighting economic-geopolitical interactions in housing dynamics.

Although macroprudential policy is still a relatively novel subject, the literature of the effects of macroprudential instruments has been growing substantially after the GFC. An early review of this literature can be found in Galati and Moessner (2018). Araujo et al. (2024) carry out a meta-analysis using data from 58 studies on macroprudential policy, identifying notable effects on credit, differing outcomes by instrument, weaker influence on housing prices, stronger responses in emerging markets, and signs of both leakages and spillovers. Muellbauer (2004) examines housing's role in financial crises, the effectiveness and limitations of housing-related macroprudential tools, their distributional impacts, and highlights the need for coordinated, general equilibrium policy approaches. Focusing on Romania, Neagu et al. (2014) analyses Romania's real estate-related financial stability risks, highlighting poor loan quality and volatile foreign capital as main concerns. It also reviews macroprudential tools, especially borrower-based measures, and evaluates their effectiveness over a decade of Romanian experience.

### 3. Data and methodology

The current paper employs the study of determinants of Romanian house prices at macroeconomic level, making use of the five principal variables found in the literature to influence them. The variables are Gross Domestic Product (GDP), construction output, inflation, monetary policy and macroprudential policy. We use quarterly data on the period 2005Q1-2024Q4, thus having 80 observations per variable. House prices, GDP and construction output are expressed as annual growth rates in real terms. Inflation is also expressed as an annual growth rate of the HICP index, thus excluding house price growth. Monetary policy is approximated by the ROBOR6M quarterly average.

Expressing the level of macroprudential policy can prove to be a challenging endeavor, as there isn't a single variable that can fully approximate it. First of all, there are capital based and borrower based instruments being active at various moments in time. An all-encompassing index will need to keep track of various instruments in use. A novel approach in the scientific literature is to construct "intensive" macroprudential indexes that quantify the restrictiveness of borrower-based measures like LTV, DSTI, and other lending restrictions to assess their impact on credit (Coulier and De Schryder, 2024). In the current paper we employ a simpler procedure by constructing an index that gives the value 1 to every BBM and CBM activated<sup>(1)</sup> and gives 0.5 to every recalibration action in any of the instruments (see equation 1). The implicit hypothesis in our method is that every instrument



has an equal effect. A summary of all the variable employed can be found in Table 1, and a visual summary of the time series is pictured in Figure 1.

$$\text{Macroprudential policy index} = \sum_n I_n, \text{ where}$$

$$I_n = \begin{cases} 1, & \text{when a measure is activated} \\ -1, & \text{when a measure is deactivated} \\ 0.5, & \text{when an existing measure is tightened} \\ -0.5, & \text{when an existing measure is loosened} \end{cases} \quad (1)$$

**Table 1.** Data series description

| Variable              | Definition                                                                          | Form                          | Source                                        | Time          | Number of observations | Average | Standard Deviation |
|-----------------------|-------------------------------------------------------------------------------------|-------------------------------|-----------------------------------------------|---------------|------------------------|---------|--------------------|
| Real house price      | Nominal house price deflated by private final consumption expenditure of households | Quarterly year-on-year growth | Eurostat                                      | 2005Q1-2024Q4 | 80                     | 2.3451  | 19.1636            |
| Real GDP              | Gross Domestic Product at 2021 prices                                               | Quarterly year-on-year growth | Eurostat                                      | 2005Q1-2024Q4 | 80                     | 3.2175  | 4.4492             |
| Construction output   | Changes in the value of construction output                                         | Quarterly year-on-year growth | Eurostat                                      | 2005Q1-2024Q4 | 80                     | 5.8937  | 14.8243            |
| Interest rate         | ROBOR 6M, monthly average                                                           | Level                         | NBR                                           | 2005Q1-2024Q4 | 80                     | 5.5141  | 3.4021             |
| Inflation             | HICP index                                                                          | Quarterly year-on-year growth | Eurostat                                      | 2005Q1-2024Q4 | 80                     | 4.7662  | 3.4884             |
| Macroprudential index | Additive index based on number of active macroprudential measures                   | Level                         | Author's calculation based on IMF information | 2005Q1-2024Q4 | 80                     | 1.9375  | 1.6286             |

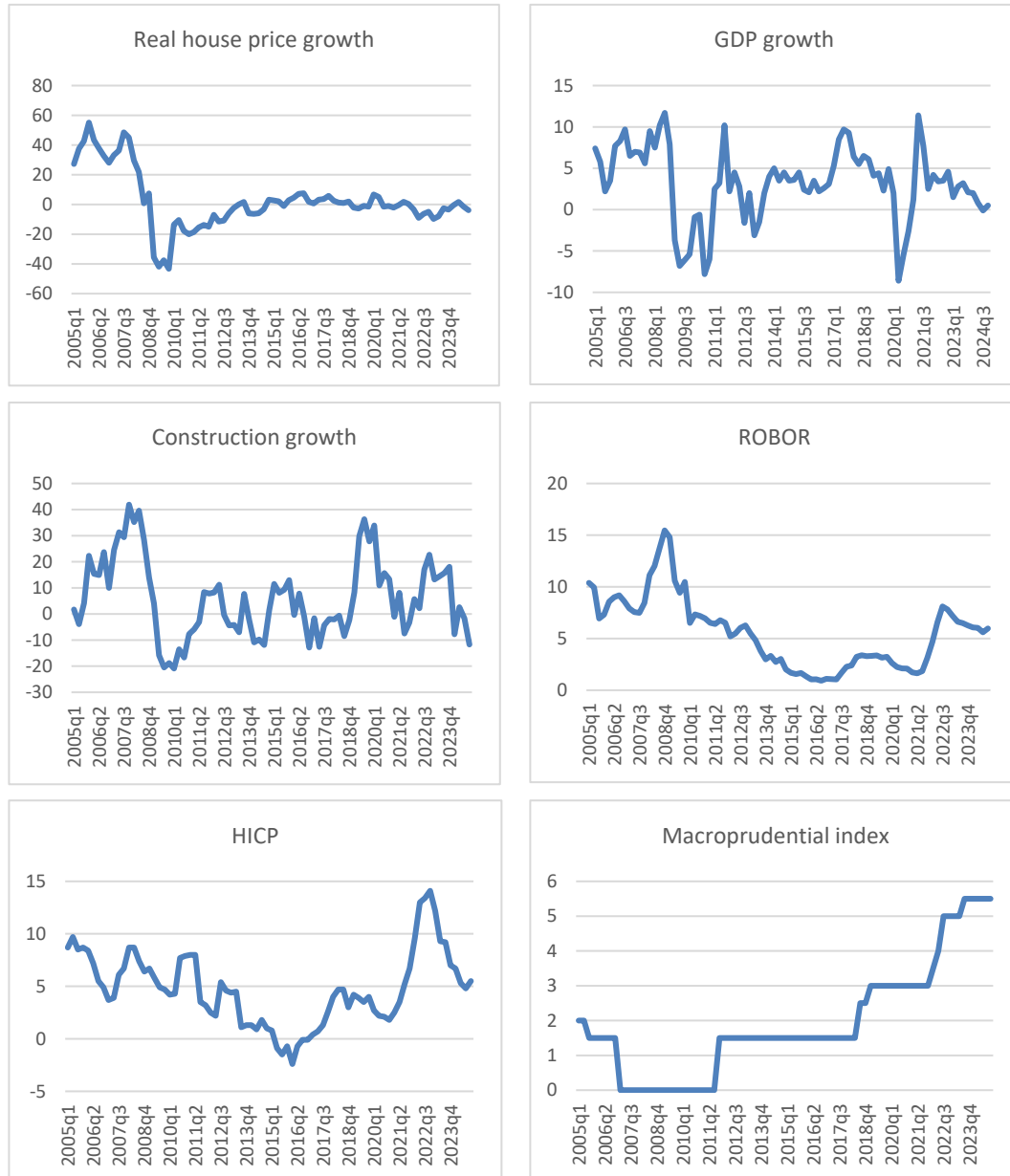
**Source:** Authors' own contribution.

We chose to leave out two explicative variables usually used in the literature of house price determinants: unemployment rate and mortgage credit growth. For practical reasons, the data available for Romania for the two variables does not cover the same period as the other variables used, thus using them would result in less observation points, having in mind that even in the current case the number of data points is not particularly large. From a technical point of view, unemployment correlates strongly with GDP growth, while credit growth is a variable that helps in the transmission of both monetary and macroprudential policy. Including these two variables could result in less robust estimates.

The methodology used to estimate the effects of the exogenous variables on house prices is a vector autoregression estimated using Bayesian techniques (BVAR). The VAR use is warranted by the research question, which is to decompose the effects of various variables on house prices, knowing that the variables interact with each other. The Bayesian

methodology offers multiple advantages compared with the frequentist approach. First of all, it works better with smaller datasets. Second, it provides better results with data that have unit roots, which is the case of some of the variables employed. Thirdly, it allows identification through sign restrictions.

**Figure 1.** *Time series used*



**Source:** Authors' own contribution based on data series presented in Table 1.

Formally, the VAR specification is given by (Hamilton, 1994):

$$Y_t = c + \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \dots + \phi_p Y_{t-p} + \varepsilon_t \quad (2)$$

where  $Y_t$  is a  $6 \times 1$  vector of the above mentioned variables,  $\phi_p$  are  $6 \times 6$  coefficient matrices,  $c$  is a vector of intercepts, and  $\varepsilon_t$  is a vector of reduced-form residuals.

To recover structural shocks, we employ two identification strategies. First, the Cholesky decomposition imposes a recursive structure on contemporaneous relations, requiring an ordering of variables. The ordering reflects assumed causal priority, where earlier variables contemporaneously affect later ones but not vice versa. This recursive identification allows for a straightforward mapping from reduced-form errors to structural shocks. The order of the variables used is the following: GDP, inflation, real house prices, construction output, macroprudential index and interest rate.

Second, a sign-restriction approach is applied to impose theoretically motivated restrictions on the responses of variables to specific shocks. As summarized in the sign restriction matrix (Table 2), aggregate demand shocks are assumed to increase GDP and decrease inflation, while aggregate supply shocks raise inflation and lower GDP. Housing demand shocks are expected to increase real house prices, whereas housing supply shocks increase construction output. Monetary policy shocks raise interest rates and reduce GDP and inflation, while macroprudential policy shocks tighten credit conditions, dampening real house prices. The sign restrictions are assumed to hold for the first four quarters of the shock.

**Table 2.** *Sign restriction identification strategy*

| Variable/Shock         | Aggregate demand | Aggregate supply | Housing demand | Housing supply | Monetary policy | Macroprudential policy |
|------------------------|------------------|------------------|----------------|----------------|-----------------|------------------------|
| GDP                    | +                | -                |                |                | -               |                        |
| Inflation              | -                | +                |                |                | -               |                        |
| House prices           |                  |                  | +              |                |                 | -                      |
| Construction           |                  |                  |                | +              |                 |                        |
| Interest rate          |                  |                  |                |                | +               |                        |
| Macroprudential policy |                  |                  |                |                |                 | +                      |

**Source:** Authors' own contribution.

The dynamic properties of the system are analyzed using impulse response functions (IRFs), which trace the time path of each variable following a one-standard-deviation structural shock. Additionally, forecast error variance decomposition (FEVD) is conducted to quantify the relative contribution of each identified shock to the fluctuations in the endogenous variables over different horizons. Together, these tools provide insight into the transmission mechanisms of macroeconomic, monetary, and macroprudential policy shocks within the housing market and the broader economy.

The model is estimated using the BEAR toolbox in Matlab (Dieppe et al. 2016), using a 4 lag specification under a Wishart prior. We employ the use of standard parameters described in Table 3.

**Table 3.** *Parameters used for the estimation*

| Parameter                    | Symbol      | Value | Description                                                          |
|------------------------------|-------------|-------|----------------------------------------------------------------------|
| Autoregressive coefficient   | $a_r$       | 0.8   | Assumed prior mean for first lag                                     |
| Overall tightness            | $\lambda_1$ | 0.2   | Shrinkage of all coefficients toward prior mean                      |
| Cross-variable weighting     | $\lambda_2$ | 0.5   | Shrinkage for coefficients of variables other than the dependent one |
| Lag decay                    | $\lambda_3$ | 1     | Shrinkage applied more heavily to longer lags                        |
| Exogenous variable tightness | $\lambda_4$ | 100   | Tightness on coefficients of exogenous variables                     |

**Source:** Authors' own contribution.

#### 4. Results

This section will comment on the results obtained on the estimations with two identifications methods: Cholesky ordering and sign restrictions. The results can be seen as complementary, each identification method having its weaknesses. The shortcomings of the Cholesky ordering come from the assumption that not all variables can affect each other contemporaneously, in our case, quarterly. With the speed that economies are moving, it is harder and harder to justify the assumption that variables don't interact with each other for 3 months. In the case of sign restrictions, some authors (Uhlig, 2005) have criticized this method as it can lead to the deletion of a large proportion of draws and make the model fit too well the researchers' assumptions.

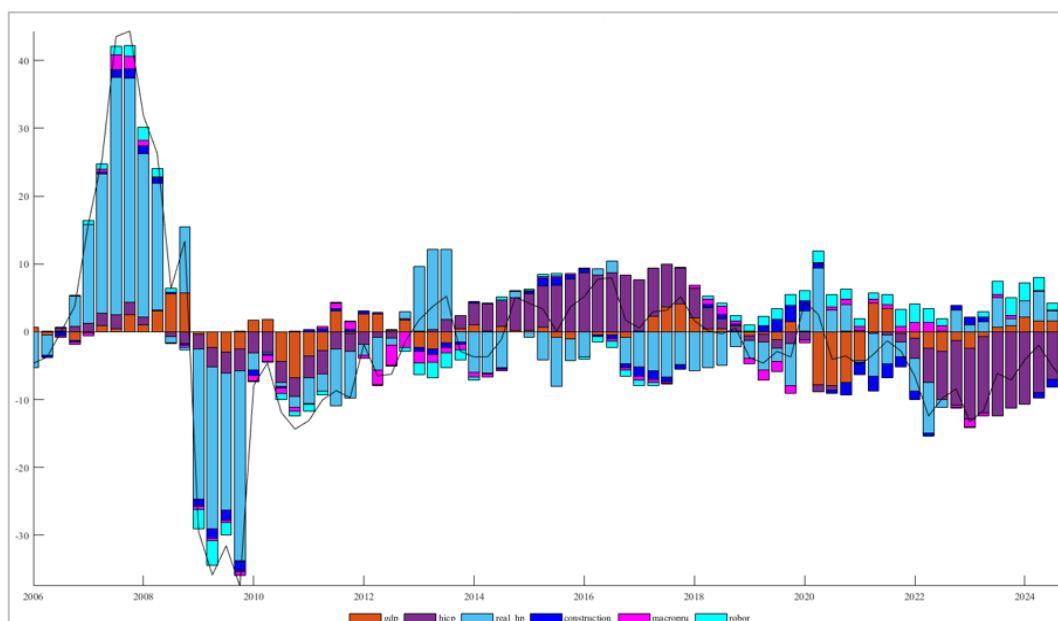
Real house prices in Romania have went through multiple phases in the last 20 years. At the GFC there was a large and almost symmetrical boom and bust cycle. Annual price growth surpassed 50% before the onset of the GFC, only then to bust to close to -40% in 2009. From then on, the housing market began a slow revamping of growth that took almost 5 years. From 2014 to 2018, house prices increased again, at relatively high paces of close to 10%, although much lower than the pre-GFC boom. From 2018 to 2021, house price stagnated, oscillating around 0% real growth. From 2022 to 2024 the market went down, showing some signs of recovery only recently. It is worth noting that is the picture of real house price, not nominal house prices, who grew more strongly. Furthermore, this is the aggregate view of the prices in the whole country, and it can differ from the situation around big cities.

##### *Cholesky ordering*

Under the Cholesky ordering, the time series decomposition of real house prices shows that multiple factors have contributed to the different phases of the market (Figure 2). The GFC boom and bust was driven almost completely by factors other than the five captured in the model. It can thus be argued that it was a bubble fueled by irrational investor behavior that resulted in a deep downturn when the bubble burst. The procyclical relaxation of macroprudential and monetary policy pre-GFC contributed to the formation of the bubble. Construction activity also played a role in inflating and deflating the bubble. In the recovery post-GFC period, house prices were mostly in line with GDP performance, marking some sporadic upturn and downturn surprises that go against the factors highlighted in our paper. From 2014 to 2018 the boom in the RRE market was strongly influenced by the evolution of inflation. The introduction of more stringent BBMs and SyRB in 2019 influenced

negatively the house prices and acted as a balancing factor to the more favorable interest rate movements. In the COVID-19 pandemic, house prices diverged from GDP as the market boomed for a short period as people were looking for more convenient houses to work remotely. The subsequent correction in prices is strongly associated with the inflation evolution. As overall prices in the economy got higher, the nominal house prices grew more modestly, thus the real price of housing decreased.

**Figure 2.** FEVD of real house price growth using Cholesky decomposition



**Source:** Authors' own contribution.

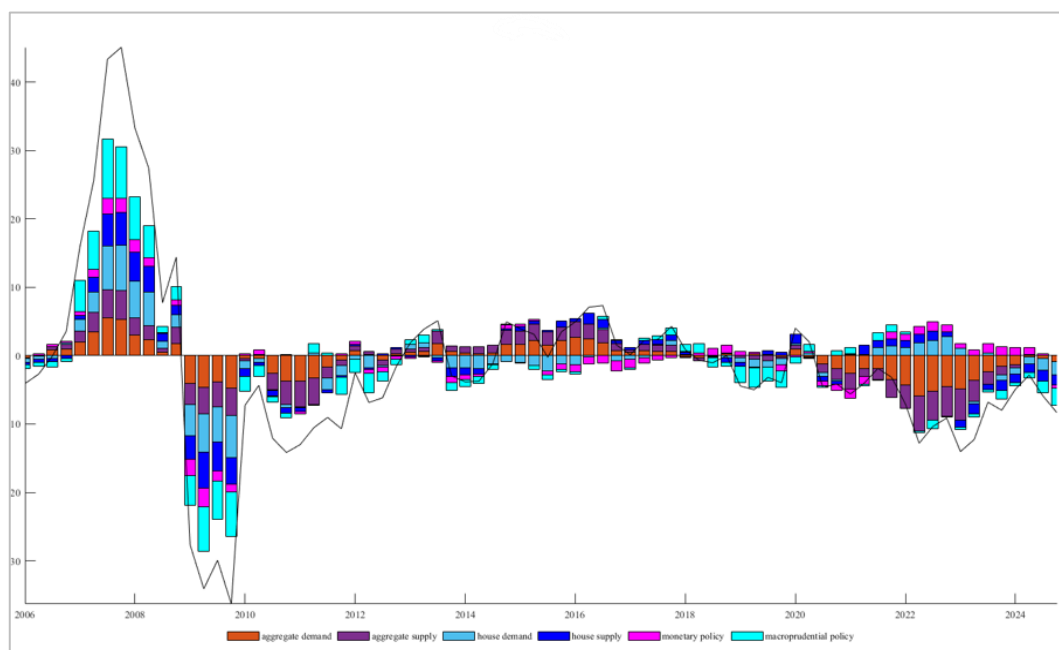
The impulse response functions to shock in variables is another type of analysis that the BVAR framework can produce. From Figure 4 it can be seen that a positive GDP shock increases house price growth by around 2 p.p. with the effect fading after 4 quarters. This strong relationship is well documented in the literature. A positive inflationary shock will depress real house prices. This again, is to be expected, as the real price of housing lowers when the overall inflation gets higher. Interestingly, a construction shock does not produce a statistically significant change in house prices. As it can be also seen in the time series decomposition, construction factors have rarely played a role in the overall house price growth. Monetary policy tightening produces a lagging contractionary shock to house price that has its maximum effect of -1 p.p. after 4 quarters, fading away afterwards. Similarly, macroprudential policy produces a contractionary shock, however with a smaller effect of -0.5% and a quicker response, but the effects are not statistically robust.

#### *Sign restrictions*

The shock identification through sign restriction poses a more balanced view of the different contributors to the variance decomposition of house price growth (Figure 3). During the GFC pump and dump of house prices, major contributors to the price movement

were aggregate demand and house demand factors. Aggregate supply and house supply were also important contributors, but the change in interest rates was only a marginal factor. However, under this setting, macroprudential policy has a decisive role in the movement of prices. The procyclical release BBMs have influenced a large part of the RRE market evolution, contributing to both the rapid increase and the abrupt decrease of prices. However, it should also be noted that a large part of the price variation could not be explained by the model, given the extreme amplitude of the RRE cycle movement. During the post-GFC recovery period, aggregate demand and supply factors continued to drag on the cycle, with the resetting of BBMs acting again in a procyclical manner. The 2014-2018 boom was driven mostly by increases in aggregate demand and aggregate supply. The introduction of the new set of BBMs starting from 2019 drove down the RRE cycle, adding to the evidence that macroprudential policy in Romania is effective in influencing house prices. After the COVID-19 pandemic, the increases in house demand and supply and relaxation of monetary conditions were not enough to offset the large downswing caused by aggregate demand and supply. In the recent quarters of 2024, the changes of house demand and supply and implementation of additional macroprudential measures were the principal factors that contributed to the downward trend in prices.

**Figure 3.** FEVD of real house price growth using sign restrictions

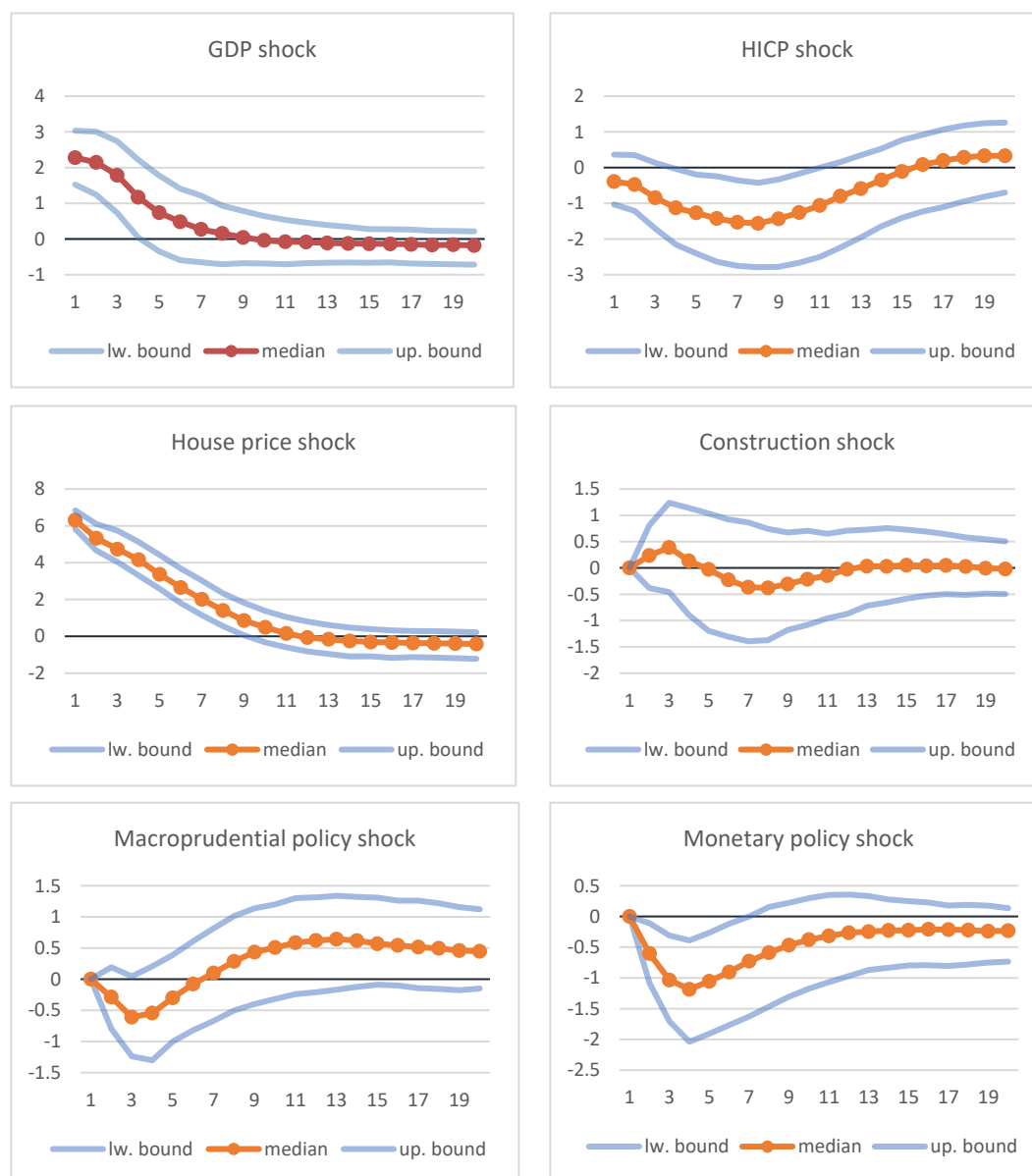


**Source:** Authors' own contribution.

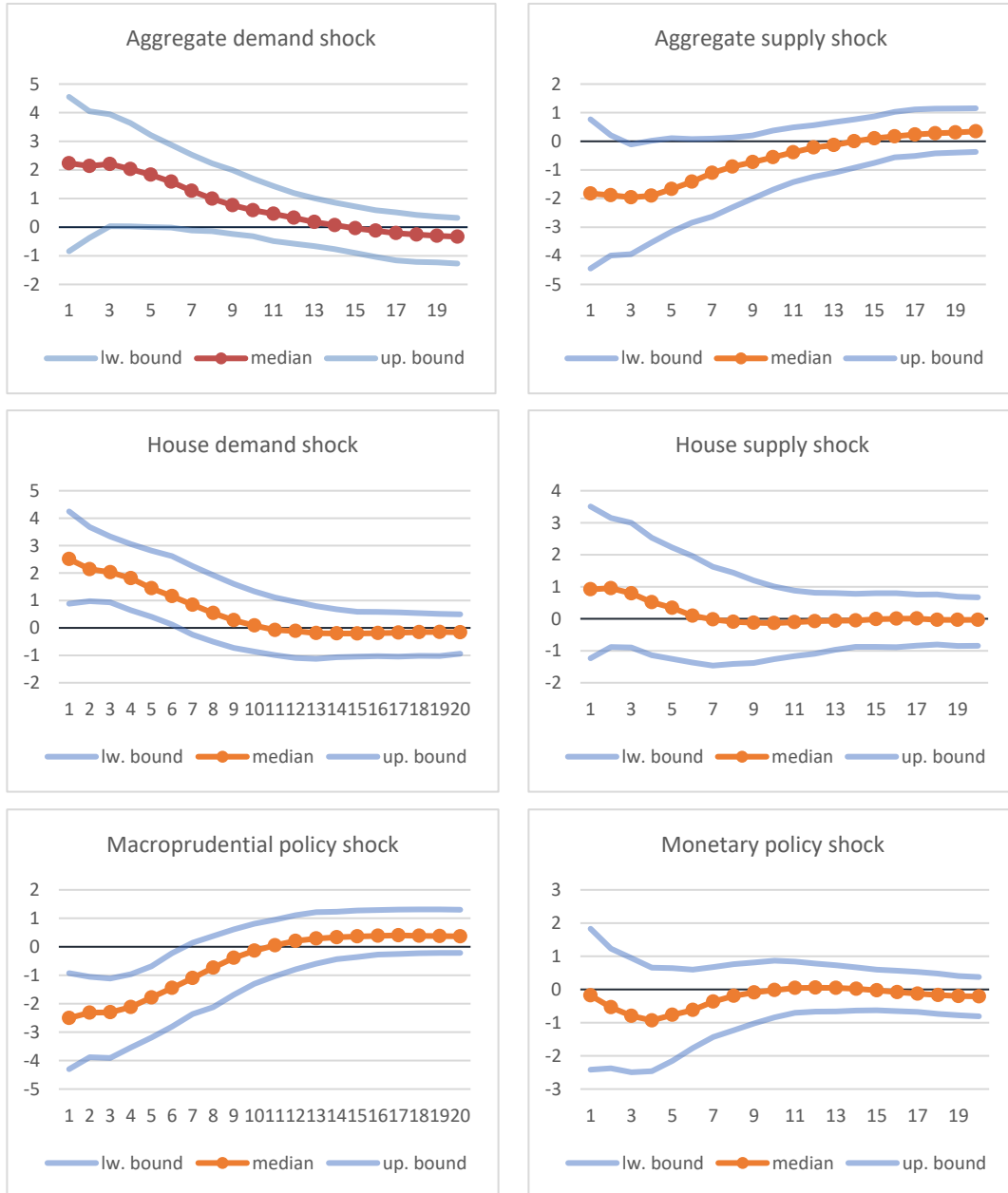
The IRF functions confirms the potency of shocks highlighted in the variance decomposition analysis (Figure 5). The aggregate demand shock increases house price growth by up to 2 p.p., with the effect lasting close to 10 quarters. Oppositely, the aggregate supply positive shock causes a drop in house prices of similar magnitude. The house demand shock has the potential to increase house price growth by more than 2 p.p., with the effect

lasting 8 quarters. However, housing supply does not cause a statistically significant shock to prices. Contrary to the results from the Cholesky decomposition, monetary policy and macroprudential policies have substantially different effects. Monetary policy registers a weak and statistically insignificant restriction in house price growth. Meanwhile, macroprudential policy has a potent effect causing over a 2 p.p. drop in house price growth, with the effect lasting 7 quarters.

**Figure 4.** IRF of real house price growth using Cholesky decomposition



**Source:** Authors' own contribution.

**Figure 5.** IRF of real house price growth using sign restrictions

**Source:** Authors' own contribution.

#### *Robustness checks*

Some robustness checks are warranted to guarantee the accuracy of the results. First of all, the BVAR were run with 2 and 3 lags as well, without significant changes of the results. Another type of test ran was to replace the construction output with a variable based on



buildings permits emitted. Similarly, the inflation measure was switched from HICP to a core HICP that excludes administered prices. Both tests did not entail significant changes in the results. Additionally, in the Cholesky ordering, the place of macroprudential policy and monetary policy were switched. No proportional differences resulted from this change, signaling that these two type of policies are independent. This aspect is out of the scope of the current paper, but features prominently in the literature (for example, Nier and Kang, 2016).

## 5. Conclusions

The current paper addressed the challenge of identifying the contributors to the RRE cycle of Romania, a small and open emerging market, over an extensive period of time, covering both the GFC and the COVID-19 pandemic. We employed a BVAR analysis with 6 variables and a standard setting of the parameters. The main results were produced through a variance decomposition and impulse response function analysis. In a first setting, we decomposed the shock using a Cholesky ordering of variables. Overall, we found that house price idiosyncratic factors were responsible for the main variation during the GFC, with inflation and GDP contributing afterwards and during the recent period. In this setting, monetary policy also played an important role, while macroprudential policy and construction activity were only marginal contributors. In a second setting, we employed an identification of shocks using sign restrictions. Aggregate demand and aggregate supply shocks play a substantial role, with house demand factor also being a major factor driving the RRE cycle. House supply shocks continue to not be statistically significant. However, in this setting, monetary policy has a limited role, while macroprudential policy has a much more important one, being capable of effectively influencing the house price growth.

The contrasting results between the two identification schemes in terms of policy effectiveness poses a challenging action plan for policy makers. Undeniably, macroprudential policy and monetary policy need to be used strategically in order to stimulate or contain house price growth. Macroprudential policy is a targeted instrument, that can cause a relatively quick reaction in house prices. Monetary policy is a blunter instrument that can affect a wider set of variables. Depending on the scale of the sought effect, the policies can be used alternatively or at the same time. Moreover, the contrasting results point out that the methodology used for shock identification can matter extensively for the results obtained. It remains up to the researcher and policy maker to choose what methods' assumptions can be better trusted over the other.

The current analysis could be extended by employing a more complex decomposition of macroprudential policies, separating into capital based and borrower based instruments. Secondly, analyzing a regional dataset of house prices could be a particularly interesting endeavor, given that, most likely, house price growth is not distributed uniformly across the country.

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## Note

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- <sup>(1)</sup> Actually only CCyB and SyRB use were considered, given that CCoB and O-SII buffers do not have a specific purpose of reducing RRE vulnerabilities.

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## **The impact of short-run and long-run dynamics on manufacturing sector development in Indonesia and Malaysia**

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**Abstract.** *This study analyzes the impact of manufacturing labor, industrial exports, lagged investment ( $t-1$ ), and industrial policy ( $t-1$ ) on manufacturing performance in Indonesia and Malaysia. The study compares short-run and long-run effects in both countries using annual data from 1991–2022 and the ARDL (Autoregressive Distributed Lag) model. In the short run, Indonesia exhibits significant positive effects from labor, exports, and lagged investment, while industrial policy has no significant impact. Malaysia records significant short-run effects from labor and exports, but not from investment and industrial policy. In the long run, all variables except industrial policy positively and significantly influence manufacturing performance in both countries. The findings highlight differing policy impacts despite structural similarities. These results imply that Indonesia should strengthen policies that sustain investment and enhance labor productivity in manufacturing. Malaysia needs to prioritize labor upgrading and export-oriented industrial strategies to ensure long-term competitiveness in the manufacturing sector.*

**Keywords:** Manufacturing performance; Labor; Industrial exports; Foreign direct investment; Industrial policy.

**JEL Classification:** F14, L60, O53.

## 1. Introduction

The manufacturing sector plays a fundamental role in the global economy, acting as a key driver of economic development, employment generation, and technological advancement (Gherghina et al., 2020; Nguimkeu & Zeufack, 2024). It involves transforming raw materials into finished goods for consumer and commercial markets (Mishra et al., 2018). Despite its critical contribution, the growth of the manufacturing industry in many countries faces several challenges, including global economic fluctuations, limited access to raw materials, stringent environmental regulations, and the impact of monetary and fiscal policies. Nevertheless, due to its high value-added and strong multiplier effects, manufacturing has enabled many developed countries to sustain economic leadership (Oladipo & Eluyela, 2019; Pahl & Timmer, 2020).

In Southeast Asia, the manufacturing industry plays a pivotal role in shaping the economies of both Indonesia and Malaysia. However, the contribution of this sector to GDP in each country has shown divergent trends. In Malaysia, the manufacturing sector's contribution to GDP increased from 22.84% in 2013 to 23.5% in 2022. In contrast, Indonesia experienced a decline from 21% in 2013 to 18.3% in 2022 (Statistics Indonesia, 2023), primarily due to the impact of the COVID-19 pandemic. During the pandemic, both countries witnessed setbacks Malaysia's manufacturing share dipped from 21.4% in 2019 to 20.9% in 2020, whereas Indonesia's contribution dropped more drastically from 19.9% in 2019 to 15.3% in 2022. Despite the disruptions, Malaysia managed to recover quickly, reaching 22.4% in 2021, suggesting greater sectoral resilience (Min & Jianwen, 2020; Song et al., 2021).

The development of the manufacturing sector in both countries has been supported by abundant natural and human resources, especially in the palm oil and rubber industries, which are key commodities for downstream industrial development and exports (Na & Kang, 2019; Ramadhani & Santoso, 2019). Over the past century, Indonesia and Malaysia have emerged as the world's largest palm oil producers, jointly accounting for nearly 85% of global crude palm oil exports (Hamidi et al., 2024). Malaysia's manufacturing base also includes pharmaceuticals, medical technologies, and electronics (Lee et al., 2022). Labor absorption in this sector is also noteworthy, with Malaysia consistently recording higher proportions 17.24% in 2022 compared to Indonesia's 14.17%.

Investment, particularly Foreign Direct Investment (FDI), is widely recognized as a crucial driver for industrial development and human capital improvement (Colen et al., 2012; Nguyen, 2022). Between 2013 and 2022, Indonesia's manufacturing industry experienced average investment growth of 33.83%, largely driven by FDI, while Malaysia recorded a higher average growth rate of 41.75%. FDI brings capital, technology, and know how to improve local production capacities and competitiveness (Ahmad et al., 2015; Fernandez et al., 2020). Additionally, industrial export performance is a vital component of manufacturing sustainability. During the same period, manufacturing exports constituted 72.96% of Indonesia's total exports and 82.17% of Malaysia's. Studies have shown that FDI positively affects export performance through spillover effects (Kastratovic, 2020; Sultanuzzaman et al., 2018).

While many studies have analyzed the determinants of Manufacturing Value Added (MVA), most focus on individual factors such as FDI, industrial exports, or labor. For instance, Borensztein et al. (1998) and Wang & Wong (2009) highlight the role of FDI and education, while Balassa (1978) and Rodrik (2009) underscore the importance of export-led industrialization. Lucas (1988) and Bloom et al. (2012) emphasize the quality of labor. However, few studies analyze the interaction of FDI, industrial exports, and labor simultaneously, especially in Indonesia and Malaysia, which share similar economic backgrounds but diverge in manufacturing outcomes.

Moreover, existing research often lacks context-specific policy insights. While Timmer et al. (2015) and OECD (2018) suggest that flexible industrial and labor regulations enhance MVA, but they do not explore policy effectiveness at the national level. Similarly, the role of technological readiness, as discussed by Lall (2000) and Ouyang et al. (2020), is rarely contextualized to country-specific innovation capabilities. Furthermore, Krugman (1994) and UNCTAD (2022) note the importance of macroeconomic stability and productivity equality, yet overlook cross-national comparisons relevant to Southeast Asia.

Given these limitations, there remains a critical research gap in understanding how FDI, industrial exports, and labor interact simultaneously to influence Manufacturing Value Added (MVA) in Indonesia and Malaysia. Most existing literature treats these factors in isolation, without examining their joint effects or comparing cross-country dynamics in detail. Furthermore, policy recommendations tailored to the specific challenges and opportunities in Indonesia and Malaysia are scarce, despite their similar industrial potentials.

This study aims to fill existing research gaps by providing a comparative analysis of how manufacturing labor, industrial exports, lagged investment, and industrial policy influence manufacturing performance in Indonesia and Malaysia. By examining both short-run and long-run dynamics using the ARDL model, this research offers evidence-based insights to support more effective industrial policies. The findings aim to inform policymakers in designing strategies that enhance labor productivity, stimulate investment, and improve export performance, thereby strengthening industrial competitiveness and promoting sustainable manufacturing growth in both countries.

## 2. Literature Review

The development of the manufacturing sector in developing countries is widely influenced by labor dynamics, industrial exports, investment, and industrial policy. Many studies confirm that labor is a fundamental factor in industrial growth, particularly through increased productivity and efficiency. According to Szirmai (2012), an abundant labor force can provide an initial competitive advantage for developing countries, while skills enhancement contributes to long-term productivity gains. An empirical study by Mahadevan, R (2007) also shows that labor has a significant impact on manufacturing output in Malaysia.

Furthermore, exports are a key driver of manufacturing growth, particularly through export-led growth mechanisms. According to Haseeb et al. (2014), exports increase economies of scale and enable companies to integrate into global value chains, thereby opening up opportunities for efficiency gains and technology transfer. Another study by Hussain et al. (2019) shows that exports are a key determinant of manufacturing growth in ASEAN countries, both in the short and long term. This confirms Krueger's (1980) classic view that trade liberalization can strengthen industrial competitiveness.

Lagged investment ( $t-1$ ) plays a strategic role in strengthening industrial capacity. The industrial growth model by Mankiw, Romer, and Weil (1992) emphasizes that physical capital formation contributes significantly to output through the accumulation of productive assets. Empirical findings by Tang, T. C., & Nair, M. (2002) using the ARDL model indicate that investment has strong short- and long-term effects on Malaysian manufacturing growth. Meanwhile, in Indonesia, Dutu (2015) asserts that increased industrial investment can improve productivity and support sustainable manufacturing growth.

Meanwhile, the effectiveness of industrial policy varies across countries. Aiginger and Rodrik (2020) argue that industrial policy will be effective if it is directed at increasing productivity, innovation, and value chain integration. However, the literature also shows that the impact of industrial policy does not always appear in the short term due to the structural nature of policies and the resulting time lag in implementation (Wade, 2016). In Malaysia, export-driven industrialization policies have been successful in boosting the medium-to-high-tech sector (Rasiah, 2010), while Indonesia faces challenges in policy consistency and institutional coordination (Aswicahyono, H., Hill, H., & Narjoko, D. (2013).

A comparison between Indonesia and Malaysia shows that although both countries have relatively similar manufacturing structures, the response of economic variables to industrial performance can differ depending on institutional conditions, trade integration, and policy quality. The ARDL approach, as introduced by Pesaran, Shin, and Smith (2001), is widely used in the literature to separate short-run and long-run effects in an industrial context. Previous research findings consistently emphasize that labor, exports, and investment are significant determinants in the long run, while industrial policies often exhibit more variable results and depend on the effectiveness of implementation. Thus, the variation in empirical results between the two countries is consistent with the literature on industrialization in East and Southeast Asia.

### 3. Data and Method

The purpose of this study is to examine the influence of manufacturing labor, industrial exports, lagged investment, and industrial policy on manufacturing performance in Indonesia and Malaysia. The analysis uses annual data from 1991 to 2022, sourced from the World Bank, Statistics Indonesia, and the Department of Statistics Malaysia. To investigate the short-run and long-run dynamics of the variable relationships in each country, this study applies the Autoregressive Distributed Lag (ARDL) bounds testing approach within a quantitative research framework. This method is suitable for small

sample sizes and allows for variables to be integrated at different levels (I(0) or I(1)), as long as none are I(2). Unit root tests are conducted to determine the stationarity of each variable before estimation. Diagnostic and stability tests are also performed to ensure model robustness.

The ARDL approach for cointegration is written in the following equation ((Shin & Pesaran, 1999):

$$\Delta MVA_t = \beta^0 + \beta^1 \Delta LABOR_t + \beta^2 \Delta EXPORT_t + \beta^3 \Delta INVEST_t + \beta^4 \Delta POLICY_t + \theta^1 LABOR_t^{-1} + \theta^2 EXPORT_t^{-1} + \theta^3 INVEST_t^{-1} + \theta^4 POLICY_{t-1} + \mu + \varepsilon_t \quad (1)$$

The Error Correction Model (ECM) is obtained by using a single-vector autoregressive and using the lag length criteria:

$$\Delta MVA_t = \beta^0 + \sum_{j=1}^p \beta^1 \Delta MVA_{t-j} + \sum_{j=0}^p \beta^2 \Delta LABOR_{t-j} + \sum_{j=0}^p \beta^3 \Delta EXPORT_{t-j} + \sum_{j=0}^p \beta^4 \Delta INVEST_{t-j} + \sum_{j=0}^p \beta^5 \Delta POLICY_{t-j} + \lambda ECT_{t-1} \quad (2)$$

Where  $ECT_t$  is the error correction term written in the equation:

$$ECT_t = MVA_t - \beta^0 - \beta^1 LABOR_t^{-1} - \beta^2 EXPORT_t^{-1} - \beta^3 INVEST_{t-1} - \beta^4 POLICY_{t-1} \quad (3)$$

Manufacturing value added (MVA), used as a proxy for manufacturing sector performance. Manufacturing labor (LABOR): percentage of employment in the manufacturing sector of total employment. Industrial exports (EXPORT): value of manufactured goods exported. Lagged investment (INVEST<sub>t-1</sub>): foreign direct investment in the previous year. Lagged industrial policy (POLICY<sub>t-1</sub>): industrial development policy or intervention lagged one year. Separate models are estimated for Indonesia and Malaysia, allowing for a comparative analysis of the variables' effects on manufacturing performance across countries.

## Results and Discussion

Before estimating the ARDL model, a unit root test was conducted using the Augmented Dickey-Fuller (ADF) method to determine the order of integration for each variable. The test results indicate that the variables Manufacturing Performance, Labor in Manufacturing, Industrial Export, and Investment (t-1) are non-stationary at their level form but become stationary after first differencing.

**Table 1.** Unit Root Test Indonesia (ADF)

| Variable                  | Level  |       | First Difference |       | Integration Order |
|---------------------------|--------|-------|------------------|-------|-------------------|
|                           | Stat   | Prob  | Stat             | Prob  |                   |
| Manufacturing Performance | -1.844 | 0.225 | -5.432           | 0.000 | I(1)              |
| Labor in Manufacturing    | -2.003 | 0.182 | -4.985           | 0.001 | I(1)              |
| Industrial Export         | -1.642 | 0.290 | -6.210           | 0.000 | I(1)              |
| Investment (t-1)          | -2.314 | 0.129 | -4.612           | 0.002 | I(1)              |
| Industrial Policy (t-1)   | -3.710 | 0.034 | –                | –     | I(0)              |

Source: Authors, 2024.

This is evidenced by their non-significant p-values at level and highly significant p-values ( $p < 0.05$ ) at the first difference. Consequently, these four variables are considered to be integrated of order one, or  $I(1)$ .

In contrast, the variable Industrial Policy (t-1) is found to be stationary at level, as indicated by an ADF test statistic of -3.710 and a p-value of 0.034, which is significant at the 5% level. Therefore, it is classified as  $I(0)$ . The combination of  $I(0)$  and  $I(1)$  variables satisfies the prerequisites for applying the ARDL approach, as the ARDL model is appropriate for time series data in which variables are integrated at different levels.

**Table 2.** Unit Root Test Malaysia

| Variable                  | Level  |       | First Difference |       | Integration Order |
|---------------------------|--------|-------|------------------|-------|-------------------|
|                           | Stat   | Prob  | Stat             | Prob  |                   |
| Manufacturing Performance | -1.625 | 0.308 | -5.530           | 0.000 | $I(1)$            |
| Labor in Manufacturing    | -1.954 | 0.211 | -4.980           | 0.001 | $I(1)$            |
| Industrial Export         | -1.730 | 0.256 | -6.140           | 0.000 | $I(1)$            |
| Investment (t-1)          | -2.390 | 0.170 | -4.540           | 0.002 | $I(1)$            |
| Industrial Policy (t-1)   | -3.460 | 0.049 | –                | –     | $I(0)$            |

Source: Authors, 2024.

The findings indicate that Manufacturing Performance, Labor in Manufacturing, Industrial Export, and Investment (t-1) exhibit non-stationarity at their level form but become stationary after taking the first difference, as evidenced by their insignificant p-values at level and significant p-values ( $p < 0.05$ ) after differencing. These results suggest that the four variables are integrated of order one, or  $I(1)$ .

Conversely, Industrial Policy (t-1) is found to be stationary at level, with an ADF statistic of -3.460 and a p-value of 0.049, indicating it is integrated of order zero, or  $I(0)$ . The presence of variables integrated at both  $I(0)$  and  $I(1)$  levels confirms the suitability of the ARDL methodology.

**Table 3.** Cointegration Test (ARDL Bounds Test)

| Test Component           | Indonesia                    | Malaysia                     |
|--------------------------|------------------------------|------------------------------|
| F-Statistic              | 5.987                        | 5.623                        |
| Number of Regressors (k) | 4                            | 4                            |
| Critical Value (5%)      | $I(0)$ : 2.86, $I(1)$ : 4.01 | $I(0)$ : 2.86, $I(1)$ : 4.01 |
| p-value                  | 0.002                        | 0.004                        |

Source: Authors, 2024.

The results of the ARDL Bounds Test for cointegration for both Indonesia and Malaysia. For Indonesia, the F-statistic is 5.987, while for Malaysia it is 5.623. In both cases, the number of regressors (k) is 4, and the corresponding critical values at the 5% significance level are 2.86 for  $I(0)$  and 4.01 for  $I(1)$ . Since the calculated F-statistics for both countries exceed the upper critical value ( $I(1)$ ) at the 5% level, the null hypothesis of no long-run relationship is rejected.

Additionally, the p-values for Indonesia (0.002) and Malaysia (0.004) are both below the 0.05 threshold, further confirming the presence of cointegration. These results indicate that a long-run equilibrium relationship exists among the variables in each model, justifying the use of the ARDL approach for both Indonesia and Malaysia.



**Table 4.** *ARDL Estimation Results for Indonesia*

| Variable                          | Coefficient | Std. Error | t-Statistic | Prob. | Significance |
|-----------------------------------|-------------|------------|-------------|-------|--------------|
| <b>Short-Run Coefficients (D)</b> |             |            |             |       |              |
| D(Labor in Manufacturing)         | 0.365       | 0.092      | 3.967       | 0.001 | ***          |
| D(Industrial Export)              | 0.412       | 0.110      | 3.745       | 0.002 | ***          |
| D(Investment (t-1))               | 0.291       | 0.085      | 3.424       | 0.004 | ***          |
| D(Industrial Policy (t-1))        | 0.073       | 0.068      | 1.074       | 0.298 | -            |
| ECT(-1)                           | -0.572      | 0.113      | -5.062      | 0.000 | ***          |
| <b>Long-Run Coefficients</b>      |             |            |             |       |              |
| Labor in Manufacturing            | 0.628       | 0.131      | 4.794       | 0.000 | ***          |
| Industrial Export                 | 0.534       | 0.154      | 3.468       | 0.003 | ***          |
| Investment                        | 0.447       | 0.121      | 3.694       | 0.002 | ***          |
| Industrial Policy                 | 0.092       | 0.081      | 1.136       | 0.271 | -            |

**Note:** \*\*\* indicates statistical significance at the 1% level, \*\*5%, \*10%.

**Source:** Authors, 2024.

The ARDL estimation results for Indonesia indicate the presence of both short-run and long-run relationships between the independent variables and the dependent variable, as evidenced by the Error Correction Term (ECT) value of -0.572, which is statistically significant at the 1% level. The negative and significant ECT coefficient suggests that the model has a mechanism for correcting disequilibrium, with approximately 57.2% of the deviation from the long-run equilibrium being adjusted within one period.

In the short run, labor in the manufacturing sector, industrial exports, and lagged investment all contribute positively and significantly to output. Specifically, a 1% increase in labor in manufacturing leads to a 0.365% rise in output, while a 1% increase in industrial exports results in a 0.412% output increase. Investment from the previous period also has a positive impact, with a coefficient of 0.291. In contrast, industrial policy in the previous period does not show a significant effect in the short run, with a p-value of 0.298, suggesting that its contribution to output may not yet be substantial or may require more time for implementation.

**Table 5.** *ARDL Estimation Results for Malaysia*

| Variable                          | Coefficient | Std. Error | t-Statistic | Prob. | Significance |
|-----------------------------------|-------------|------------|-------------|-------|--------------|
| <b>Short-Run Coefficients (D)</b> |             |            |             |       |              |
| D(Labor in Manufacturing)         | 0.398       | 0.089      | 4.472       | 0     | ***          |
| D(Industrial Export)              | 0.376       | 0.103      | 3.65        | 0.002 | ***          |
| D(Investment (t-1))               | 0.086       | 0.093      | 0.925       | 0.366 | -            |
| D(Industrial Policy (t-1))        | 0.065       | 0.071      | 0.915       | 0.37  | -            |
| ECT(-1)                           | -0.609      | 0.107      | -5.692      | 0     | ***          |
| <b>Long-Run Coefficients</b>      |             |            |             |       |              |
| Labor in Manufacturing            | 0.642       | 0.134      | 5.958       | 0     | ***          |
| Industrial Export                 | 0.488       | 0.136      | 4.088       | 0.001 | ***          |
| Investment                        | 0.275       | 0.123      | 2.537       | 0.021 | **           |
| Industrial Policy                 | 0.102       | 0.079      | 1.101       | 0.286 | -            |

**Note:** \*\*\* indicates statistical significance at the 1% level, \*\*5%, \*10%.

**Source:** Authors, 2024.

In the long run, the three variables labor, industrial exports, and investment—continue to exhibit positive and significant effects on output. Labor in manufacturing has the strongest long-run impact with a coefficient of 0.628, followed by industrial exports at 0.534, and

investment at 0.447. However, industrial policy again shows an insignificant effect in the long run, with a p-value of 0.271. This indicates that the effectiveness of industrial policy needs to be reassessed and strengthened to provide a meaningful contribution to industrial output growth in Indonesia.

The ARDL estimation for Malaysia provides empirical evidence of a dynamic adjustment process, where both short-term fluctuations and long-term relationships exist between the independent variables and industrial output. This is confirmed by the Error Correction Term (ECT), which is negative and statistically significant at the 1% level, with a value of -0.609. This indicates that deviations from the long-run equilibrium are corrected by nearly 61% in the following period, suggesting a relatively strong speed of adjustment toward long-term stability.

In the short run, the variables representing labor in the manufacturing sector and industrial exports are found to significantly influence output. An increase of 1% in manufacturing labor corresponds to a 0.398% rise in output, while a similar increase in industrial exports leads to a 0.376% increase. Both variables exhibit high statistical significance, implying their immediate responsiveness in supporting short-term growth. In contrast, investment and industrial policy lagged by one period—do not show significant effects in the short term, suggesting that their influence may be delayed or indirect, possibly reflecting the time it takes for such measures to translate into tangible economic outcomes.

Over the long term, labor in manufacturing remains the most influential factor, with a coefficient of 0.642, highlighting its central role in driving sustained industrial output. Industrial exports continue to contribute positively with a coefficient of 0.488. Interestingly, investment despite being insignificant in the short-term equation becomes significant in the long run with a coefficient of 0.275, pointing to the importance of consistent capital accumulation over time. However, industrial policy does not show a statistically significant effect, even in the long term, with a relatively low coefficient of 0.102 and a p-value of 0.286, raising questions about the efficacy or implementation strength of existing policy measures.

### **Discussion and Recommendation Policy**

These findings provide critical insights into the dynamics of factors influencing the performance of the manufacturing sector in Indonesia and Malaysia, both in the short and long run. In the short term, Indonesia shows a significant positive response to labor, exports, and lagged investment. This is in line with the findings of Rodrik (2018) who emphasized that the manufacturing sector in developing countries is very sensitive to changes in production inputs and external forces such as global demand. This indicates that manufacturing production activities in Indonesia are quite sensitive to quantitative changes in real economic inputs. For instance, increasing global demand and export activities is quickly translated into higher manufacturing output. Additionally, although investment effects are lagged, they still appear to influence output in the short run, likely due to project backlogs or accelerated investment realization by the government and private sector. These

results support the study by Szirmai & Verspagen (2015) which found that investment has a significant impact on manufacturing output, especially in countries with a developing industrial base. On the other hand, industrial policy in Indonesia does not show a significant short-term impact, suggesting that the government's role in boosting this sector through policy interventions may not yet be effective, lacks coordination, or requires more time for implementation before observable results emerge.

In contrast, Malaysia exhibits a similar pattern to Indonesia regarding the short-term positive impact of labor and exports on manufacturing performance. However, unlike Indonesia, investment and industrial policies in Malaysia do not have an immediate impact in the short term. Economically, this condition may reflect that Malaysia's investment structure flows more heavily into the non-manufacturing sector, thus requiring a longer time for investment transmission to the industrial sector. This finding aligns with Doner, R. F. (2016), who asserted that industrial transformation in Southeast Asia is often hampered by institutional fragmentation and dependence on specific sectors that do not always directly support manufacturing upgrading. Furthermore, the ineffectiveness of Malaysian industrial policies in the short term may indicate that policy design and implementation do not fully address the needs of industry players. Yusuf, S., & Nabeshima, K. (2020) explain that the success of industrial policies is highly dependent on government coordination capacity and intersectoral alignment; therefore, if coordination is weak, policies tend to produce delayed effects. In the Malaysian context, complex bureaucracy and the gap between policy formulation and implementation may explain why the impact of new policies is felt over a longer time horizon.

In the long run, both countries demonstrated that labor, exports, and investment are the main determinants of manufacturing performance, while industrial policy has yet to exert a significant impact. This finding aligns with Bartelme, D. (2024) findings, which show that despite the manufacturing sector's large economies of scale, the impact of industrial policy is often "non-transformative" due to its limited welfare effects. This confirms that efficient labor markets and long-term investment structures play a stronger role in driving productivity gains than poorly targeted policy interventions. Furthermore, a study by Gebrewolde, T. M., & Rockey, J. (2022) found that industrial policy in developing countries often fails to increase productivity or production capacity when it is not tailored to the industry's actual needs, resulting in a lack of impact even over long-time horizons. Rodrik (2023) also emphasized that the effectiveness of industrial policy is highly dependent on coordination mechanisms and institutional capacity; when bureaucracy is less responsive and regulatory overlap exists, policies struggle to generate long-term structural transformation. Therefore, the lack of long-term impact of industrial policy signals that existing policies lack a strategic orientation or adequate implementation design to promote sustainable manufacturing growth.

The differences in policy impacts between the two countries, despite their structural economic similarities, underscore the need for a more context-specific and adaptive policy approach. For Indonesia, these results confirm that strengthening investment and labor

productivity must be a top priority in the national manufacturing development agenda. Regulatory reform is a critical starting point the OECD notes that legal certainty, simplified licensing, and improved bureaucracy are key factors in creating a more competitive investment climate and attracting productive capital flows to the industrial sector. At the same time, improving workforce quality requires a more comprehensive strategy than simply expanding formal education. A study by the ADB (2021) emphasizes the importance of upskilling and reskilling the workforce to adapt to the needs of Industry 4.0, including the digitalization and automation of production processes. Additional evidence from Pambudi (2020) indicates that vocational education in Indonesia still faces a gap between graduate competencies and actual industry needs, making curriculum updates and partnerships with the private sector crucial for improving workforce readiness. Furthermore, Tjiptady, B. C., & Yoto, T. (2019) emphasize that technical training based on the latest technology is essential for increasing manufacturing productivity in the digital era. Thus, the combination of investment regulatory reform and improving the quality of the workforce through vocational and technical training provides an important foundation for Indonesia to strengthen its manufacturing competitiveness in the long term.

On the other hand, Malaysia needs to focus more on enhancing labor quality and revitalizing its export strategy. The country's shift toward medium- and high-tech manufacturing products must be supported by workforce development and innovation incentives at the enterprise level. Malaysia must also reorient its industrial policy to be more integrated into the global value chain, encouraging businesses to move beyond raw or semi-finished exports toward high-value-added final products. This requires stronger collaboration between the government, industrial actors, research institutions, and educational bodies.

The effectiveness of industrial policy in supporting manufacturing growth must be thoroughly evaluated in both countries. Such evaluation should be based on data and empirical evidence while considering structural challenges, technological changes, and global market dynamics. Industrial policy should not merely exist as macro-strategy documents, but must also be translated into concrete programs that enhance productivity, competitiveness, and sustainability within the sector. A policy approach that is evidence-based, participatory, and forward-looking is essential for Indonesia and Malaysia to ensure that their manufacturing sectors can serve as reliable engines of national economic growth amidst global uncertainties.

## **Conclusion**

This study has explored the short- and long-run determinants of manufacturing performance in Indonesia and Malaysia by examining the roles of labor, exports, investment, and industrial policy. The empirical findings reveal that, in the short run, labor and exports significantly influence manufacturing output in both countries. In Indonesia, lagged investment also plays a significant role, indicating the responsiveness of manufacturing activities to real economic inputs. Conversely, industrial policy in both

countries appears to lack short-term impact, suggesting implementation delays or ineffectiveness in addressing immediate sectoral needs.

In the long run, labor, exports, and investment continue to show a strong and positive influence on the manufacturing sector in both Indonesia and Malaysia. However, the persistent insignificance of industrial policy points to structural weaknesses in the formulation and execution of such policies. This highlights a critical gap between policy intent and outcomes, emphasizing the need for evidence-based, industry-driven, and forward-looking policy frameworks.

The policy implications are clear. For Indonesia, strengthening labor productivity through skill development and promoting a more conducive investment environment are essential for sustaining manufacturing growth. Reforms should target regulatory efficiency, investment incentives, and the alignment of workforce skills with industrial needs, particularly in the context of digital and automated production. For Malaysia, the focus should be on upgrading labor capabilities and refining its export-oriented industrial strategies. The country must support innovation and industrial transformation toward higher value-added manufacturing by fostering collaboration between government, industry, and research institutions. Additionally, reorienting industrial policy to integrate more fully with global value chains will be critical in maintaining competitiveness.

Ultimately, both countries must reassess the design and delivery of industrial policy to ensure it evolves beyond strategic documents into actionable programs that enhance productivity, innovation, and resilience in the manufacturing sector. A coordinated and data-driven approach will be vital for making the manufacturing sector a key engine of sustainable economic development in the face of ongoing global uncertainty.

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## **Purchasing Power Parity theory in exchange rate determination: evidences from the G-20 nations**

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**Abstract.** *This research work is focused on evaluating the Purchasing Power Parity (PPP) theory using a sample of the top 20 economies of the world (G-20 countries) for the time period 1960-2022. The primary objective of the research is to understand the implications and utility of PPP theory in the context of time. Additionally, the research aims to test the effectiveness of the PPP theory in the exchange rate determination process. The study relies on derived and actual measures of exchange rates for analysis. It also tries to develop a model for exchange rate determination based on the PPP theory and do a comparative analysis of the results. The study highlights the inefficiencies and efficiencies of the system to suggest for areas of improvement with effective policy implications. The research has found more conclusive evidence supporting the PPP theory in short to medium term rather than long term. Also, it highlights that the actual exchange rates are not caused by price and inflation dynamics, contrary to the common rationale.*

**Keywords:** PPP, Foreign exchange, G-20 nations, Macroeconomics.

**JEL Classification:** F31, F45, F63.

## 1. Introduction

Foreign exchange rates are a type of commodity which has a usage in almost all sectors of an economy [Kilian & Zhou; Adler & Tovar (2014)]. Foreign exchange market includes traders, investors, speculators and arbitrageurs operating at individual and institutional level. The Purchasing Power Parity (PPP) theory is an economic theory that asserts that exchange rates between the currencies of two countries are in equilibrium when their purchasing power is the same for a given basket of goods and services [see Rogoff (1996); O'Connell (1998)]. In other words, PPP suggests that the exchange rate between two currencies should equalize the prices of identical goods and services in different countries, once converted into a common currency [Frankel & Rose (1996); Vo & Vo (2023)]. The 'absolute PPP' theory suggests that the exchange rate between two currencies should be such that a basket of goods and services costs the same in both countries when measured in a common currency. The 'relative PPP' theory relaxes the assumption of identical baskets of goods and services. It suggests that the rate of change in exchange rates should be equal to the rate of change in relative price levels between countries [see Taylor (2002); Rogoff (1996); O'Connell (1998)].

A central bank adopts a monetary strategy to affect various macroeconomic parameters such as inflation, exchange rate and economic growth (Ahmad & Premaratne, 2020). Kasem & Al-Gasaymeh (2022) studied the relationship between exchange rate, domestic and foreign price levels for the selected countries. Exchange rate determination is an integral and imperative process of international macroeconomics [Stockman (1980); Rossi (2013); Altavilla & De Grauwe (2010)]. Taylor (1995) observes that the exchange rate economics has been the most dynamic and challenging area of the last 20 years. Bilson (1984) and Hau & Rey (2006) comment that the early exchange rate theories faltered because they relied primarily on trade balance and price levels, as well as their lack of addressing the speed of transmission of information in the study variables. Sbeiti et al., (2025) studied the interaction of foreign exchange rates with other macroeconomic variables for the BRICS countries.

The local foreign exchange rate is a derived price and should move in consonance with the local inflation rate and with the local demand/supply dynamics in free market system. Oh (1996) reports the results of unit root tests for real exchange rates using a panel framework and found evidence supporting PPP over the recent flexible exchange rate period for G-6 and OECD countries. In the short run, there is a possibility that exchange rates deviate from PPP measures however, the vast majority of economic theories suggest that PPP holds in the long run. Quy et al., (2023) found evidence of PPP utility in foreign exchange price determination whereas studies [O'Connell (1998); Wu et al. (1999)] are among those who rejected the influence of PPP in foreign exchange determination.

The PPP is also closely related to the 'law of one price' (Isard, 1977) which states that in the absence of transportation costs and trade barriers, identical goods should have the same price in different markets when expressed in a common currency. The 'Big Mac Index', is another popular and less formal measure of PPP derived from burger prices (Atla, 2014). The PPP has several implications for international economics and finance. It can be applied as an economic measure to predict movements in exchange rates [Taylor (2002); Rogoff

(1996)]. It highlights the arbitrage opportunities in the foreign exchange markets where price differences can be exploited by arbitrageurs [Frankel & Rose (1996); Vo & Vo (2023)]. PPP can be used as a benchmark for assessing the valuation of different currencies in concurrence with Rogoff (1996).

A contrary view (see Rogoff, 1996) for the PPP theory is based on the assumption of identical baskets of goods and services across countries which may not hold in reality due to differences in preferences, quality, and availability of goods. The factors such as transportation costs, trade barriers and taxes will always create a price differential between currencies. Also, that PPP holds better in the long run rather than in the short run as short-term deviations can occur due to sporadic factors such as speculation [see O'Connell (1998); Frankel & Rose (1996); Vo & Vo (2023)].

### 1.1. Need of the study

The PPP theory is one of the prominent and applied theories of foreign exchange rate determination. This study collects evidences from a sample of G-20 countries to further strengthen the effectiveness and application of the PPP theory. Kasem & Al-Gasaymeh (2022) examines the validity of Purchasing Power Parity between Jordan and Turkey, Qatar, Iraq, United Arab Emirates and Saudi Arabia. There have been several studies on testing the PPP theory but hardly any study is found which focuses on the G-20 nations. The G-20 nations influence the economies and currencies of the world because of their scale of contribution to the global income and thus a study on these countries is expected to shed light on new findings.

*G-20 Members:* As per 'www.g20.org', the Group of Twenty (G-20) comprises 19 countries (Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Republic of Korea, Mexico, Russia, Saudi Arabia, South Africa, Türkiye, United Kingdom and United States) and two regional bodies, the European Union and the African Union (as in the year 2023). The G-20 members represent around 85% of the global GDP, over 75% of the global trade, and about two-thirds of the world population. Any macroeconomic study with G-20 countries as a sample will have wider acceptability and usage.

## 2. Literature Review

The process of foreign exchange rate determination is an integral part of the international macroeconomic structure [see Gabaix & Maggiori (2015); Dornbusch (1976); Taylor (1995); Flood & Rose (1999)]. Theories such as International Fisher Effect (IFE) and Purchasing Power Parity (PPP) govern the process of exchange rate determination [Hau & Rey (2006); Perera et al. (2018); Quy et al. (2023)]. The earliest reference to PPP dates to sixteenth century in Spain (Rogoff, 1996) when economists began exploring the idea of parity between different currencies based on their purchasing power. However, PPP theory gained prominence in the 20th century with the development of formal economic models and empirical testing methodologies (Cassel, 1918).

Purchasing Power Parity (PPP) theory remains a cornerstone in exchange rate determination studies, positing that currencies will adjust to equalize the cost of a basket of goods across different countries. This theoretical framework, vital for understanding international financial mechanisms, has been extensively explored, analysed, and contested within the academic community. Choji & Sek (2023) delve into the PPP theory through a rigorous cross-sectional dependence panel data analysis encompassing sixteen developed countries and affirm the theory's relevance in gauging exchange rate movements. Khan & Qayyum (2007) present a compelling case for PPP in Pakistan and provide substantive evidence supporting the presence of a long-run PPP effect. Oh (1996) found evidence supporting PPP in a flexible exchange rate regime for G-6 and OECD countries. O'Connell (1998) found no evidence against the random walk null hypothesis in a panel of 64 real exchange rates. Vo & Vo (2023) studied the application of PPP theory and observed that the forces of arbitrage and resource re-allocation are sufficient to overcome many of these distortions of the foreign exchange rates in the longer term. Kasem & Al-Gasaymeh (2022) applied unit root tests and Johansen cointegration test to analyze the data during 2000-2020. Taylor (2002) provides evidence of long-run PPP for OECD countries using panel data analysis. However, empirical support for PPP is mixed in the short run, with deviations from parity attributed to factors such as transaction costs, trade barriers, non-tradable goods, and market imperfections (Engel & Rogers, 1996). PPP also tends to hold better in the long run than in the short run, and short-term deviations can occur due to factors like speculative trading, capital flows, and macroeconomic shocks (Rogoff, 1996).

There have been several studies [see Gasaymeh (2022); Quy et al. (2023)] on testing the PPP theory but no study was found focused on the G-20 countries. This study adds to the novelty by deriving a PPP based exchange rate and comparing it with the actual exchange to analyse the inefficiencies. Considering the research aim and objective, three null hypotheses are formulated,

- Null Hypothesis 1 (H01): *Derived ER and Inflation rate are not significantly correlated [see Stockman (1980); Rossi (2013); Gabaix & Maggiori (2015)].*
- Null Hypothesis 2 (H02): *Actual ER and Inflation rate are not significantly correlated [see Dornbusch (1976); Altavilla & De Grauwe (2010)].*
- Null Hypothesis 3 (H03): *There is no significant difference between the derived ER and actual ER [see Taylor (1995); Flood & Rose (1999)].*

### 3. Research Methodology

The primary objective of the research is to evaluate the PPP theory and its effectiveness in exchange rate determination. Additionally, PPP theory is evaluated over the time horizon and its interactions with price and inflation. Researchers have employed various econometric techniques to test PPP theory, including unit root tests, cointegration analysis, panel data methods, and time series models [see MacDonald (1996); Narayan (2022); Kilicarslan (2018)]. These methodologies aim to assess the stationarity of exchange rates and relative prices, estimate long-run equilibrium relationships, and identify deviations from PPP (Cheung & Lai, 1993). This research applies descriptive analysis, correlation analysis, regression analysis (see Sbeiti et al., 2025) including panel regressions (Hausman,

1978) and the Ganger causality analysis (Granger, 1987). A ‘paired t test’ is conducted to validate the difference in actual exchange rate and the derived exchange rate.

Inflation, prices and exchange rates have been used as the primary study variables for the sample countries (see table 1 and 2). Annual average values for these variables have been considered for the time period 1960 to 2022. Effectively the analysis is done for 18 countries, excluding the European Union and African Union. Inflation is measured as the consumer price index reflecting the annual percentage change in the cost to the average consumer of acquiring a basket of goods and services. Official exchange rate refers to the exchange rate determined by national authorities or to the rate determined in the legally sanctioned exchange market. It is calculated as an annual average based on monthly averages (local currency units relative to the U.S. dollar). Economists widely use CPI or basket of goods to derive and compare foreign exchange rates ([www.forex.com](http://www.forex.com)).

**Table 1.** Study variables

| Variable             | Explanation                                                      | Source                                       |
|----------------------|------------------------------------------------------------------|----------------------------------------------|
| <i>Inflation</i>     | Inflation, consumer prices (annual %)                            | World Development Indicators, The World Bank |
| <i>Exchange rate</i> | Official exchange rate (LCU per US\$, period average)            | World Development Indicators, The World Bank |
| <i>Prices</i>        | Consumer price index (base 2010 = 100). Data is period averages. | World Development Indicators, The World Bank |

To study the PPP theory, exchange rates have been derived as in equation 1. For the purpose a derived measure (DER) and the actual measure of foreign exchange rates (AER) are considered or analysis. Derived Exchange Rates ( $DER_{xy}$ ) were calculated following the PPP theory and using the prices for respective countries (see equation 1). The prices for the United States (US) were considered as the common standard country prices.

$$DER_{xy} = Price_x / Price_y \quad \dots (1)$$

Here, ‘x’ is the foreign country price and ‘y’ is the US Price. The Consumer Price Index (see table 1) has been used as proxy to represent country prices, respectively. Subsequently, deviations were calculated between actual exchange rates (AER) and derived exchange rates as equation 2. Here, ‘t’ is the respective year which varies from 1960 to 2022.

$$DEV_t = AER_t - DER_t \quad \dots (2)$$

$$DEV_t = [(AER_t - DER_t) / AER_t] * 100 \quad \dots (3)$$

Two types of averages and one yearly time series, based on  $DEV_t$ , were used to analyse the short term, medium term and long-term trends in the gap or deviations of PPP exchange rate (DER) from the actual exchange rate (AER). The 63 years average represents long term deviations and 5 years average indicating medium term deviations. The annual deviations represent the short-term deviations between AER and DER.

#### 4. Data Analysis

This section illustrates the data and related calculations and comment on the outcome. Based on equation (1, 2, 3), table 2 indicates the average gap (deviation) between actual exchange rate and derived exchange rate for the full time period (63 years) across countries. The maximum difference between actual and derived exchange rate was observed for Japan (99.9%) while the lowest was observed for Canada (12.7%). The composite overall average

for 63 years across countries is 62%, implying that in long term PPP theory does not holds and the PPP exchange rates deviates from the actual exchange rates. Table 2 can also be read together with chart 1, which depicts the trends in annual average deviations across countries. A country is represented by the respective serial number (see table 2).

**Table 2.** *Average deviations (1960-2022)*

| Sl.No. | Country             | Average deviation (%) |
|--------|---------------------|-----------------------|
| 1      | Argentina           | NA                    |
| 2      | Australia           | 26.21                 |
| 3      | Brazil              | 72.28                 |
| 4      | Canada              | 12.73                 |
| 5      | China               | 91.66                 |
| 6      | France              | 43.15                 |
| 7      | United Kingdom (UK) | 88.88                 |
| 8      | Indonesia           | 97.4                  |
| 9      | India               | 55.01                 |
| 10     | Italy               | 99.11                 |
| 11     | Japan               | 99.91                 |
| 12     | South Korea         | 92.48                 |
| 13     | Mexico              | NA                    |
| 14     | Russian Federation  | 67.95                 |
| 15     | Saudi Arabia        | 51.59                 |
| 16     | Turkiye             | 84.88                 |
| 17     | United States       | -54.19                |
| 18     | South Africa        | NA                    |

**Chart 1:** *Yearly deviations (%)*

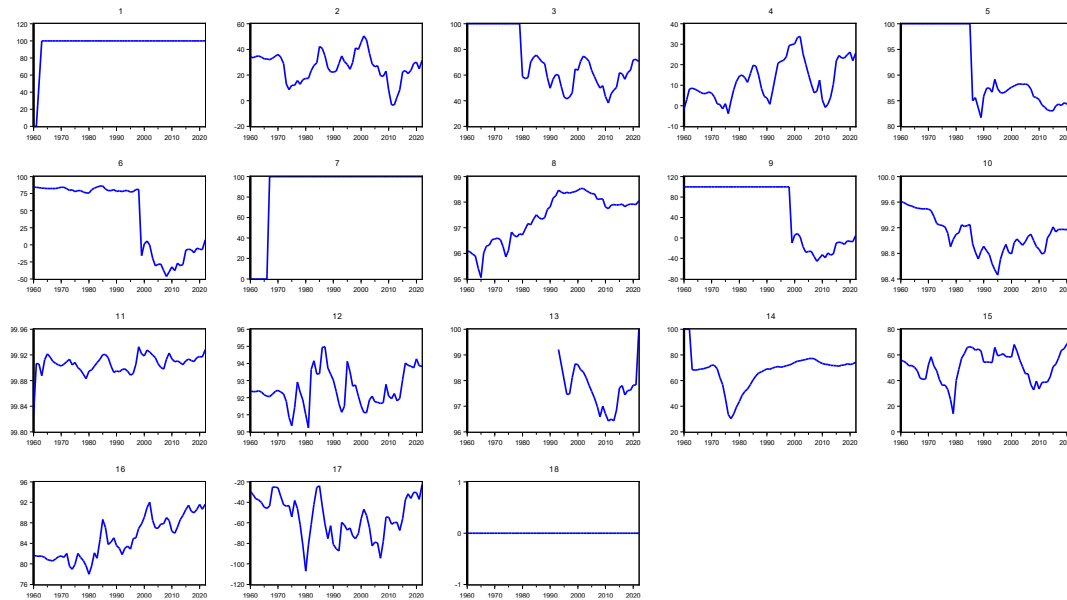
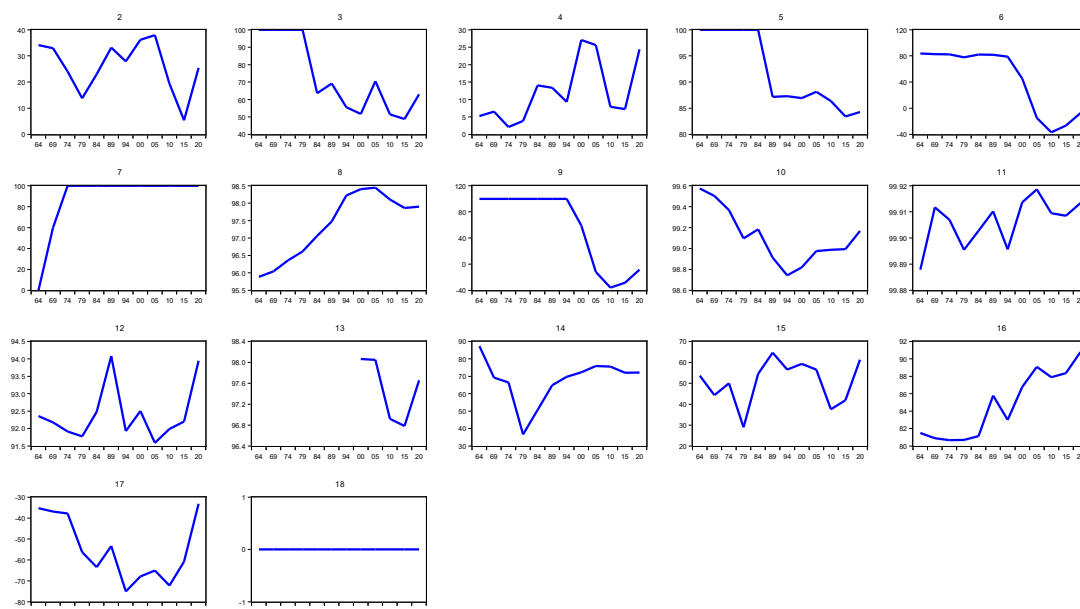
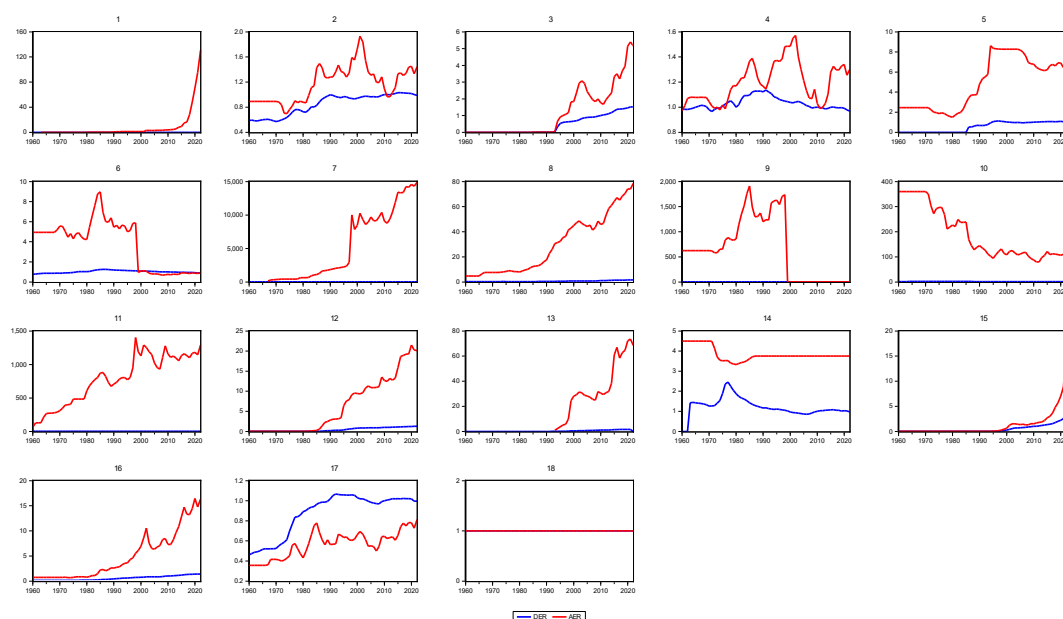


**Chart 2:** 5 year deviations (%)

The chart 2 graphically demonstrates the trends in medium term (5 years) deviations across countries. A country is represented by the respective serial number (see table 2). Chart 1 and chart 2 are read together for a comparative analysis in deviations across countries. Countries numbered 2, 6, 11, 12 and 17 show a divergent trend while other countries show a similar trend in medium term and long-term deviations.

**Chart 3.** Actual exchange rate vs derived exchange rate (Log values)

The chart 3 compares the actual exchange rates (in red colour) against the derived exchange rates (in blue colour) across countries and over the years. The data is presented as annual averages. A country is represented by the respective serial number (see table 2). The chart 3 can be used to compare the trends in movements of both the exchange rates. It is observed that for China (5), Saudi Arabia (15), Turkiye (16) and USA (17), the trend (graph) for both the exchange rates is similar while for Russia (14), a divergent trend is observed.

Null hypothesis H01 and H02 could be validated based on panel correlations (table 3) while the null hypothesis H03 could be validated based on the paired sample 't' test. Derived ER and Inflation rate demonstrate a negative and significant correlation (-0.174) while Actual ER and Inflation rate demonstrate a negative and non-significant correlation (-0.022). Thus, null hypothesis (H01) was rejected and null hypothesis (H02) could not be rejected. A paired sample 't' test rejected the third null hypothesis (p-value=0).

**Table 3. Panel correlations**

|           | AER      | Inflation | Prices   | DER |
|-----------|----------|-----------|----------|-----|
| AER       | 1        |           |          |     |
| Inflation | -0.022   | 1         |          |     |
| Prices    | 0.125*** | -0.124*** | 1        |     |
| DER       | 0.042    | -0.174*** | 0.715*** | 1   |

\*\*\* indicates significance at 99% level

**Table 4. Pairwise Granger causality tests (lag 2)**

| Null Hypothesis                         | p-value |
|-----------------------------------------|---------|
| INFLATION does not Granger Cause AER    | 0.994   |
| AER does not Granger Cause INFLATION    | 0.939   |
| PRICES does not Granger Cause AER       | 0.604   |
| AER does not Granger Cause PRICES       | 0.037   |
| DER does not Granger Cause AER          | 0.401   |
| AER does not Granger Cause DER          | 0.812   |
| PRICES does not Granger Cause INFLATION | 0.007   |
| INFLATION does not Granger Cause PRICES | 0.044   |
| DER does not Granger Cause INFLATION    | 0.000   |
| INFLATION does not Granger Cause DER    | 0.028   |
| DER does not Granger Cause PRICES       | 0.000   |
| PRICES does not Granger Cause DER       | 0.000   |

The causality tests (table 4) indicate that prices cause inflation as the Consumer Price Index is based on prices of a basket of commodities. It also indicates that inflation (p-value=0.028) and prices (p-value=0) cause DER. However, no causal relationship was observed between AER and DER and no impact of inflation (p-value=0.9) or prices (p-value=0.6) was observed on AER.

**Table 5. Paired sample test**

| Paired Differences |           |       |                    | p-value |
|--------------------|-----------|-------|--------------------|---------|
|                    |           | Mean  | Standard deviation |         |
| Pair 1             | AER - DER | 379.8 | 1691.79            | 0       |

Subsequent to the comparative analysis between DER and AER, as a robustness test, a panel data pooled regression was applied to further understand the impact of inflation on actual exchange rates.



In panel data analysis (the analysis of data over time), the Hausman test (Hausman, 1978) helps to choose between fixed effects model or a random effects model (see Hahn et al., 2011). The null hypothesis for Hausman test is that the preferred model is random effects while the alternate hypothesis is for a fixed effects model. The Hausman test to validate the significance of random effects in panel cross-sections was rejected ( $p\text{-value}=0.8$ ). Thus, the POLS regression was tested for the significance of fixed effects in cross-sections (see table 6). The null hypothesis of fixed effect redundancy was rejected indicating the relevance of fixed effects in this data panel. A significant regression (with fixed effects) with an R-squared of 51% was reported however a negative coefficient is observed (table 7) for inflation when regressed over AER.

**Table 6.** Fixed effect redundant test results

| Effects Test             | p-value |
|--------------------------|---------|
| Cross-section F          | 0       |
| Cross-section Chi-square | 0       |

**Table 7.** Fixed effect panel regression results (Dependent Variable: AER)

| Sample: 1960-2022                                 |             |         |
|---------------------------------------------------|-------------|---------|
| periods included: 63, Cross-sections included: 17 |             |         |
| Variable                                          | Coefficient | p-value |
| Inflation                                         | -0.10       | 0.73    |
| Constant                                          | 426.17      | 0       |

## 5. Discussion

The ‘absolut PPP’ theory suggests that the exchange rate between two currencies should be such that a basket of goods and services costs the same in both countries when measured in a common currency. The ‘relative PPP’ theory relaxes the assumption of identical baskets of goods and services. It suggests that the rate of change in exchange rates should be equal to the rate of change in relative price levels between countries [see Taylor (2002); Rogoff (1996); O’Connell (1998); Frankel & Rose (1996); Vo & Vo (2023)].

The highest difference between actual and derived exchange rate was observed for Japan (99.9%) while the lowest was observed for Canada (12.7%). The composite overall average is observed as 62% (deviation) for 63 years across countries indicating that the PPP theory does not holds in the long run and the PPP exchange rate deviates from the actual exchange rates in long run. This finding is contrary to Rogoff (1996) and Vo & Vo (2023). Comparing the medium term and long term graphs, five countries show a divergent trend while other countries show a similar trend in medium term and long term deviations. Thus, no conclusive evidence is found studying the graphs. Comparing the deviations (chart 3), it is observed that for China (5), Saudi Arabia (15), Turkiye (16) and USA (17), the trend (graph) for both the exchange rates is similar while for Russia (14) a divergent trend is observed. This implies that for large economies like China and USA, the actual and derived exchange rates show a similar movement.

The null hypothesis (H01) was rejected implying that DER and Inflation rate are significantly correlated (-0.174) and thus holding the PPP theory true (see Rogoff, 1996 and VO & Vo, 2023).

A paired sample 't' test rejected the third null hypothesis (H03) (p-value=0) of 'no difference' indicating that there is a difference between DER and AER rates. This was further validated by the acceptance of null hypothesis (H01).

The causality tests (table 4) indicate that prices cause inflation in concurrence with the concept of the Consumer Price Index. It also indicates that inflation (p-value=0.028) and prices (p-value=0) cause DER, holding the PPP theory true, in principle [see Vo & Vo (2023); Rogoff (1996)]. However, no causal relationship was observed between AER and DER and no impact of inflation (p-value=0.9) or prices (p-value=0.6) was observed on AER. This implies a disconnect between the actual prevailing exchange rates and the PPP derived exchange rates. This also highlights the fact that the actual exchange rates are not caused by price dynamics [see Gabaix & Maggiori (2015); Dornbusch (1976); Altavilla & De Grauwe (2010)]. This is revalidated in robustness test using a cross-country panel of AER and inflation data where a negative and insignificant coefficient (-0.1) is observed for inflation when regressed with AER with a R-squared value of 51%.

## 6. Conclusion

Since the primary objective of the research was to understand the dynamics between prices and exchange rates, the research was successful in contributing to the literature considering this context. For the purpose a derived measure (DER) of prices and a direct measure (AER) of foreign exchange rates have been used in the study along with evaluation of three hypotheses.

The impact of price and inflation on the derived measure of exchange rate validates the rationale of the PPP theory. This finding is supported by results from the panel correlation test and the causality test. Alternatively, the study also concluded that the actual prevailing exchange rates across the countries is not caused by prices and inflation. This finding was validated by causality tests and the panel data analysis.

The study found no evidence of connect between AER and DER indicating that the PPP theory in reality does not determines the actual exchange rates. This poses a question on the validity of the PPP theory in exchange rate determination. This finding also makes a pertinent case for further studies on the effectiveness of PPP in international macroeconomics. The DER formulae (equation 1) may be a suggestive rationale for future PPP studies.

*Limitations and future scope:* The PPP theory considers the view that the assumption of identical baskets of goods and services across countries may not hold in reality due to differences in preferences, quality, and availability of goods. Also, that PPP holds better in the long run rather than in the short run as short-term deviations can occur due to sporadic factors such as speculation. Despite its limitations, PPP theory has important implications for international trade, investment, and monetary policy. PPP serves as a benchmark for assessing whether currencies are overvalued or undervalued, informing decisions on currency trading, investment allocation, and policy interventions by central banks. Understanding the dynamics of exchange rates and relative price levels is crucial for

policymakers, investors, and businesses operating in global markets. Although the study is from the domain of international finance with a focus on foreign exchange theory, the scope of the study spreads to other areas of managerial decisions making such as currency trading, investment allocation, and policy interventions. The learnings will keep the researchers and practitioners interested from the domains of economics, general management and banking to look for further improvements in the PPP based exchange rate determination policy.

This study not only reinforces PPP's empirical validity but also stresses the importance of monetary policy in stabilizing exchange rates, imparting valuable policy implications. The PPP theory, by assuming away transaction costs, tariffs, and the differentiated baskets of goods across countries, opens up avenues for critique and further investigation. Future research might build upon these foundations by incorporating such factors into the analysis, exploring the nonlinear aspects of PPP, or examining the impact of digital currencies and globalization on the theory's predictions.

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## **Assessment of external macroeconomic imbalances in Romania**

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**Abstract.** *The issue of external macroeconomic imbalances – the case of Romania – arouses particular interest among policymakers, the business community, and citizens, considering the measures that should be adopted by the authorities to adjust these imbalances. This research aims to assess the key trends observed in Romania in the recent years in the context of the Macroeconomic Imbalances Procedure and to identify the specific challenges. The second part of the paper focuses on the macroeconomic imbalances indicators, using time-series data to assess the Romania's situation within the European Union. Where possible, the assessed indicators were examined with the purpose of identifying the macroeconomic imbalances outlooks. Finally, the paper briefly presents the main conclusions of the analysis, as well as potential policy recommendations for mitigating macroeconomic vulnerabilities at the national level.*

**Keywords:** European Semester, macroeconomic imbalances, current account deficit, budget deficit.

**JEL Classification:** E62, F32, H62, O52.

## 1. Introduction

The European Semester was introduced in 2011 to enhance the coordination of economic, budgetary, employment, and social policies within the European Union. The cycle begins each year in November with the publication by the European Commission of the “European Semester Autumn Package”, which includes, among other documents, the Alert Mechanism Report.

This report analyses the latest economic developments in all EU Member States and identifies those for which In-Depth Reviews must be conducted, in order to assess whether they are affected by imbalances that require a policy response. Subsequently, the European Commission prepares the in-depth reviews for the relevant Member States. These are released in the first half of the subsequent year and is the main document that Commission considers in determining the categorisation of the macroeconomic imbalances.

As part of the “European Semester Spring Package” (generally published in May-June), Member States receive country-specific policy recommendations aimed at reducing imbalances or providing tailored guidance on economic policy. In this context, it is important to clarify that imbalances denote macroeconomic evolutions that adversely affect the functioning of a national economy, the Economic and Monetary Union, or the EU as a whole. By contrast, excessive imbalances refer to particularly acute distortions that pose risks to the adequately functioning of the Economic and Monetary Union.

The Alert Mechanism Report includes both quantitative and qualitative economic and financial assessments, based on a scoreboard comprising a set of 13 headline indicators (alongside 23 auxiliary indicators), their values being compared to a set of specific thresholds. The report may also take into account other economic and financial indicators, as well as the evolution of imbalances within the European Union, indicating whether the breach of certain thresholds may signal the emergence of an imbalance. Therefore, it can be concluded that detecting macroeconomic imbalances is not a mechanical process, but the result of a comprehensive and multidimensional analysis. However, at the European level, the economic assessment of countries with high current account deficits, such as Romania, may differ from that of Member States that record significant current account surpluses.

The role of the scoreboard and its 13 measurable indicators is to facilitate the identification and the assessment of macroeconomic imbalances. In particular, these can be classified as follows:

- Internal imbalances, which may be reflected by indicators such as public and private debt, household credit, housing prices, and others;
- External imbalances, associated with developments in the current account deficit, the net international investment position, the real effective exchange rate, export dynamics and unit labour cost trends.

The indicators included in the scoreboard, their structure, thresholds for the euro area and non-euro area countries, as well as the methodology applied, may be revised, the most recent update taking place at the end of the previous year.

For countries whose economic developments indicate the possible emergence of imbalances, the European Commission prepares an In-Depth Review, a detailed analysis determining whether the Member State is experiencing imbalances. Following this analysis, a Member State may be classified as having “no imbalances,” “imbalances,” “excessive imbalances,” or “excessive imbalances with corrective measures needed.”

In cases where the Excessive Imbalance Procedure is triggered, the Council of the European Union requests the Member State concerned to implement corrective actions outlined in a Corrective Action Plan.

Failure to comply with these corrective measures may result in sanctions of up to 0.1% of GDP for euro area countries or the suspension of access to EU funds, the latter applying to all Member States. Although the corrective arm has not yet been operational, the new governance framework aims to make this procedure effective.

Until 2024, Member States submitted in April their National Reform Programmes and Stability/Convergence Programmes, which included measures and actions to correct imbalances or to respond to the previous year’s Country-Specific Recommendations.

In the context of the new EU economic governance rules, applicable from 2024, Member States are required to submit medium-term fiscal-structural plans, setting out the net expenditure trajectory, as well as priority investments and reforms, including those aimed at addressing macroeconomic imbalances in countries facing such challenges. Member States should also report on the progress related to the adjustment of the imbalances within the Annual progress reports, which are submitted since 2025.

Another important process is the Excessive Deficit Procedure (EDP), which was launched for Romania in 2020, but it was put on hold during the pandemic when fiscal requirements were temporarily relaxed for all Member States to allow them to better manage the health crisis. Meanwhile, energy market tensions, rising inflation, and the war in Ukraine have further deteriorated fiscal conditions in several European economies, prompting the activation of the EDP for several countries.

The new economic governance framework could offer Romania an opportunity to ensure the fiscal predictability needed for long-term sustainable development in the investment and reform commitments foreseen in the medium-term fiscal-structural plan will be adequately implemented.

## **2. Literature review**

The academic literature reveals a sustained concern on macroeconomic imbalances, their origins, and their correction mechanisms. The discussion begins with the definition proposed by Wieser (2011), former Chair of the Economic and Financial Committee (European Union committee), who described them as the negative or positive position of internal, external, or financial variables which, if not corrected over time, leads to an unsustainable national savings-investment balance that will self-correct abruptly, causing significant adjustment shocks.

Therefore, the persistence of imbalances over an extended period implies losses of competitiveness, excessive credit growth, rising housing prices, and debt accumulation. In this regard, Dăianu et. al (2025) analyses the economic and social implications of deficits and suggests solutions to prevent or mitigate their negative effects on the economy.

According to Blanchard and Giavazzi (2002), the launch of the Economic and Monetary Union (EMU) led to a marked decline in the correlation between savings and investment among Member States, driven by the greater financial integration that accompanied the adoption of the single currency. The authors further observed a positive relationship between per capita income and current account balances among Member States, with capital typically flowing from richer, capital-abundant countries to poorer nations with scarce financial resources.

Although Blanchard and Giavazzi (2002) did not initially consider the persistent current account imbalances within the euro area as a major concern, they acknowledged the existence of significant nominal rigidities, the inability to adjust nominal exchange rates, and the absence of sufficiently countercyclical fiscal rules as factors that distort resource allocation. Capital flows proved to fuel imbalances driven by domestic distortions and misallocation of capital. These included credit-fueled asset price bubbles, excessive budget deficits, and unrealistic expectations of future growth (Kämpfe and Knedlik, 2017).

In the mid-2000s, other authors pointed out that differences in macroeconomic conditions across euro area Member States could pose significant concerns (Lane, 2006; Mongelli and Wyplosz, 2008). In addition, Zemanek et al. (2009) and Berger and Nitsch (2010) documented a tendency for capital to flow toward countries where domestic economic distortions were most pronounced, particularly in the absence of effective structural reforms.

Several studies (Trichet, 2005 and 2006; ECB, 2008; Bini-Smaghi, 2007; Papademos, 2007) highlighted substantial competitiveness challenges and macroeconomic imbalances in multiple countries, emphasizing that, even ten years after the EMU's establishment, most euro area Member States continued to face structural constraints due to rigid legal and regulatory frameworks, high labour taxation, and inflexible wage-setting practices.

Overall, relatively little focus was given to the institutional variations among the countries that joined the euro area, despite Acemoglu's (2004) influential findings demonstrating that long-term real convergence depends not only on per capita income disparities but also on the quality of governance and institutional frameworks. More recently, studies have begun to examine in greater depth the interaction between macroeconomic outcomes and the initial levels of public debt in euro area countries (Masuch et al., 2017).

High-growth economies experienced stronger wage and price inflation, which reduced real interest rates and further stimulated domestic demand. The rapid expansion of nominal demand meant that fiscal rules were effectively non-binding, as rising nominal GDP and sustainable tax revenues eased fiscal constraints. In slow-growing economies, the opposite dynamic prevailed: weaker nominal growth translated into higher real interest rates and tighter budgetary positions, making fiscal rules more binding and reinforcing austerity pressures.



These divergent trajectories generated persistent external imbalances - current account deficits in the fast-growing economies and surpluses in the slower ones - creating creditor-debtor relationships that ultimately proved unsustainable. After the “sudden stop” of the crisis, these imbalances were corrected asymmetrically: adjustment fell disproportionately on deficit countries, which were compelled to enact severe and unilateral deflationary austerity policies, with extremely high economic and social costs (Koll and Watt, 2022).

### 3. Methodology

The assessment was conducted using Eurostat data for the period 2015-2023 covering the 27 EU Member States, with a particular focus on Romania. The analytical method applied consists in the comparative analysis (based on graphical approach), aiming to highlight Romania's situation by comparing indicators reflected in the Macroeconomic Imbalance Scoreboard and the 2025 Alert Mechanism Report. The data presented in these documents refer to the year 2023, while subsequent evaluations also use additional data sources.

In this respect, we used the following indicators to assess the external imbalances:

3.1. Current Account - calculated as the total of the trade balance (exports minus imports of goods and services), the income balance, and net current transfers. The current account represents a component of the balance of payments, which records the country's economic and financial transactions with the rest of the world over a specific period, usually one year. It measures the net flow of income and payments between a country and other economies, indicating either a surplus or a deficit. According to the scoreboard, the reference range for the current account balance, expressed as a percentage of GDP and averaged over three years, lies between -4% (lower limit) and +6% (upper limit) of GDP.

3.2. Net International Investment Position (NIIP) - denotes the balance between a country's external financial assets and liabilities. When the NIIP is positive, the country holds a net creditor position, while when negative, it is considered a net debtor.

3.3. Real Effective Exchange Rate (REER) - calculated as a weighted average of the national currency against a basket of currencies (corresponding to 42 trading partners) and adjusted for inflation (using the Harmonised Index of Consumer Prices - HICP). This indicator assesses shifts in a country's price or cost competitiveness compared with other nations. A rise in the REER index signals a decline in competitiveness.

The reference thresholds for this indicator's variation are  $\pm 3\%$  for euro area countries and  $\pm 10\%$  for non-euro area countries, calculated as a three-year average.

3.4. Export Market Share relative to Advanced Economies - indicates the proportion of a country's goods and services exports within the total exports of advanced economies. In addition, there is a need to clarify that advanced economies includes OECD member states as well as five EU countries not in the OECD: Bulgaria, Croatia, Cyprus, Malta, and Romania. The threshold considered for this indicator is -3%.

3.5. Nominal Unit Labour Cost Index (ULC) - defined as the ratio between labour costs and labour productivity.

Labour cost is calculated as the ratio of employee compensation to the number of hours worked, while labour productivity is measured as the ratio of GDP to total hours worked.

The scoreboard indicator is expressed as a percentage change over three years, with thresholds set at 9% for euro area countries and 12% for non-euro area countries.

The procedure applicable to external deficit correction aims to ensure that all Member States maintain a low level of public debt or reduce their indebtedness to sustainable levels. Therefore, this analysis also includes the level of public debt as a share of GDP, even though this indicator is generally part of the assessment of internal imbalances.

Public debt refers to the total financial obligations of the state (government, public institutions, financial institutions, and local administrative units) at a given time, arising from domestic and external borrowing (in local and foreign currency) contracted over the short, medium, and long term, as well as the state's obligations to its own treasury for temporarily advanced amounts aimed at covering the budget deficit.

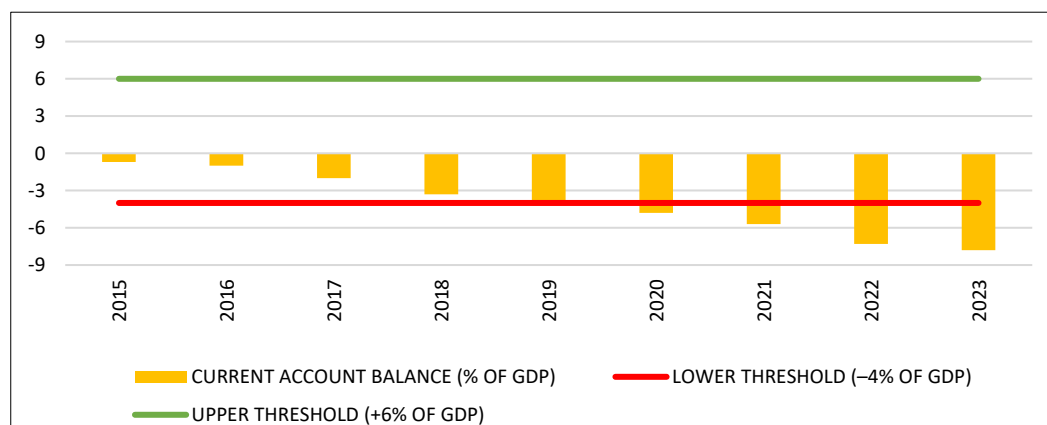
#### 4. Results and interpretations

According to the 2025 Alert Mechanism Report, published at the end of last year, macroeconomic risks for Romania related to external sustainability and competitiveness are increasing. Analysing the scoreboard for external imbalances, in 2023, three indicators exceeded the prescribed thresholds: the current account balance, the net international investment position, and the nominal unit labour cost.

To understand the scale of external imbalances at the national level, this analysis aims to compare these indicators with those reported for other EU Member States and to identify the magnitude of deviations from the thresholds set in the scoreboard.

Regarding the evolution of the current account deficit (three-year average), according to *Figure 1*, the scoreboard data indicate a continuous deterioration since 2019, with the -4% of GDP threshold being exceeded.

**Figure 1.** Current account balance – Romania (%GDP)



**Source:** Authors' processing based on data extracted from the Eurostat platform

Negative performances in the current account deficit led, in 2023, to it reaching the highest value in the EU, at -7.8% of GDP as a three-year average. Romania was followed by Greece, with a deficit of 7.7% of GDP, and Cyprus (-6.7% of GDP).

In fact, according to Eurostat data, more pronounced deteriorations of the current account deficit began to appear in the post-pandemic period, with 2021 marking a deepening of the deficit by 2.1 percentage points of GDP. This deterioration, which brought the current account deficit to -7.2% of GDP (*Table 1*), was mainly driven by the trade balance, which contributed to worsening the external imbalance, in the context of global supply chain disruptions and widespread increases in commodity prices.

The process continued the following year, with 2022 marking a peak in the current account deficit of 9.5% of GDP, the highest level recorded since 2008. The current account deficit thus reached EUR 26.8 billion, an increase of 54% compared to 2021. Once again, the widening of the current account deficit was mainly driven by the trade deficit, as domestic production was insufficient to cover domestic absorption.

**Table 1.** *The evolution of deficits*

|                                         | 2015 | 2016  | 2017  | 2018  | 2019  | 2020  | 2021  | 2022  | 2023  |
|-----------------------------------------|------|-------|-------|-------|-------|-------|-------|-------|-------|
| Current account deficit (billion euros) | -1.0 | -3.5  | -6.0  | -9.5  | -10.9 | -11.2 | -17.4 | -26.8 | -21.5 |
| - % of GDP                              | -0.7 | -2.1  | -3.2  | -4.6  | -4.8  | -5.1  | -7.2  | -9.5  | -6.6  |
| Trade deficit - goods (billion euros)   | -8.4 | -10.0 | -13.0 | -15.4 | -17.6 | -18.7 | -24.4 | -34.1 | -29.0 |
| - % of GDP                              | -5.2 | -6.0  | -6.9  | -7.5  | -7.8  | -8.5  | -10.1 | -12.1 | -8.9  |

**Source:** Authors' processing based on data extracted from the Eurostat platform

A significant adjustment occurred in 2023, when the current account deficit decreased to 6.6% of GDP, following a recovery in the goods trade balance, particularly due to a reduction in commodity prices. The analysis above highlights the key role of goods trade in the evolution of the current account balance, indicating the need for measures aimed at enhancing export competitiveness to reduce the current account deficit.

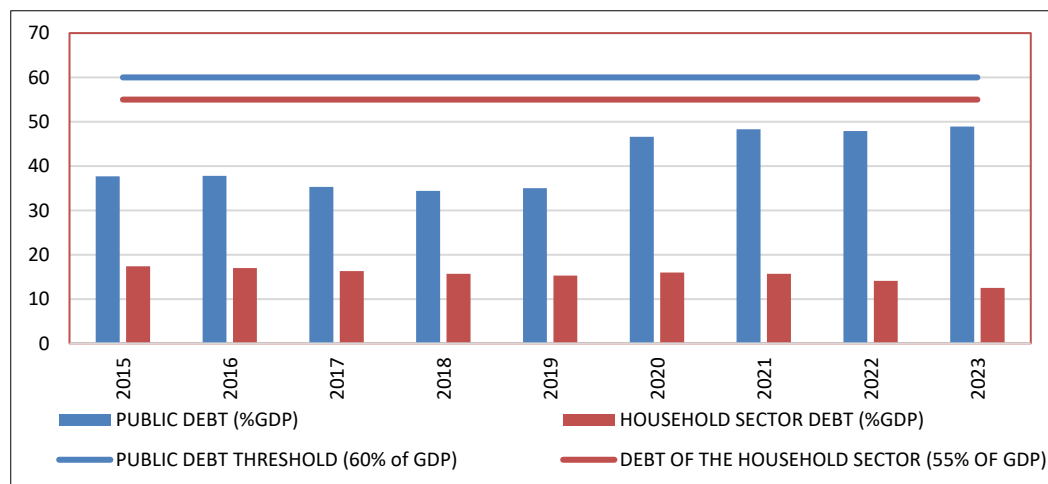
However, it should be noted that this reduction in the current account deficit is not reflected in the scoreboard indicator, due to unfavorable results in previous years. Considering that, according to National Bank of Romania data, the current account deficit exceeded €29 billion in 2024, equivalent to approximately 8.3% of GDP, which is in line with a three-year average over 8% of GDP for 2024, signaling a continuation of the negative trend.

Another important cause of the significant current account deficit consists in the high budget deficit, which have fueled domestic demand. Indeed, within the EU, Romania is among the countries with the most pronounced current account and budget deficits (twin deficits). In this context, it is important to consider the positive effect of the budget deficit on the current account deficit in Romania, estimated at between 0.43 and 0.65 percentage points of GDP for each 1 percentage point increase in the budget deficit (Dăianu et al., 2025).

Pressure on budget deficits also comes from the increasing cost of government debt, which, although still below the 60% of GDP threshold set by the Maastricht Treaty, has accelerated in recent years, reaching 48.9% of GDP in 2023.

Romania's public debt as a share of GDP reached 54.6% by the end of 2024, according to the Ministry of Finance (*Figure 2*), approaching the maximum allowed threshold of 60%. In absolute terms, government debt exceeded €964 billion lei, with the budget deficit being the main driver of the increase.

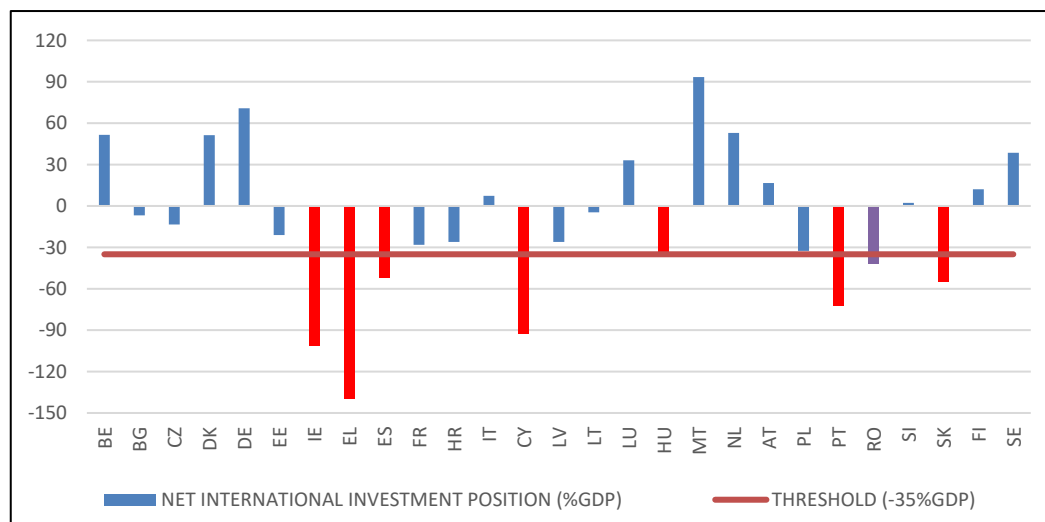
**Figure 2.** Public debt and household sector debt



**Source:** Authors' processing based on data extracted from the Eurostat platform.

At the same time, household debt (% of GDP) declined from 17.4% in 2015 to 12.5% in 2023. Romania currently has the lowest level of household debt among EU member states, but with the expected reduction in loan interest rates, it is anticipated that household debt will return to an upward trend.

**Figure 3.** Net international investment position (% of GDP - 2023)



**Source:** Authors' processing based on data extracted from the Eurostat platform.

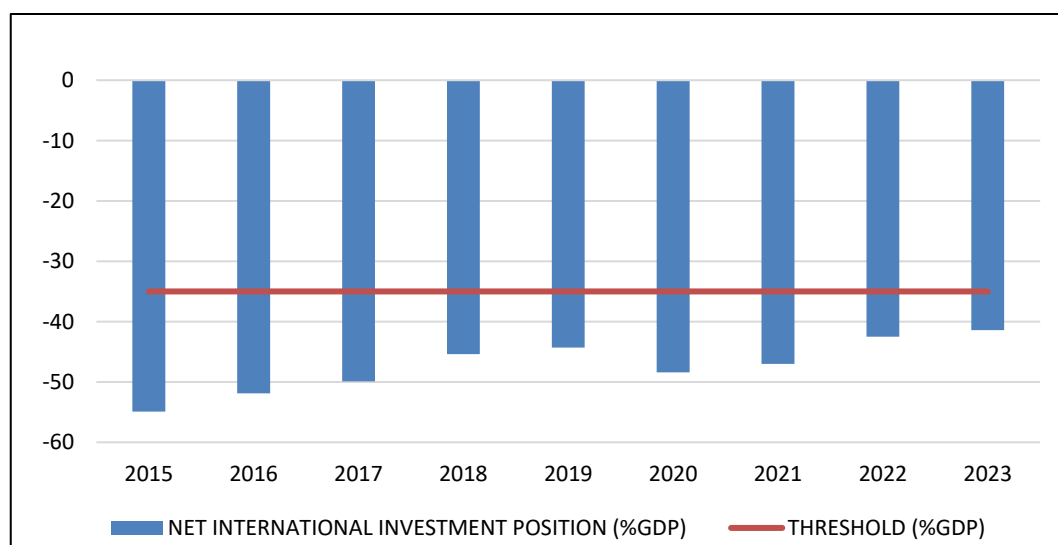
The net international investment position (*Figure 3*), another relevant indicator of external macroeconomic imbalances, reflects the transactions recorded in the financial account of the balance of payments and is an important measure in assessing the external sustainability of the economy. Similar to other emerging European Union economies, Romania records a negative net international investment position, indicating a significant reliance on foreign investment to finance both the current account deficit and the economy in general.

The situation is not alarming for Romania, as there are countries, such as Greece and Ireland, where the negative threshold of 100% of GDP is exceeded. Other countries with more pronounced negative values than Romania include Cyprus, Portugal, Slovakia, and Spain.

As can be observed in *Figure 4*, Romania has experienced a significant improvement since 2015, when the net international investment position (NIIP) was nearly -55% of GDP, reaching -41.4% of GDP in 2023, only 6.4 percentage points above the prescribed threshold. It is worth noting that an improvement in the absorption of non-reimbursable EU funds could contribute to further adjustment of this indicator.

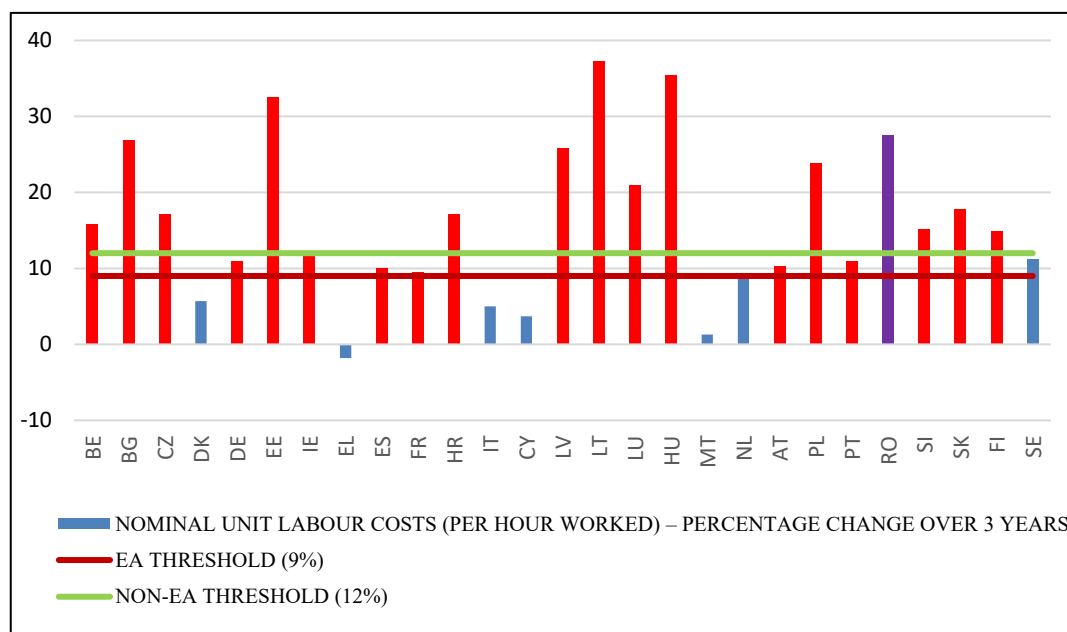
Unit labour cost (ULC) represents another indicator of external imbalances for which Romania exceeds the 12% threshold set for non-euro area countries. Romania is not an isolated case, as unit labour costs have risen in most European Union countries.

**Figure 4.** Net international investment position - Romania (% of GDP)



**Source:** Authors' processing based on data extracted from the Eurostat platform.

The increase in costs, calculated as a three-year average, is widespread and has been driven by a period of high inflation, which led to significant wage growth. Labour productivity was unable to offset the rises in compensation, resulting in an increase in unit labour costs. In the ranking of unit labour cost increases for 2023, Romania is in fourth place, after Lithuania, Hungary, and Greece (*Figure 5*).

**Figure 5.** *Nominal unit labour costs (per hour worked) – percentage change over 3 years*

**Source:** Authors' processing based on data extracted from the Eurostat platform.

Concerns regarding labour costs remain relevant for 2024 due to wage increases, including the minimum wage, which have created some pressures on the business environment. The adverse effects have been felt on external competitiveness, negatively impacting the evolution of goods and services exports and, consequently, the current account balance.

## 5. Conclusions

Given the unfavorable trends of the main indicators monitoring external imbalances, it is expected that the European Commission will decide to keep Romania in the category of countries with excessive imbalances in the next European Semester cycle (2026). Additionally, the challenges in managing the budget deficit, which increased to 9.3% of GDP in 2024, as well as losses in competitiveness, highlighted by both rising unit labour costs and an increase in the real effective exchange rate, must also be taken into account.

Our paper recommends an in-depth structural investigation of trade deficits, identifying the main factor behind the deterioration of the current account. Such an analysis is essential to identify sectoral vulnerabilities and guide policies aimed at recovering activities that traditionally generate trade deficits, results that should be also reflected in a national strategy for adjusting trade balance.

In addition, there is a need to implement the appropriate policies to end the excessive budget deficit situation and to keep public debt under 60% of GDP.

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## Remittances and domestic demand: evidence from Romania

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**Abstract.** *This paper examines the impact of remittances on domestic demand in Romania using a log-linear OLS model based on macroeconomic data for 2015–2024. While GDP growth and inflation emerge as the primary drivers of household consumption, remittances show a positive but statistically insignificant effect once macroeconomic fundamentals are controlled for. The results suggest that remittances support short-term welfare but play a limited role in shaping aggregate demand. The study highlights measurement challenges and calls for policies that better channel remittance inflows toward investment and long-term economic development.*

**Keywords:** remittances, household consumption, domestic demand, Romania, macroeconomic analysis.

**JEL Classification:** F24; E21; O15; O52.

## Introduction

Remittances have become one of the most significant outcomes of Romania's large-scale labor migration over the past two decades. The country has consistently ranked among the top emigration states in the European Union, generating annual inflows of migrant transfers that have frequently exceeded 3–5% of GDP. For many households, remittances function as a stabilizing source of income, supporting daily consumption, education, housing improvements, and access to services. At the macroeconomic level, they have contributed to smoothing consumption during periods of economic volatility.

Romania's economic structure, characterized by a high reliance on domestic demand, raises an important question regarding the role of external income flows in shaping consumption dynamics. While previous studies emphasize that remittances alleviate poverty and improve household welfare, the extent to which they influence aggregate consumption remains debated. Some evidence suggests strong consumption effects, whereas other analyses point to savings, housing investment, or debt repayment as primary uses.

This paper investigates the impact of remittances on household consumption and domestic demand in Romania, using an econometric approach based on ordinary least squares (OLS) and a log-linear specification. Using Eurostat macroeconomic series for 2015–2024, the study estimates how remittances, alongside GDP, inflation, and income levels, shape consumption patterns.

The contribution of the paper is twofold. First, it provides updated empirical evidence for Romania, an EU member state with structurally high migration and persistent remittance inflows. Second, it assesses whether remittances play a significant macroeconomic role once fundamental economic drivers such as GDP and prices are controlled for. The findings offer insights into the potential of remittances to support long-term development and the policy instruments needed to channel these resources more productively.

## Literature Review & Theoretical Background

Remittances, financial transfers made by migrant workers to their households of origin, have long been recognized as a major driver of household consumption and welfare in developing and emerging economies. Adams and Cuecuecha (2010) provide early microeconomic evidence showing that remittances directly increase expenditures on food, housing, and education, thereby improving household living standards and acting as an effective poverty-reduction mechanism. Their analysis reveals that remittances function not merely as supplemental income but as a stabilizing instrument that supports consumption smoothing among vulnerable households. Chami et al. (2005), however, offer a contrasting macroeconomic perspective, arguing that remittances behave primarily as compensatory transfers rather than productive capital, which limits their potential to generate long-term growth despite their clear short-term welfare benefits.

These mechanisms are particularly visible in Central and Eastern Europe, a region profoundly shaped by large-scale emigration over the past three decades. Romania provides one of the clearest cases: remittance inflows have consistently ranged between 2% and 3%

of GDP, levels comparable to foreign direct investment. World Bank reports consistently highlight that these transfers have “helped households to escape poverty,” especially in rural and economically distressed regions, by stabilizing family budgets and providing a reliable source of liquidity during downturns.

A considerable body of empirical work focuses specifically on Romania. Goschin (2013) demonstrates that remittances significantly sustained domestic consumption before the 2008 crisis, functioning as a buffer against economic volatility. Mehedințu et al. (2020) reaffirm that remittances are a stable and countercyclical financial resource, raising living standards and reducing vulnerability, even though much of the inflow tends to be spent on short-term consumption rather than on productive investment. These findings align with broader international evidence showing that households allocate remittances primarily to essentials, food, utilities, housing, and healthcare, thus improving material welfare.

The literature also identifies important nuances regarding the balance between consumption and investment. Using cross-country data, Meyer and Shera (2017) argue that remittances can stimulate economic growth indirectly via higher household consumption. Yet their results point to significant heterogeneity across institutional settings, suggesting that the growth impact of remittances is conditional on financial development and governance quality. In Romania, Maha (2012) finds that remittances directed through formal channels may have a stronger association with investment-related activities, such as housing construction or small-business financing, indicating that aggregate-level analyses may underestimate productive uses of migrant transfers.

Beyond Romania, regional evidence supports similar conclusions. Podkaminer (2007) documents a strong positive relationship between rising remittances and household consumption across Poland, Bulgaria, Latvia, and Lithuania. Markova and Reilly (2007), studying Bulgarian migrants, report that most remittances are allocated to basic necessities, with only a smaller proportion directed toward durable goods or entrepreneurial investment. OECD analyses (2018, 2022) further emphasize the stabilizing effect of remittances on domestic demand, especially during periods of economic turbulence preceding and following the global financial crisis.

In addition to strictly migration-focused research, several studies provide important contextual insights into Romania’s labour market, structural transformation, and socio-economic environment, factors that influence how remittances are used and how they affect consumption. Serban (2012) examines labour market flexibility and employability in Romania, arguing that structural vulnerabilities and regional disparities push many workers toward temporary migration, which subsequently fuels remittance flows. Serban, Pelinescu, and Dospinescu (2022) analyse beta-convergence in high-technology manufacturing, highlighting Romania’s uneven regional development, an important backdrop for understanding why remittance inflows matter more in certain communities. Picatoste, Aceleanu, and Serban (2021) explore job quality and well-being across OECD countries, offering relevant insights into how labour market conditions and social protection systems shape migrant behaviour, remittance motives, and ultimately spending patterns in origin households. At a broader level, Lytras et al. (2024) discuss digital transformation and the role of advanced technologies in shaping future education systems,

illustrating how structural modernization and human capital formation, which are often financed by remittances, can fundamentally influence long-term development trajectories.

Additional contributions expand the understanding of how remittances interact with financial systems and macroeconomic stability. Bettin and Zazzaro (2012) show that remittances can promote both household consumption and small-scale investment when financial institutions are sufficiently developed, implying that the absorptive capacity of the financial sector mediates the ultimate impact of migrant transfers. Dustmann and Mestres (2010) highlight that consumption-oriented remittances are especially prevalent among temporary migrants who maintain close ties to their origin households. Bugamelli and Paternò (2009) emphasize the shock-absorbing nature of remittances, demonstrating that stable inflows help countries avoid deep contractions in domestic demand during economic crises. Similarly, IMF analyses (2016) underscore the countercyclical nature of remittances, noting that households receive increased support from abroad precisely when local economic conditions deteriorate.

Taken together, the literature paints a coherent and multidimensional picture: remittances serve as a crucial mechanism for income smoothing, poverty reduction, household welfare improvement, and domestic demand stabilization in Romania and comparable Central and Eastern European economies. They supplement limited local labour market opportunities, reinforce financial resilience during crises, and sustain consumption levels even when macroeconomic conditions are fragile. At the same time, scholars consistently warn that an excessive reliance on remittances for consumption may limit long-term development potential if too few resources flow into productive investment. Nonetheless, the cumulative evidence, from Adams and Cuecuecha (2010) to Lytras et al. (2024), demonstrates that remittances remain a cornerstone of household welfare and a key contributor to domestic demand dynamics in Romania.

In addition to these established findings, several strands of research offer broader context for understanding how remittances interact with labour markets, structural change, and long-term development trajectories. For example, Şerban (2012) shows that labour market flexibility in Romania has played a crucial role in shaping employment dynamics and household vulnerability, indirectly influencing the way remittances are absorbed by local economies. In regions where employment is precarious or seasonal, remittances often compensate for institutional weaknesses, becoming an informal stabilizer for households that face uncertain labour market prospects. This observation is consistent with the notion that remittances rarely operate in isolation; rather, they complement domestic income sources in contexts characterised by structural volatility.

A more recent body of work highlights how economic convergence, productivity gaps and industrial transformation affect the broader environment in which remittances are used. Şerban, Pelinescu, and Dospinescu (2022) analyse beta-convergence in high-technology manufacturing and show that regional disparities persist even in advanced sectors. Such disparities help explain why remittances tend to flow disproportionately toward lagging regions, where they often substitute for missing economic opportunities. This territorial imbalance reinforces the view that remittance-driven consumption patterns cannot be fully understood without considering regional structural differences.

Relatedly, studies on job quality and well-being, such as Picatoste, Aceleanu, and Șerban (2021), provide further insight into why migrant households prioritise consumption smoothing: migrants often come from backgrounds where job insecurity, low wages, and limited career prospects constrain upward mobility. Their transfers reflect not only altruism but also an effort to compensate for domestic labour market shortcomings. These findings reinforce the argument that remittances operate as a private welfare mechanism.

Finally, a forward-looking perspective is offered by Lytras et al. (2024), who examine the transformative role of digitalization and AI in reshaping education and skills. Their insight is relevant because the long-term potential of remittances, whether directed toward consumption, education, or investment, depends heavily on human capital formation and institutional adaptation. As Romania continues its digital and educational transition, the way migrant transfers are used could shift, potentially moving from short-term consumption toward more productive, skill-enhancing expenditures.

## Data and Methodology

The empirical analysis relies on survey-based and aggregate data designed to capture household income and expenditure patterns in Romania. The primary potential sources are the European Union Statistics on Income and Living Conditions (EU-SILC) and the Household Budget Survey (HBS), both of which provide micro-level observations on household financial behaviour, demographic characteristics, and remittance receipt. These surveys are widely used in empirical studies of consumption and poverty and offer a reliable basis for distinguishing between households that receive external transfers and those that do not.

At the aggregate level, complementary series from Eurostat and the World Bank's World Development Indicators (WDI) are used to trace annual trends in key macroeconomic indicators, including total remittance inflows, household consumption expenditure, GDP, inflation (HICP), and GDP per capita. Combining micro-level and macro-level data ensures a more comprehensive view: while survey data capture intrahousehold behavioural responses, macro indicators provide the broader economic environment in which these decisions occur.

The main focus of the empirical exercise remains on the household level. For this purpose, households are classified into two categories based on self-reported survey information: (1) those that receive remittances from abroad, and (2) those that do not.

This binary classification allows the construction of a straightforward treatment–control framework, enabling a clean initial comparison of mean consumption levels between the two groups before moving toward regression-based inference.

The dependent variable is household consumption expenditure ( $\text{Cons}_i$ ), measured either in absolute monetary terms or in logarithmic form ( $\ln \text{Cons}_i$ ) to mitigate right-skewness typical of consumption distributions. Using a log transformation also facilitates elasticity-based interpretations.

The key independent variable is Remittances ( $Remit_i$ ), defined primarily as a dummy variable equal to 1 if the household reports receiving remittances and 0 otherwise. In alternative specifications, the actual monetary value of remittances received is used, which permits an intensity-of-treatment interpretation, although this measure may be more affected by underreporting.

The model includes several control variables commonly used in the consumption literature:

- Household income ( $Income_i$ ): total disposable income excluding remittances, used to isolate the direct effect of external transfers from overall income effects.
- Education ( $Educ_i$ ): either years of schooling or categorical indicators for the education level of the household head, reflecting human capital effects on earning potential and consumption behaviour.
- Urban ( $Urban_i$ ): a dummy capturing urban versus rural residence, accounting for structural differences in prices, access to goods, and labour markets.
- Household size ( $HHsize_i$ ): number of members in the household, controlling for economies of scale and demographic composition.

These controls reduce omitted variable bias and align the model with standard household-consumption specifications in the empirical migration literature.

The baseline empirical strategy employs an ordinary least squares (OLS) regression model of the form:

$$Cons_i = \alpha + \beta_1 \times Remit_i + \gamma \times X_i + \varepsilon_i$$

where:

$Cons_i$  = household consumption expenditure

$Remit_i$  = remittances dummy (or remittance amount)

$X_i$  = vector of control variables (income, education, urban/rural residence, household size)

$\varepsilon_i$  = error term

Given the skewness of the dependent variable, a log-linear specification is also estimated:

$$\ln(Cons_i) = \alpha + \beta_1 \times Remit_i + \gamma \times X_i + \varepsilon_i$$

This formulation permits interpreting  $\beta_1$  as the approximate percentage change in consumption associated with receiving remittances. The log transformation is also consistent with the literature, where elasticities are preferred to absolute marginal effects.

The empirical estimation follows a stepwise approach:

1. Descriptive Statistics: Compare mean consumption levels between remittance-receiving and non-receiving households to detect raw differences in expenditure patterns.
2. Baseline Regression: Estimate the effect of remittances on consumption without controls. This specification captures the unconditional association but may suffer from omitted variable bias.
3. Extended Regression: Introduce socio-demographic and income controls to isolate the net effect of remittances. This model provides the primary estimate for interpretation.

This sequential structure allows observing how the coefficient on remittances evolves once confounders are added, shedding light on whether the raw consumption premium for

remittance households reflects actual behavioural differences or simply underlying disparities in income and demographics.

**Table 1.** *Log-transformed macroeconomic variables (2015–2024)*

| Year | LN_CONS  | LN_GDP   | LN_GDPPC | LN_HICP  | LN_REMIT |
|------|----------|----------|----------|----------|----------|
| 2015 | 11.47092 | 4.742207 | 3.370738 | 4.605170 | 7.685244 |
| 2016 | 11.52870 | 4.770405 | 3.394508 | 4.594413 | 7.803435 |
| 2017 | 11.64431 | 4.849175 | 3.468856 | 4.605170 | 7.945485 |
| 2018 | 11.75072 | 4.908580 | 3.540959 | 4.645160 | 7.998604 |
| 2019 | 11.81437 | 4.947063 | 3.600048 | 4.683519 | 8.212111 |
| 2020 | 11.78686 | 4.909628 | 3.624341 | 4.706553 | 8.137893 |
| 2021 | 11.89821 | 4.963600 | 3.640214 | 4.746757 | 8.261526 |
| 2022 | 12.08005 | 5.002489 | 3.711130 | 4.860277 | 8.395342 |
| 2023 | 12.18267 | 5.026246 | 3.793239 | 4.953289 | 8.433768 |
| 2024 | 12.24602 | 5.034352 | 3.839452 | 5.010035 | 8.558719 |

**Source:** Author's calculations based on Eurostat and World Bank data.

Table 1 presents the log-transformed annual data series used in the econometric analysis. The variables include household consumption, GDP, GDP per capita, the Harmonised Index of Consumer Prices (HICP), and remittances for the period 2015–2024. All variables display a clear upward trajectory, reflecting steady economic growth and increasing nominal values across the decade. The transformation into natural logarithms ensures comparability, stabilizes variances, and allows for elasticity-based interpretation in the regression model. This dataset forms the empirical foundation for the OLS estimations presented in the following tables.

**Table 2.** *OLS Estimation Results for the Consumption Model (2015–2024)*

| Variable                  | Coefficient     | Std. Error | t-Statistic | Prob.  |
|---------------------------|-----------------|------------|-------------|--------|
| Constant (C)              | -0.012993       | 0.982551   | -0.013224   | 0.9900 |
| ln_remit                  | 0.025560        | 0.135958   | 0.187964    | 0.8583 |
| ln_gdp                    | 1.591959        | 0.344538   | 4.620555    | 0.0057 |
| ln_hicp                   | 1.081749        | 0.150287   | 7.197888    | 0.0008 |
| ln_gdppc                  | -0.363652       | 0.296342   | -1.227135   | 0.2744 |
| <b>R-squared</b>          | <b>0.998099</b> |            |             |        |
| <b>Adjusted R-squared</b> | <b>0.996579</b> |            |             |        |
| <b>F-statistic</b>        | <b>656.3752</b> |            |             |        |
| <b>Prob(F-statistic)</b>  | <b>0.000001</b> |            |             |        |

**Source:** Author's calculations based on Eurostat data (2025).

Table 2 presents both the summary statistics of the variables included in the model and the results of the OLS estimation for the log-linear household consumption equation. The descriptive indicators show a consistent upward trend in all variables during 2015–2024, with household consumption (mean ln value 11.87), GDP (4.91), and remittances (8.04) increasing steadily over time. The relatively low standard deviations indicate moderate variability and support the stability of the macroeconomic environment across the decade.

The OLS estimates highlight that Romania's household consumption is primarily driven by domestic macroeconomic fundamentals. Both GDP and the consumer price index (HICP) exhibit positive and highly significant coefficients, with elasticities of 1.59 and 1.08 respectively. These results imply that higher national output and rising price levels translate directly into increased nominal household expenditure, consistent with macroeconomic theory and earlier empirical findings.

By contrast, the coefficient of remittances (0.0256) is positive but statistically insignificant ( $p = 0.8583$ ). This suggests that once GDP and price effects are controlled for, remittance inflows do not exert a measurable impact on aggregate consumption. The GDP per capita coefficient is negative but also insignificant, likely reflecting multicollinearity with the GDP variable.

The overall fit of the model is exceptionally strong ( $R^2 = 0.998$ ), indicating that the selected macroeconomic variables nearly fully explain the variation in household consumption. The Durbin–Watson statistic ( $\approx 2.08$ ) points to the absence of autocorrelation, confirming the robustness and reliability of the specification.

**Table 3.** *Summary Statistics for the Main Variables (2015–2024)*

| Variable | Mean  | Std. Dev. | Min   | Max   | Observations |
|----------|-------|-----------|-------|-------|--------------|
| ln_cons  | 11.87 | 0.27      | 11.47 | 12.25 | 10           |
| ln_remit | 8.04  | 0.33      | 7.68  | 8.56  | 10           |
| ln_gdp   | 4.91  | 0.11      | 4.74  | 5.03  | 10           |
| ln_hicp  | 4.76  | 0.18      | 4.60  | 5.01  | 10           |
| ln_gdppc | 3.66  | 0.18      | 3.37  | 3.84  | 10           |

**Source:** Author's calculations based on Eurostat data.

Table 1 reports the summary statistics for the macroeconomic variables used in the empirical analysis, expressed in logarithmic form. The data cover the period 2015–2024 and reflect a consistent upward trend across all indicators. Household consumption (ln\_cons) shows relatively low variability, indicating steady growth in domestic demand over the decade. Remittances (ln\_remit) also increase gradually, though with slightly higher dispersion, consistent with fluctuations in Romania's migration patterns. GDP, HICP, and GDP per capita exhibit moderate variation, confirming a stable macroeconomic environment throughout the sample. The number of observations (10) corresponds to the annual frequency of the dataset.

### Discussion, Limitations, and Policy Implications

While the empirical findings confirm the strong link between GDP, inflation, and household consumption, the limited role of remittances raises important questions about the structure and efficiency of Romania's economic model. Remittances have historically represented a substantial source of foreign income, at times exceeding 4% of GDP, yet their contribution to domestic demand appears marginal once macroeconomic fundamentals are accounted for. This apparent disconnect suggests that remittances may operate through mechanisms other than immediate consumption, or that their effects are unevenly distributed across household categories and regions.

One plausible explanation lies in the allocation behaviour of recipient households. Previous research (Giuliano & Ruiz-Arranz, 2009; Chami et al., 2005) suggests that remittance inflows are often used as a form of insurance or precautionary saving rather than for sustained consumption. In the Romanian case, many households receiving remittances are located in rural or semi-urban areas, where spending opportunities are limited and much of the money is either saved or directed toward housing improvements, debt repayment, or



informal investments. This behavioural pattern could explain the weak elasticity of consumption with respect to remittances found in the model, as households may prioritize financial security or asset accumulation over immediate expenditures.

Another factor to consider is the underreporting and informal nature of remittance flows. Not all transfers are captured in official statistics, particularly those made through informal channels or carried in cash. Such practices remain common among migrants working in seasonal or irregular employment, especially in Southern Europe. This underestimation may bias the econometric results downward, leading to an apparent disconnect between actual remittance inflows and measured household spending. In addition, recorded remittances sometimes include inflows earmarked for specific non-consumption purposes, such as house construction, which do not translate into short-term consumption despite their economic relevance.

Moreover, the model does not explicitly account for reverse causality that is, the possibility that higher consumption needs (or rising living costs) drive migrants to send more money home. In small open economies like Romania, where migration has been a structural feature for over two decades, such feedback effects can blur the causal direction. For example, periods of rapid price increases, such as during the post-2020 inflationary surge, may have prompted migrant workers to send larger amounts to support household budgets rather than stimulating consumption themselves.

In terms of policy, the findings suggest that remittances represent an underutilized resource in supporting long-term economic development. While they contribute to short-term welfare, their productive potential remains largely untapped. Public policy could encourage a reallocation of remittance flows from pure consumption toward investment-oriented uses, such as entrepreneurship, education, or small business development. This would align Romania with international best practices observed in countries where diaspora contributions have been successfully integrated into development strategies.

Financial literacy programs, tax incentives for remittance-based investments, and the creation of diaspora-linked financial products could serve as effective tools to channel part of these funds into Romania's formal economy. Microcredit schemes and matched savings programs, for example, have been used effectively in other countries to convert remittance inflows into capital for small enterprises. In addition, partnerships between local governments and diaspora associations could facilitate targeted development projects in high-emigration regions, such as Moldova or Oltenia.

Additionally, the government could strengthen data collection mechanisms for remittance tracking, integrating information from financial institutions, money transfer operators, and digital platforms. Improved measurement would allow for more accurate assessments of their macroeconomic impact and facilitate evidence-based policymaking. Enhanced data could also support more granular analyses, distinguishing between consumption, investment, and savings use of remitted funds.

Finally, future research could expand on this study by incorporating panel data at the regional level or micro-level household surveys (such as EU-SILC or HBS datasets). This would allow researchers to distinguish between consumption patterns across different

income groups and better capture the heterogeneity of remittance use. Moreover, the inclusion of variables such as unemployment, interest rates, or exchange rate volatility would improve the understanding of how remittances interact with broader macroeconomic conditions.

In summary, while remittances have undeniably supported Romania's economic stability and reduced poverty, their role in stimulating household consumption appears limited once GDP and prices are taken into account. The challenge for policymakers lies in transforming these external financial flows into a catalyst for sustainable, investment-driven growth, ensuring that migration continues to benefit not just households, but the broader Romanian economy. A more strategic use of remittances could help Romania transition from a consumption-dependent model to one based on long-term productivity and resilience.

## Conclusion

The empirical results of this study reveal a complex interaction between economic growth, inflation, remittances, and household consumption in Romania over the period 2015–2024. Using a multiple linear regression model estimated in logarithmic form, the analysis confirms that household consumption is predominantly determined by macroeconomic fundamentals, particularly GDP growth and price dynamics, while remittances exert only a limited and statistically insignificant influence.

The model, characterized by a very high coefficient of determination ( $R^2 = 0.998$ ), shows that more than 99% of the variation in household consumption can be explained by the selected macroeconomic variables. Among them, GDP growth emerges as the strongest and most significant determinant, reflecting the natural connection between national income and consumer spending. This finding is consistent with Keynesian consumption theory, which posits that increases in aggregate income lead to higher consumption through the multiplier effect.

The inflation variable (HICP) also exhibits a statistically significant and positive relationship with consumption, suggesting that in the Romanian context, moderate price growth is often associated with periods of economic expansion. This could be interpreted as an indicator of a demand-driven economy, where inflation and consumption tend to rise together in response to higher production, wages, and employment.

By contrast, the remittances variable does not show a significant impact on household consumption, despite the considerable volume of transfers received by Romanian households. This result aligns with recent empirical evidence indicating that remittance inflows are frequently used for non-consumption purposes, such as savings, home construction, or debt repayment. Moreover, part of these transfers may be underreported or circulated through informal channels, making their macroeconomic effect appear smaller than it truly is.

The findings thus support the interpretation that Romania's post-crisis economic expansion and rising living standards have been driven mainly by domestic economic growth rather than external inflows. Although remittances have provided stability and reduced short-term

poverty, they have not become a key driver of aggregate demand. This underlines a structural limitation of remittance-based development: while they improve household welfare, they do not automatically stimulate productive investment or long-term economic growth.

From a policy standpoint, these results highlight the need for a strategic reorientation of remittance flows toward more productive uses. The Romanian government, in cooperation with financial institutions and diaspora organizations, could implement mechanisms that encourage remittance recipients to invest part of their income in small enterprises, education, or innovation. Financial education programs, savings incentives, and improved access to credit could transform remittances from a consumption buffer into a lever for sustainable development.

At the same time, the study reveals important avenues for further research. Future analyses could employ regional panel data or microeconomic household surveys to explore the heterogeneity of remittance usage across income groups and regions. Extending the model to include additional variables, such as unemployment, interest rates, or exchange rate fluctuations, would also help refine the understanding of Romania's consumption dynamics in a broader macroeconomic context.

In conclusion, the Romanian economy continues to rely primarily on its internal productive capacity and GDP growth to sustain consumption and welfare. Remittances, although significant in magnitude, play a complementary rather than decisive role. The challenge for policymakers and researchers alike is to design policies capable of channelling these external financial flows toward investment and innovation, transforming migration from a temporary survival mechanism into a genuine engine of national development.

Additionally, as demographic pressures, emigration trends, and labour market shortages intensify within the EU, the role of remittances may evolve. Understanding this evolution will be critical for Romania's future development strategy, particularly if policymakers aim to leverage diaspora engagement as part of a broader and more sophisticated economic modernization agenda.

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## **How do energy consumption, natural resources, trade openness and FDI affect environmental quality in Algeria? Fresh insights from the novel DYNARDL simulations and KRLS approach**

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**Abstract.** *This study investigates the impact of energy consumption, natural resource use, foreign direct investment (FDI), and trade openness on environmental degradation in Algeria over the period 1970–2022. To achieve this, we applied advanced econometric and machine learning approaches, including the Augmented ARDL model, the New DYARDL framework, and the Kernel Regularized Least Squares (KRLS) technique. The empirical results revealed divergent findings regarding the role of energy consumption: while traditional econometric models identified it as a primary driver of emissions, the dynamic specification attenuated its significance, reflecting the increasing reliance on relatively less polluting natural gas. Furthermore, the results provided evidence in support of the pollution haven hypothesis for trade openness and indicated that natural resource use contributes positively to environmental quality. In contrast, FDI exhibited no significant or consistent effect, as its scale remained insufficient to generate measurable environmental outcomes. Finally, the KRLS results confirmed the presence of complex and nonlinear interactions between economic and environmental factors.*

**Keywords:** environmental quality, energy consumption, natural resources, trade openness and FDI, DYARDL and KRLS.

**JEL Classification:** Q53, Q56, Q43, F21, C32.

## 1. Introduction

In recent years, the reduction of carbon dioxide emissions and the improvement of environmental quality have emerged as pressing global concerns. Environmental degradation transcends national borders, as its adverse effects are not confined to polluting countries alone but extend to the international community as a whole. This global interdependence has heightened interest in environmental health and positioned it as a central priority on the United Nations agenda. The pursuit of economic growth, development, and improved standards of living has been accompanied by intensified natural resource extraction and rising energy consumption, thereby accelerating environmental degradation (Opuala et al., 2023). Over the past few decades, the world has experienced profound climate change, primarily driven by greenhouse gas emissions from human activities, particularly industrialization. According to the International Energy Agency (2023), global carbon dioxide emissions from energy combustion and industrial processes increased dramatically, rising from 17.5 Gt in 1990 to 36.8 Gt in 2022.

Addressing and reducing environmental degradation is mainly related to identifying the factors causing it. Recently, the issue of identifying potential factors affecting carbon dioxide emissions and Ecological Footprint has occupied an important space in modern economic research. Researchers have presented several variables that can explain the quality of environmental quality, including economic growth (Gulistan et al, 2020), degree of urbanization (Islam et al, 2021), energy consumption (Shahzad, 2020; Udeagha & Ngepah, 2022), Natural resources abundance (Onifade et al, 2021; Shittu et al, 2021), trade openness (Tachie et al, 2020; Van Tran, 2020), institutional quality (Xaisongkham & Liu, 2022), degree of financial development (Al-Mulali et al , 2015), FDI flows (Opoku & Boachie, 2020; Khan & Ahmad, 2021), and globalization (Islam et al, 2021). Despite the successive and multiplicity of studies, how these factors influence and the degree of their influence is still a matter of controversy and debate.

Although China, the United States, the European Union (27 countries), India, Russia, and Japan are among the world's largest emitters of carbon dioxide together accounting for 67.8% of global fossil fuel-related emissions in 2021 (Crippa et al., 2022) the responsibility for addressing environmental degradation cannot be confined to these economies alone. The contributions of other countries, while relatively smaller in scale, remain significant in the aggregate. This underscores the necessity of collective international action and the intensification of global efforts to safeguard the environment and ensure long-term sustainability.

In this context, Algeria is classified among the developing countries with relatively high carbon emissions, contributing approximately 0.44% of global emissions and ranking third among the largest emitters in Africa. Carbon dioxide emissions in Algeria have shown a persistent upward trend, tripling from 62,936.9 kilotons in 1990 to 170,582 kilotons in 2019, before declining to 161,563 kilotons in 2020 due to the economic slowdown associated with the Covid-19 pandemic (World Bank Indicators, 2024). Algeria's economic and social development is heavily dependent on the hydrocarbons sector, reflecting its status as a rentier state. The country is endowed with significant natural resource wealth, ranking as the fifth-largest producer and fourth-largest exporter of natural

gas, as well as the third-largest producer and ninth-largest exporter of oil worldwide (Boukli Hacene et al., 2020). Hydrocarbons dominate Algeria's foreign trade, accounting for an average of 98% of exports during the period 2002–2014. Furthermore, the domestic energy supply required to sustain economic activity and meet rising societal demand is overwhelmingly derived from oil and gas. A substantial share of foreign direct investment flowing into Algeria is also concentrated in the hydrocarbons sector, further reinforcing the centrality of this industry to the national economy.

Thus, this research paper aims to study one of the most controversial issues in recent years, which is the impact of energy consumption, natural resources, trade openness, and foreign direct investment on environmental quality in one of the oil countries. Our study will focus on Algeria, as its continuing rise in carbon emissions makes it an interesting case study. In addition, we seek to present new evidence from a rentier state characterized by an abundance of natural resources and a continuous rise in demand for non-renewable energy, in addition to being a primary supplier of natural gas and oil in the world, and a destination for foreign direct investments in the hydrocarbons sector. We will focus on these four factors in particular as they are linked to the hydrocarbons sector, which represents the backbone of the economy and development in Algeria, and which may explain the state of environmental quality in Algeria.

The remainder of this study is structured as follows. Section 2 provides a review of the relevant literature. Section 3 outlines the data and methodological framework. Section 4 presents and discusses the empirical results. Finally, Section 5 concludes the study and offers policy recommendations.

## 2. Literature review

The environmental implications of energy consumption remain a subject of considerable debate. On one hand, proponents argue that economic growth necessitates the increased use of low-cost, non-renewable energy sources; on the other hand, critics emphasize that excessive reliance on such energy undermines environmental sustainability. Energy derived from oil, coal, and natural gas is particularly problematic, as it generates substantial emissions and contributes significantly to global environmental degradation. Empirical evidence supports this view. For instance, Gulistan et al. (2020), using data from 112 countries for the period 1995–2017, found that energy consumption exerts a detrimental effect on the environment. Similarly, Zhang et al. (2022), applying the CS-ARDL approach to a panel of 48 developing countries from 1990 to 2020, demonstrated that intensive reliance on carbon-based energy resources exacerbates environmental degradation. Opuala et al. (2023) reported comparable findings for West African countries between 1980 and 2017, highlighting the adverse role of energy consumption in environmental decline. Furthermore, Islam et al. (2021), employing a novel dynamic ARDL simulation approach for Bangladesh over the period 1972–2016, confirmed that energy use increases CO<sub>2</sub> emissions and environmental degradation in both the short and long run.

The relationship between FDI and the environment is still controversial and debated. Despite the many economic benefits that foreign direct investment brings to the host country, it has

many negatives, especially in terms of depleting the host country's natural resources and causing damage to the environment (Solarin & Al-Mulali, 2018). Theoretically, the theoretical literature linking FDI to the environment is focused on two hypotheses: the pollution haven hypothesis, which believes that foreign investment harms the environment, and the pollution halo hypothesis, which confirms that FDI enhances environmental quality. The pollution haven hypothesis suggests that as developing countries compete to attract foreign direct investment, they impose less stringent environmental standards on foreign firms. On the other hand, to escape the high costs of environmental compliance in developed countries and in order to maximize their profits, multinational companies are turning to these developing countries where they benefit from less stringent environmental laws. This means that FDI negatively affects the environment. In contrast, the pollution halo hypothesis argues that multinational companies, especially from developed countries, bring with them cleaner technology techniques, environmentally friendly production methods and better environmental management systems, which reflects positively on the work of local companies and on environmental standards in host developing countries (Seker et al, 2015; Solarin & Al-Mulali, 2018; Demena & Afesorgbor, 2020).

The theoretical literature suggests that foreign direct investment (FDI) influences environmental outcomes through three main channels: scale, structure, and technology. The scale effect implies that rising FDI inflows expand economic activity and energy consumption, thereby exerting a negative impact on the environment. The structural effect highlights that increased FDI can alter the industrial composition of the host economy, typically shifting it from an agrarian base toward a more energy-intensive industrial sector, and eventually, as development advances, toward a service-oriented economy with lower energy demands. Finally, the technological effect reflects the transfer of advanced production and management practices embedded in FDI, which may reduce energy consumption and enhance environmental quality (Christoforidis & Katrakilidis, 2022).

The topic of the impact of trade openness on the environment occupies an important space within current studies. Theoretically, the relationship between trade and environmental quality is usually explained by the environmental Kuznets curve (EKC), the pollution haven hypothesis and the endowment factor hypothesis. According to the EKC hypothesis, during the early stages of development, the main goal of developing countries is to drive economic growth, regardless of whether this growth may harm the environment, by encouraging industries that often cause pollution. However, as these countries develop, environmental awareness in society increases and governments set strict environmental standards. These countries stop producing some pollution-intensive goods and instead begin to import these goods from countries with less stringent environmental laws (Yu et al, 2019). While the pollution haven hypothesis indicates that foreign companies in developed countries with strict environmental regulations work to reduce their production costs by transferring their pollution-intensive industrial activities towards less developed countries, which are often characterized by relatively lenient environmental regulations. The endowment factor hypothesis also means that since specialization in production is based on the relative availability of production factors, and since pollution control is a low-cost factor in developing countries, the latter are more attractive for pollution-intensive production (Ssekibaala et al, 2022).



On the other hand, Antweiler et al (2001) divides the channels through which trade affects the environment into three: scale, composition, and technology. The scale means that trade openness is accompanied by the expansion of economic activities and increased demand for exported or imported products, which harms the environment due to increased energy consumption and depletion of natural resources. While composition refers to the structural composition of industrial production, trade openness can cause environmental degradation if the products and goods in trade are polluted. While technology indicates that with trade openness, the flow of advanced and cleaner technology and technologies increases towards developing countries, which may help them improve their environmental quality (Gulistan et al, 2020; Yu et al, 2019; Chang, 2015).

The relationship between natural resource extraction, resource depletion, and environmental quality has long been central to scholarly debate. Natural resources are widely recognized as a key driver of environmental degradation, primarily through their interaction with economic growth (Isiksal et al., 2022). In the early stages of development, rapid economic expansion is often the central objective of governments; however, such growth is typically accompanied by intensified exploitation of natural resources for energy production and industrial activities. The excessive reliance on and processing of non-renewable resources particularly fossil fuels and minerals has led to rising emissions and severe environmental consequences. Resource depletion has further contributed to biodiversity loss, deforestation, and widespread air and water pollution, thereby exacerbating climate change and accelerating environmental degradation (Huo & Peng, 2023).

Empirically, the majority of studies indicate that natural resources have a negative impact on the environment. The Aladejare (2022) study on the 5 richest African economies during the period 1990-2019, Li et al (2023) study on South Asian countries during the period 1990-2018, and Zhang et al (2024) study on a group of economies abundant in natural resources during The period 1990-2016, indicates that natural resources contributed to increasing environmental degradation (Aladejare, 2022; Li et al, 2023; Zhang et al, 2024).

Conversely, several studies have reported that natural resources and resource rents may have a positive effect on environmental quality. For instance, Khan, Hou, and Le (2021), analyzing data from the United States for the period 1971–2016, and Khan, Hou, Le, and Ali (2021), examining the top ten industrialized countries over 1970–2016, both found that natural resources are negatively associated with environmental degradation, suggesting that resource abundance can enhance environmental quality.

### 3. Methodology and data

#### 3.1. Methodology

##### 3.1.1. ARDL, Augmented ARDL and Dynamic NARDL approach

In light of the above discussions, the following two models are proposed:

$$CO_2 = (EC, NAR, TRA, FDI) \quad (1)$$

$$LCF = (EC, NAR, TRA, FDI) \quad (2)$$

Through this study, we will attempt to study the impact of energy consumption (EC), natural resources (NAR), trade openness (TRA) and foreign direct investment (FDI) on environmental quality, which is the internal variable represented by carbon dioxide emissions (CO2) and the Load Capacity Factor (LCF) and each of them is expressed by two independent equations as follows:

$$CO2_t = \beta_0 + \beta_1 EC_t + \beta_2 NAR_t + \beta_3 TRA_t + \beta_4 FDI_t + \varepsilon_t \quad (3)$$

$$LCF_t = \delta_0 + \delta_1 EC_t + \delta_2 NAR_t + \gamma_3 TRA_t + \delta_4 FDI_t + \varepsilon_t \quad (4)$$

To detect the long-run relationship between the study variables, we use the ARDL bound testing approach developed by Pesaran et al (2001), and to clarify this approach, we will rely only on equation (1), which concerns carbon gas emissions. The long-run cointegration test is verified using the value of the F-state value significant at less than 5%. To perform this test, we rely on the following equation (5):

$$\begin{aligned} \Delta CO2_t = & \theta + \rho_1 CO2_{t-1} + \rho_2 EC_{t-1} + \rho_3 NAR_{t-1} + \rho_4 TRA_{t-1} + \rho_5 FDI_{t-1} \\ & + \sum_{i=1}^q \tau_1 \Delta CO2_{t-i} + \sum_{i=1}^q \tau_2 \Delta EC_{t-i} + \sum_{i=1}^q \tau_3 \Delta NAR_{t-i} \\ & + \sum_{i=1}^q \tau_4 \Delta TRA_{t-i} + \sum_{i=1}^q \tau_5 \Delta FDI_{t-i} + \varepsilon_t \end{aligned} \quad (5)$$

In the framework of the Wald test to test hypothesis  $H_0$ , which states that “there is no cointegration between the variables in the model,” where:

$$H_0: \rho_1 = \rho_2 = \rho_3 = \rho_4 = \rho_5 = 0 \quad (6)$$

and

$$H_1: \rho_1 \neq \rho_2 \neq \rho_3 \neq \rho_4 \neq \rho_5 \neq 0 \quad (7)$$

However, despite this, the cointegration method using the bound testing approach developed by (Pesaran & al, 2001) was not without some defects, especially since its tests were placed under a number of basic restrictions (Pata & Caglar, 2021).

In the face of these shortcomings, (McNown & Al, 2018), (Sam & al, 2019) developed a new approach known as the Augmented ARDL Bounds Test, which incorporates additional and more precise tests to detect the presence of long-term equilibrium relationships. In addition to the overall F-test on the lagged dependent variable and independent variables, and the T-test on the lagged dependent variable introduced by (Pesaran & al, 2001), the Augmented ARDL Bounds Test includes an F-test on the lagged independent variables aimed primarily at detecting the possibility of a breakdown in the cointegration relationship, without the necessity for the dependent variable to be stationary at first differences (I(1)), as required by the traditional bounds test approach (Pesaran & al, 2001). As for the critical values specific to this test (Exogenous F-bounds test on lagged independent variable), they are explained in the research paper provided by (Sam & al, 2019).

To investigate the existence of cointegration through this new approach, the following three tests are mandatory as follows (Caglar et al, 2024):

$$F_{overall}^{test} \quad H_0: \rho_1 = \rho_2 = \rho_3 = \rho_4 = \rho_5 = 0 \quad (8)$$

$$t_{DV}^{test} \quad H_0: \rho_1 = 0 \quad (9)$$

$$F_{IDV}^{test} \quad H_0: \rho_2 = \rho_3 = \rho_4 = \rho_5 = 0 \quad (10)$$

If the values of all three test statistics exceed their respective upper limit critical values, it is inferred that there exists full cointegration among the variables.

The Dynamic ARDL (DYNARDL) approach, introduced by Jordan and Philips (2018), employs a uniform lag length for all variables in the analysis. This feature distinguishes it from the traditional ARDL model developed by Pesaran et al. (2001), which is characterized by greater complexity due to the inclusion of varying lag lengths across different variables (Kartal et al., 2023). An additional advantage of the DYNARDL framework is its ability to generate graphical simulations of counterfactual differences between variables. Specifically, the model illustrates how endogenous variables respond to shocks in exogenous variables, providing a dynamic visualization of causal relationships. These simulations plot the counterfactual reaction of an explanatory variable while holding all other explanatory variables constant, thereby isolating its effect on the dependent variable (Lin & Ullah, 2024). A fundamental requirement of the DYNARDL approach is that the dependent variable must be integrated of order one,  $I(1)$ .

The dynamic ARDL algorithm conducts 5000 simulations utilizing a standard multivariate function for the vector parameter. Additionally, graphs are employed to verify the precise modification of regressors and their response to the response variable (Zhou et al, 2022).

The equation (4) includes a dependent variable integrated in zero order  $I(0)$ , we will estimate it using the Augmented ARDL model, while the dynamic ARDL framework can only be presented for the equation (3) as follows:

$$\Delta CO2_t = \pi + \gamma_0 CO2_{t-1} + \varphi_1 \Delta EC_{t-1} + \gamma_1 EC_{t-1} + \varphi_2 \Delta NAR_{t-1} + \gamma_2 NAR_{t-1} + \varphi_3 \Delta TRA_{t-1} + \gamma_3 TRA_{t-1} + \varphi_4 \Delta FDI_{t-1} + \gamma_4 FDI_{t-1} + \partial ECT_{t-1} + \epsilon_t \quad (11)$$

In Eq. (11),  $\varphi_1, \varphi_2, \varphi_3, \varphi_4$  capture the short-term estimates of the designated variables, whereas  $\gamma_1, \gamma_2, \gamma_3, \gamma_4$  are long-term estimates of the selected variables, which is applicable to model (1),  $\epsilon_t$  denotes an error term and  $ECT_{t-1}$  represents error correction term.

### 3.1.2. The KRLS approach

The KRLS model at first was designed by Hainmueller and Hazlett (2014) primarily for social science researchers to conduct regression analysis and inference without any prior assumptions of linear (Sarkodie, 2021). After estimating and examining the DYNARDL model, we employ these methode (KRLS), an algorithm in machine learning that uses pointwise derivatives to investigate the causal-effect relationship (Sarkodie & Owusu, 2020). This methodology is applied to verify the results of DYNARDL simulations (Kartal, 2023). The KRLS method proves to be fitting for application in social science research due to its nonlinear nature, utilization of radially basis functions to determine the most suitable surface, facilitation of acquiring marginal effects, evasion of rigid parametric assumptions, and facilitation of interpreting intricate relationships (Kartal et al; 2023). The KRLS estimator exhibits all the sought-after statistical properties, being unbiased and consistent.

It asymptotically adheres to the normal distribution under mild regularity conditions. Remarkably, its efficiency is not significantly lower than that of the OLS estimator, even in scenarios where the data exhibit a linear pattern (Dmitraki & Emmanouilidis, 2023).

### 3.2. Data sources and variables

This study estimates an econometric modeling technique to address the effect of energy consumption (EC), natural resources (NAR), trade openness (TRA) and foreign direct investment (FDI) on environmental quality which is the endogenous variable presented by Carbon Dioxide emissions (CO<sub>2</sub>) & Load Capacity Factor (LCF) and each of them is expressed in an independent model. Our analysis uses annual data from 1970 to 2022 (see table 1):

**Table 1.** Definition of variables and data sources

| Symbols (sign)  | Variables: Description (units)                                                                 | Expected sign      |        | Sources                  |
|-----------------|------------------------------------------------------------------------------------------------|--------------------|--------|--------------------------|
|                 |                                                                                                | On CO <sub>2</sub> | On LCF |                          |
| CO <sub>2</sub> | Carbon Dioxide emissions CO <sub>2</sub> emissions (kt)                                        | N/A                |        | WDI                      |
| LCF             | Load Capacity Factor: Biocapacity is expressed in terms of global hectares per capita (gha)    | N/A                |        | Global Footprint Network |
| NAR             | Natural resources abundance (% of GDP)                                                         | -                  | -      | WDI                      |
| FDI             | FDI net inflows (% of GDP)                                                                     | +                  | -      | WDI                      |
| EC              | Energy consumption (% of total final energy consumption)                                       | +                  | -      | EIA                      |
| TRA             | Trade openness index measured by the sum of exports and imports of goods and services % of GDP | + or -             | + or - | WDI                      |

Expected sign: N/A: indicates the dependent variable. - Negative, + Positive, + or - Negative or Positive

Source: Authors' own compilation.

## 4. Results and discussions

### 4.1. Descriptive statistics and correlation matrix

Table 2. represents the results of descriptive statistics. In our case, all series is characterized by a lower degree of dispersion this is confirmed by low values of standard deviations where all the data are located around their mean therefore they are homogeneous. Skewness statistics indicate that CO<sub>2</sub>, EC, NAR & TRA are negatively skewed in other words left-skewed however LCF & FDI are exhibit a right-skewed distribution. The sample data is normally distributed therefore we accept the null hypothesis of normality except LCF & EC where the Jarque-Bera' probability is lower than the critical value 5%.

**Table 2.** Descriptive statistics

| Variables  | CO <sub>2</sub> | LCF      | EC       | NAR      | TRA      | FDI      |
|------------|-----------------|----------|----------|----------|----------|----------|
| Mean       | 11.21444        | 0.805449 | 9.189075 | 2.957367 | 4.041064 | 0.693346 |
| Median     | 11.24426        | 0.734976 | 9.334632 | 3.012232 | 4.061573 | 0.702589 |
| Std. dev.  | 0.547072        | 0.19358  | 0.472673 | 0.394131 | 0.194625 | 0.674673 |
| J-B        | 5.320995        | 20.24174 | 26.84711 | 3.268159 | 3.586872 | 4.733169 |
| Prob (J-B) | 0.069913        | 0.00004  | 0.000001 | 0.195132 | 0.166387 | 0.093801 |

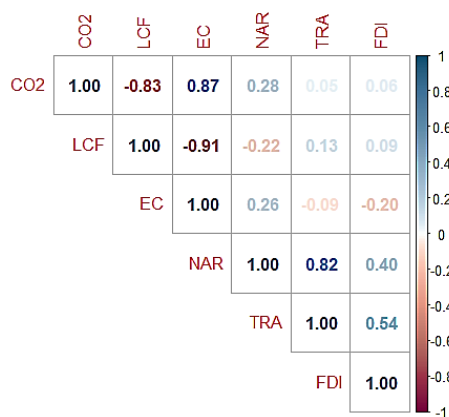
Source: Authors' own computations using EViews 13 software.

### 4.2. Matrix of correlation

The findings of the correlation matrix, as illustrated in Fig. 1, show carbon dioxide emissions (CO<sub>2</sub>) a strong positive correlation with energy consumption (EC), suggesting

that higher fossil-fuel-based energy use conduct leads to increased emissions. Concerning natural resources (NAR), the correlation is weakly positive with CO<sub>2</sub> and feebly negative with LCF, suggesting that resource exploitation contributes only marginally to environmental degradation. Trade openness (TRA) and foreign direct investment (FDI) demonstrate very weak correlations with both CO<sub>2</sub> and LCF (Load Capacity Factor), suggesting that their role in forming environmental quality in Algeria stays relatively limited. Generally, these results emphasize that energy consumption is the most influential driver of environmental degradation, while the other variables exert secondary.

**Figure 1.** Results of Pair-wise correlation



**Source:** Authors' own computations using R studio.

#### 4.3. Unit Root without a Structural Breakpoint and with a Structural Breakpoint

Tables 3 present the results of a unit root test in the presence of structural breaks (L-S) as follows:

**Table 3.** Lee and Strazicich (2003) Unit Root Test With two Structural Break

| Variables       | At level  |                  |                  | At first difference |                  |                  | Results |
|-----------------|-----------|------------------|------------------|---------------------|------------------|------------------|---------|
|                 | t-stat    | DT <sub>1t</sub> | DT <sub>2t</sub> | t-stat              | DT <sub>1t</sub> | DT <sub>2t</sub> |         |
| CO <sub>2</sub> | -5.943    | 1988             | 2012             | -6.832 *            | 1983             | 2011             | I(1)    |
| LCF             | -6.330 ** | 1983             | 2002             | -8.194 *            | 2002             | 2012             | I(0)    |
| EC              | -6.335 ** | 1991             | 1996             | -5.471              | 1981             | 1998             | I(0)    |
| TRA             | -5.878    | 1984             | 2005             | -7.961 *            | 1985             | 2000             | I(1)    |
| NAR             | -5.128    | 1984             | 2004             | -8.563 *            | 1984             | 1995             | I(1)    |
| FDI             | -5.627    | 1987             | 2000             | -10.017 *           | 1980             | 1989             | I(1)    |

**Note:** \*, \*\* and \*\*\* indicate significance at 10%, 5% and 1% level, respectively.

DT<sub>1t</sub> and DT<sub>2t</sub> refer to the first and second break dates, respectively.

**Source:** Authors' own computations using EViews 13 software.

To decide the degree of integration of all-time series and determine their order we relied more on the results of the unit root test of Lee and Strazicich (2003) with two structural breaks. The results show that LCF and CE are constant at the level, while CO<sub>2</sub>, TRA, NAR and FDI are constant at the first difference. Since all the definite variables are integrated in either I(0) or I(1). Hence, the novel dynamic ARDL simulation approach proves to be suitable for implementation on such time series variables.

#### 4.4. Bound tests

For the first model, the upper part of table 4 reports the results of the bounds testing procedure. For both models and according to Pesaran et al. (2001) the computed F-test statistic is found to be exceeding the upper limit, additionally, the calculated t-test statistic is greater than the asymptotic upper bound in absolute values. In these terms, we accept the alternative hypothesis, so there is strong evidence of cointegration. Next, we report the summary of outcomes in the lower part of table 4 using the Augmented ARDL bounds testing approach. It is clear that test statistics are big than the critical value at a 1% level of significance, suggesting the long-run association between load capacity factor, natural resources, energy consumption trade openness and FDI.

**Table 4.** *Bounds test results: Pesaran, Shin, and Smith bounds testing*

| K                                                         |          | 10%    |        | 5%    |        | 1%    |        | p       | value   |
|-----------------------------------------------------------|----------|--------|--------|-------|--------|-------|--------|---------|---------|
|                                                           |          | I(0)   | I(1)   | I(0)  | I(1)   | I(0)  | I(1)   | I(0)    | I(1)    |
| Model 1: $CO_2$ , The ARDL bounds test                    |          |        |        |       |        |       |        |         |         |
| F                                                         | 16.560 * | 1.930  | 3.310  | 2.369 | 3.952  | 3.432 | 5.486  | 0.000 * | 0.000 * |
| t                                                         | -6.986 * | -1.589 | -3.355 | 1.965 | -3.797 | 2.713 | -4.688 | 0.000 * | 0.000 * |
| Model 2: $LCF_t$ - The augmented ARDL bounds test (AARDL) |          |        |        |       |        |       |        |         |         |
| F                                                         | 8.667 *  | 1.9    | 3.01   | 2.26  | 3.48   | 3.07  | 4.44   | --      | --      |
| $\Delta DEP$                                              | -6.537 * | -1.62  | -3.26  | -1.95 | -3.6   | -2.58 | -4.23  | --      | --      |
| $F_{IND}$                                                 | 10.434 * | 2.09   | 3.65   | 2.61  | 4.36   | 3.84  | 6.12   | --      | --      |

**Note:** I(0) and I(1) denote the lower and upper band critical values at 10%, 5%, and 1% significance level of Pesaran, Shin, and Smith bounds test (PSS); P-values are Kripfganz & Schneider critical values and approximate P-values; \* indicates the presence of cointegration at the 1% significance level.

**Source:** Authors' own computations using STATA 17 software.

#### 4.5. ARDL and AARDL estimation

We summarize the findings of long run estimation in Panel A: firstly, the energy consumption and FDI affect  $CO_2$  emissions positively implying that any increase in EC (FDI) by 1% boost  $CO_2$  with 0.699% (0.281%), whereas they reduce LCF with 0.886% (0.030%). Juxtaposing, trade openness index has a positive impact on both  $CO_2$  & LCF while natural resources abundance affect  $CO_2$  & LCF negatively. All these results are significant at 1% level, except FDI coefficient in AARDL model, which is significant at 10%.

Panel B presents the short-run estimates. The coefficients for FDI, trade openness, and natural resource abundance are consistent with the long-run specifications; however, they are statistically insignificant, except for natural resource abundance in Model 1. Energy consumption exhibits a negative effect on  $CO_2$  emissions and a positive effect on LCF, but these coefficients are insignificant and contradict the results reported in Panel A.

For the ARDL model, the error correction term (ECT) is negative and highly significant at the 1% level, indicating the speed of adjustment toward long-run equilibrium. The estimated coefficient of  $-0.630$  suggests that approximately 63% of the disequilibrium from the previous period is corrected in the short run. Similarly, in the Augmented ARDL (AARDL) model, the ECT is also negative ( $-0.859$ ) and statistically significant at the 1% level, confirming the existence of a cointegrating relationship. This result indicates that about 85.9% of the disequilibrium is corrected in the subsequent period, implying a faster speed of adjustment compared to the  $CO_2$  model.

The determination coefficient of the first model is 85.6%, implying that is 85.6% of CO<sub>2</sub> emissions variations are explained by EC, TRA, NAR and FDI while the rest of the variation is explained by other factors that are not mentioned in the model. Concerning the second model, the value of R<sup>2</sup> means that 66.9% of LCF variations can be explained by the same exogenous variables and 33.1% are determined by other variables.

**Table 5.** ARDL and Augmented ARDL results estimation

| Model 1: ARDL(1,4,3,4,4)               |              |       |          | Model 2: Augmented ARDL(1,4,2,3,0) |        |          |
|----------------------------------------|--------------|-------|----------|------------------------------------|--------|----------|
| Parameters                             | Coefficients | t     | p values | Coefficients                       | t      | p values |
| <b>Panel A: Long run coefficients</b>  |              |       |          |                                    |        |          |
| EC                                     | 0.699        | 7.44  | 0.000    | -0.886                             | -5.288 | 0.000    |
| TRA                                    | 2.005        | 7.21  | 0.000    | 2.571                              | 7.483  | 0.000    |
| NAR                                    | -1.179       | -7.50 | 0.000    | -0.660                             | -4.216 | 0.002    |
| FDI                                    | 0.281        | 4.29  | 0.000    | -0.030                             | -2.029 | 0.050    |
| <b>Panel B: Short run coefficients</b> |              |       |          |                                    |        |          |
| ECM(-1)                                | -0.630       | -6.99 | 0.000    | -0.859                             | -6.982 | 0.000    |
| ΔEC                                    | -0.320       | -1.11 | 0.278    | 1.032                              | 0.975  | 0.336    |
| ΔEC(-1)                                | 0.416        | 1.43  | 0.165    | 0.919                              | 0.748  | 0.459    |
| ΔEC(-2)                                | -0.268       | -1.01 | 0.323    | 0.274                              | 0.234  | 0.816    |
| ΔEC(-3)                                | -0.766       | -2.59 | 0.016    | -3.949                             | -3.473 | 0.001    |
| ΔTRA                                   | 0.179        | 0.85  | 0.403    | 0.419                              | 1.153  | 0.257    |
| ΔTRA(-1)                               | -1.098       | -5.61 | 0.000    | -1.021                             | -2.525 | 0.016    |
| ΔTRA(-2)                               | -0.844       | -3.10 | 0.005    | --                                 | --     | --       |
| ΔNAR                                   | -0.293       | -3.30 | 0.003    | -0.037                             | -0.377 | 0.708    |
| ΔNAR(-1)                               | 0.512        | 5.33  | 0.000    | 0.569                              | 4.685  | 0.000    |
| ΔNAR(-2)                               | 0.233        | 2.41  | 0.024    | 0.320                              | 3.478  | 0.001    |
| ΔNAR(-3)                               | -0.144       | -2.29 | 0.031    | --                                 | --     | --       |
| ΔFDI                                   | 0.051        | 1.69  | 0.104    | --                                 | --     | --       |
| ΔFDI(-1)                               | -0.131       | -3.18 | 0.004    | --                                 | --     | --       |
| ΔFDI(-2)                               | -0.108       | -3.13 | 0.004    | --                                 | --     | --       |
| ΔFDI(-3)                               | -0.093       | -3.86 | 0.001    | --                                 | --     | --       |
| D1                                     | 0.142        | 2.56  | 0.017    | --                                 | --     | --       |
| D2                                     | --           | --    | --       | -0.145                             | -6.615 | 0.000    |
| R-squ                                  | 0.856        |       |          | 0.669                              |        |          |
| Adj R-squ                              | 0.735        |       |          | 0.578                              |        |          |
| P-value F s                            | 0.000        |       |          | 0.000                              |        |          |

**Source:** Authors' own computations using STATA 17 software.

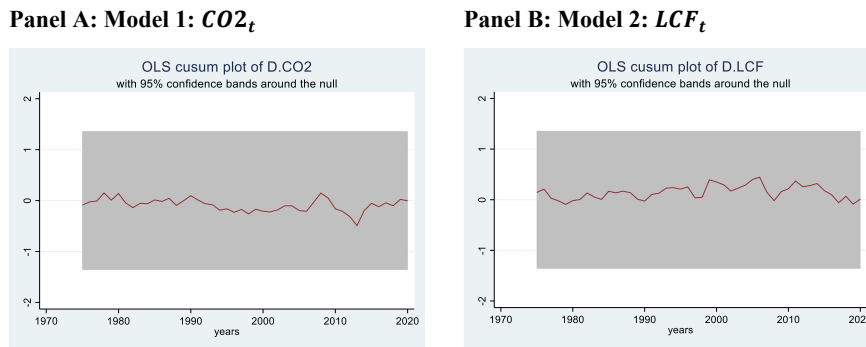
Table 6 explicates the findings of this model diagnostic tests on the time series dataset. We applied the Breusch-Godfrey LM test to discover any potential serial correlation in the two model. The results indicated that did not exhibit any concerns regarding serial autocorrelation In both proposed econometrics models. The White's heteroscedasticity test is also applied to confirm the homoscedasticity of two our models.

**Table 6.** Model diagnostic test

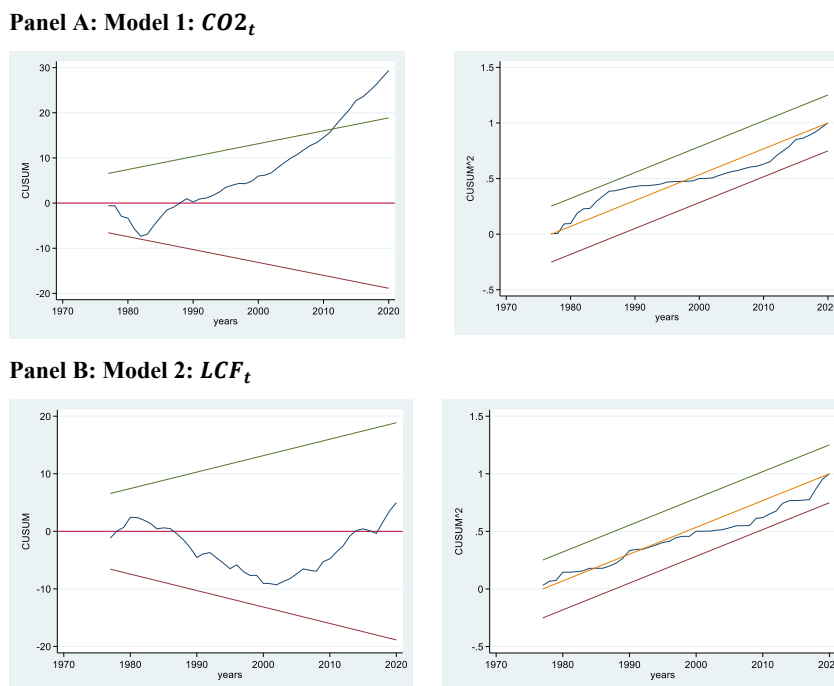
| <b>Panel A: Breusch-Godfrey LM test for autocorrelation</b>                     |                            |         |                            |         |
|---------------------------------------------------------------------------------|----------------------------|---------|----------------------------|---------|
|                                                                                 | Model 1 : CO <sub>2t</sub> |         | Model 2 : LCF <sub>t</sub> |         |
| Lags (P)                                                                        | F-statistic                | df      | F-statistic                | df      |
| 1                                                                               | 1.001 [0.3271]             | (1, 24) | 0.252 [0.6194]             | (1, 30) |
| 2                                                                               | 0.967 [0.3950]             | (1, 23) | 1.969 [0.1578]             | (2, 29) |
| <b>Panel B: White's test (Cameron &amp; Trivedi's decomposition of IM-test)</b> |                            |         |                            |         |
| Source                                                                          | Chi-square                 | df      | Chi-square                 | df      |
| Heteroskedasticity                                                              | 46.00 [0.4306]             | 45      | 46.00 [0.4306]             | 45      |
| Skewness                                                                        | 9.23 [0.9873]              | 21      | 13.19 [0.5873]             | 15      |
| Kurtosis                                                                        | 0.22 [0.6379]              | 1       | 0.24 [0.6227]              | 1       |
| Total                                                                           | 55.45 [0.8421]             | 67      | 59.44 [0.5328]             | 61      |

**Note:** For autocorrelation, H<sub>0</sub>: No serial correlation. P-values in [ ]

**Source:** Authors' own computations using STATA 17 software.

**Figure 2.** Parameter stability plots: Cum sum test using OLS CUSUM plot for parameter stability

**Source:** Authors' own computations using STATA 17 software.

**Figure 3.** Cumulative sum and cumulative sum squares plots for two models estimated

**Source:** Authors' own computations using STATA 17 software.

#### 4.6. Dynamic ARDL simulations estimation

Table 7 shows the findings of the novel Dynamic ARDL simulations as follow. The results showed that in the short term, the abundance of natural resources had a negative and significant effect on  $CO_2$  emissions, and that energy consumption had a negative but insignificant effect, while the effect of trade openness and foreign direct investment was positive but insignificant.



In the long term, the results showed a positive and insignificant effect of energy consumption on CO<sub>2</sub> emissions. The results indicate that increase in energy consumption leads to an increase in CO<sub>2</sub> emissions. This means that energy consumption in Algeria has caused further environmental degradation. This is because power generation in Algeria relies heavily on non-renewable sources, such as coal and natural gas, which are the main sources of carbon and greenhouse gases, and thus ecosystem degradation. These results are consistent with the work of Bélaïd & Youssef (2017) who found that the effect of renewable and non-renewable electricity consumption on CO<sub>2</sub> emissions in Algeria was positive but insignificant. These results support the work of Adedoyin et al. (2021) who found that non-renewable energy consumption caused an increase in emissions levels in sub-Saharan Africa, and Islam et al. (2022) who concluded that energy use negatively affected the ecological footprint and caused environmental degradation in Bangladesh.

While trade openness showed a positive and significant effect on CO<sub>2</sub> emissions in the long run, which means that trade openness harmed environmental quality in Algeria. A 1% increase in trade openness leads to an increase in CO<sub>2</sub> emissions by 0.403%. These results are logical in a country like Algeria, where hydrocarbon exports constitute the main component of exports. Algeria is the fifth largest producer and fourth largest exporter of natural gas, and the third largest producer and ninth largest exporter of oil in the world (Boukli Hacene et al, 2020). These results are consistent with those presented by Hakimi & Hamdi (2016) and Yu et al (2019). Khan et al. (2019) concluded that trade has contributed to increased environmental degradation in Pakistan, noting that the negative impact of trade openness on the environment is due to developed countries shifting their polluting production processes to developing countries.

The results also revealed that the abundance of natural resources had a negative and significant impact on carbon dioxide emissions in the long run, as a 1% increase in natural resources results in a 0.235% decrease in CO<sub>2</sub> emissions. This means that natural resources contribute to improving environmental quality. This can be explained by the fact that companies use environmentally safe technologies to extract natural resources, which reduces the amount of carbon dioxide emitted into the environment. It can also be explained by the fact that Algeria, despite its abundance of natural resources, does not exploit these resources efficiently in the industrial sector, which is still not developed enough to allow it to use this abundance intensively in production processes. These results are consistent with those presented by Khan et al (2021), Majeed et al (2021), Huo & Peng (2023). However, these results conflict with the works of Bekun et al. (2019) and Guo et al. (2023), who revealed that natural resource rents are a source of environmental degradation in the long run.

The results further indicate that FDI exerts a positive but statistically insignificant effect on CO<sub>2</sub> emissions in the long run, implying that increases in FDI are associated with higher emissions. This outcome is plausible in the Algerian context, where FDI is predominantly resource-seeking and concentrated in the extractive industries sector. Such findings lend support to the pollution haven hypothesis in Algeria, which posits that firms from developed countries—facing stringent environmental regulations and higher compliance costs—relocate their production activities to developing economies with more lenient

regulatory frameworks. These results are in line with Mukiyen Avcı (2023), who demonstrated that Turkey functions as a pollution haven for advanced economies. Similarly, Khan et al. (2019) found that FDI had a positive but insignificant effect on environmental degradation in Pakistan in the long run, emphasizing that much of the FDI flowing from developed to developing economies is directed toward manufacturing, mining, and electricity generation, sectors that contribute substantially to environmental degradation.

ECT refers to the error correction term, which measures the speed of adjustment toward long-run equilibrium. The results show that the estimated ECT has a negative and statistically significant value, indicating that the imbalance will be corrected by approximately 19% in the long run. Moreover, the  $R^2$  value suggests that the independent variables explain around 67% of the total variation in the dependent variable. The estimated p-value of the F-statistic further confirms that the model provides a good overall fit.

The new dynamic ARDL simulation model proves effective in automatically generating graphs and predicting the future values of the dependent variable in response to changes in the explanatory variables while holding other factors constant. In this study, we predicted the variation in CO<sub>2</sub> emissions in response to a positive or negative 1% change in the explanatory variables, namely energy consumption, trade openness, natural resource abundance, and foreign direct investment.

**Table 7.** Estimates of DYARDL simulations model

| Parm                         | Coef   | SE          | t     | P-value | Min 95 | Max 95 |
|------------------------------|--------|-------------|-------|---------|--------|--------|
| <b>Long-run analysis</b>     |        |             |       |         |        |        |
| EC <sub>t-1</sub>            | 0.135  | 0.143       | 0.94  | 0.354   | -0.155 | 0.425  |
| TRA <sub>t-1</sub>           | 0.403  | 0.131       | 3.07  | 0.004   | 0.137  | 0.667  |
| NAR <sub>t-1</sub>           | -0.235 | 0.091       | -2.58 | 0.014   | -0.420 | -0.050 |
| FDI <sub>t-1</sub>           | 0.021  | 0.060       | 0.36  | 0.721   | -0.099 | 0.143  |
| <b>Short-run analysis</b>    |        |             |       |         |        |        |
| ECM(-1)                      | -0.189 | 0.108       | -1.75 | 0.087   | -0.408 | 0.029  |
| ΔFDI                         | 0.032  | 0.046       | 0.70  | 0.488   | -0.060 | 0.125  |
| ΔEC                          | -0.143 | 0.441       | -0.32 | 0.747   | -1.036 | 0.749  |
| ΔTRA                         | 0.289  | 0.275       | 1.05  | 0.300   | -0.266 | 0.844  |
| ΔNAR                         | -0.245 | 0.129       | -1.90 | 0.065   | -0.507 | 0.016  |
| D <sub>1</sub>               | -0.232 | 0.146       | -1.59 | 0.121   | -0.527 | 0.063  |
| <b>Model characteristics</b> |        |             |       |         |        |        |
| R <sup>2</sup>               | 0.67   | Prob > F    | 0.026 |         |        |        |
| Adj R-squa                   | 0.51   |             |       |         |        |        |
| Num of obs.                  | 50     | Simulations | 5000  |         |        |        |

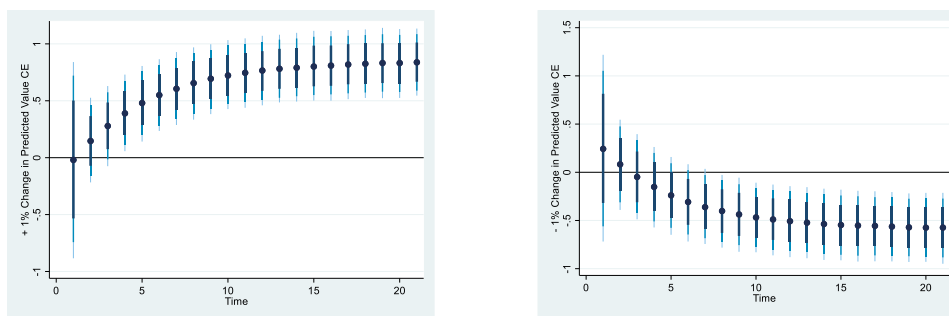
**Notes:** The table show the estimation results of the DYNARDL simulation and the associated diagnostic checks. ECM(-1) indicates the error correction term coefficient. D<sub>1</sub> dummy variable symbolizing the structural changes detected in the model. SE is the standard error.

Keeping other things constant, Fig. 4 shows that positive shock of energy consumption increase the propagation of CO<sub>2</sub> emissions, while a -1% changes in energy consumption reduce the effect of CO<sub>2</sub>, therefore the irrational utilization of energy provoke the CO<sub>2</sub> emissions. Likewise, in Fig. 5, a 1% counterfactual shocks in trade openness have a positive effect on CO<sub>2</sub> emissions, whereas, the negative changes have a negative effect (decrease) on the dependent variable. In contrast, positive (negative) shock of natural resources abundance reduce (improve) the CO<sub>2</sub> emissions. Finally, Fig. 7 illustrates that +1% changes

in FDI increase the CO<sub>2</sub> emissions, but -1% changes have a slight positive effect on the endogenous variable. According to the results of DYARDL diagrams, only natural resources abundance that can decline CO<sub>2</sub> emissions & improve the environmental quality in Algeria.

The DARDL model stands out for its ability to aid in visually representing, modeling, and of counterfactual alterations in a dependent variable caused by a shock in an explanatory variable (Hassan et al, 2024).

**Figure 4.** *Effects of  $\pm 1\%$  Counterfactual Shocks in EC on the CO<sub>2</sub>*



**Notes:** dot (●) Dots represent average predicted value while dark blue to light blue lines stands for 75, 90 and 95% confidence interval by +1% and – 1% shock in EC.

**Figure 5.** *Effects of  $\pm 1\%$  Counterfactual Shocks in TRA on the CO<sub>2</sub>*

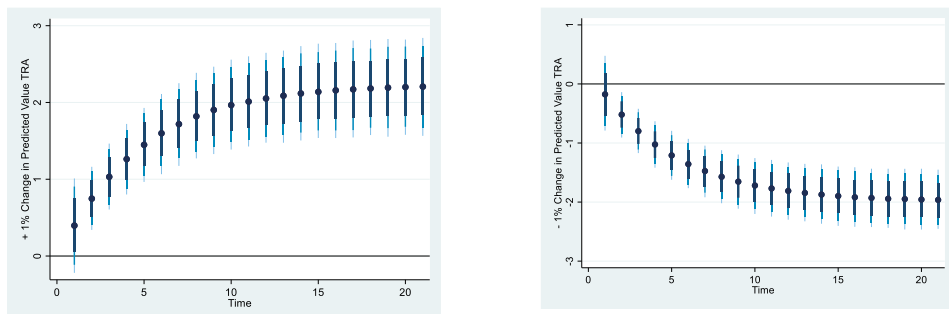


**Figure 6.** *Effects of  $\pm 1\%$  Counterfactual Shocks in NAR on the CO<sub>2</sub>*

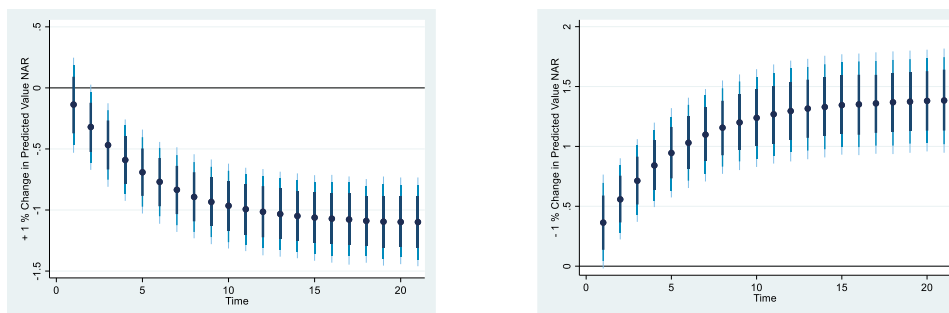
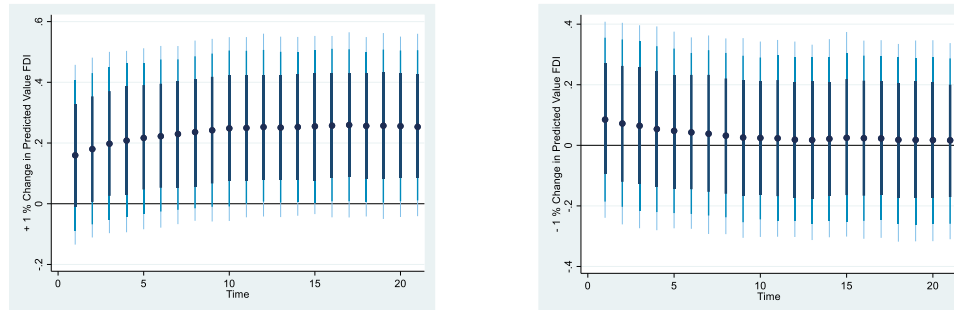


**Figure 7.** Effects of  $\pm 1\%$  Counterfactual Shocks in FDI on the CO<sub>2</sub>

**Source:** Authors' own computations using STATA 17 software.

#### 4.7. KRLS estimation

The KRLS approach is executed to research, with the help of pointwise derivatives, the link between CO<sub>2</sub> and the independent parameters. The KRLS results for CO<sub>2</sub> emissions is appear in Table 8. The KRLS approach is applied to check the results of the DYNARDL simulations. Table 8. presents the KRLS approach results as follow:

**Table 8.** Pointwise derivatives using KRLS

| CO <sub>2</sub>    | Avg.   | SE      | t      | P>t     | P25    | P50    | P75   |
|--------------------|--------|---------|--------|---------|--------|--------|-------|
| EC                 | 0.808  | 0.053   | 15.077 | 0.000   | 0.329  | 0.997  | 1.198 |
| TRA                | 0.103  | 0.133   | 0.775  | 0.442   | -0.356 | 0.136  | 0.630 |
| NAR                | -0.212 | 0.071   | -2.968 | 0.005   | -0.483 | -0.260 | 0.068 |
| FDI                | 0.167  | 0.024   | 6.930  | 0.000   | -0.030 | 0.174  | 0.355 |
| D1                 | 0.254  | 0.043   | 5.868  | 0.000   | 0.066  | 0.240  | 0.422 |
| <b>Diagnostics</b> |        |         |        |         |        |        |       |
| Lambda             | 0.061  | Sigma   | 5      | R2      | 98.1   | obs    | 51    |
| Tolerance          | 0.051  | Eff. df | 25.09  | Looloss | 7.352  |        |       |

**Notes:** Where Avg. is the average marginal effect; SE is the standard error; P-25, P-50, and P-75 represent 25th, 50th, and 75th percentile.

**Source:** Authors' own computations using STATA 17 software.

Table 8 presents, the predictive power of the KRLS model is 98.1 implying that the explanatory variables explain 98.1% of the variation in the CO<sub>2</sub> emissions in the Algeria. According to the results, the mean pointwise marginal effects for natural resources, FDI, Energy consumption and trade openness are 0.808, 0.103, -0.212, 0.167 and 0.254 respectively. However, only natural resources, FDI, Energy consumption and dummy variable found to be statistically significant at all examined levels. It is clear that the positive sign of the energy consumption coefficient, trade openness and also FDI is consistent with the results obtained from the DARDL model. Also, Table 8 gives percentiles at the 25th, 50th, and 75th levels for an analysis of various marginal effects using regressor derivatives. Specifically, at the first quartile, a unit increase in energy consumption causes a 0.329% increase in CO<sub>2</sub>, at 50% and 75% the effect is still positive but it increases with higher degrees (0.997%, 1.198% respectively).

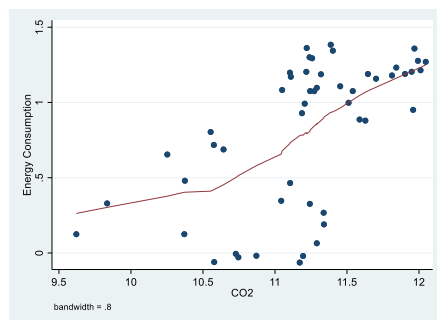
As for trade openness (TRA), its impact was small, at 0.103, and statistically insignificant. However, the percentiles reveal that its value is negative (P25 = -0.356) at the lower

quintiles, while it takes positive values ( $P50 = 0.136$ ,  $P75 = 0.630$ ) at the middle and upper quintiles. This can be explained by the fact that at the beginning of trade liberalization, under certain conditions, it may have a positive or neutral impact on the environment through the transfer of clean technology. However, under other conditions, with the increase in trade volume in polluting industries, its impact on the environment becomes negative through the increase in  $CO_2$ .

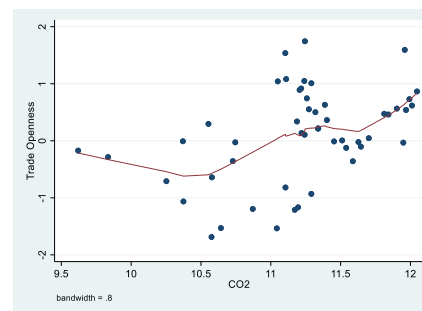
We also find that natural resources contribute to improving environmental quality by reducing  $CO_2$  emissions. The positive environmental impact appears stronger in the lower and middle quintiles but weakens in the upper quintile. This pattern may reflect a substitution effect, whereby less polluting natural gas replaces more carbon-intensive energy sources, or it may indicate that revenues generated from oil exports are being used to finance cleaner technologies and environmentally friendly infrastructure.

Contrary to the DYNARDL results, the KRLS technique reveals a significant negative impact of FDI on the environment, starting close to zero in the lower quintile and increasing in the upper quintiles. The high elasticity of the KRLS enables it to capture nonlinear effects. This result could support the "pollution haven" hypothesis and emphasizes the importance of investment quality, not just quantity.

**Figure 8.** Pointwise marginal effects of the energy consumption, natural resources and trade openness on the  $CO_2$  emissions

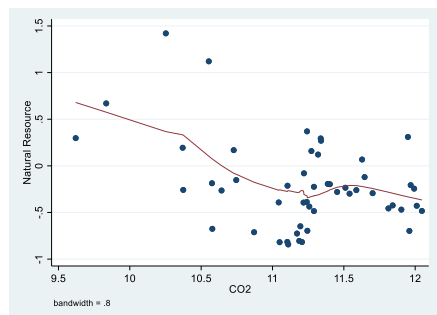


A. Pointwise Marginal Effect of the Energy Consumption on the  $CO_2$  Emissions



B. Pointwise Marginal Effect of the Trade openness on the  $CO_2$  Emissions

C.



D. Pointwise Marginal Effect of the Natural Resource on the  $CO_2$  Emissions

## 5. Conclusion and policy implications

This paper would contribute to the existing literature on the determinants of environmental quality by providing empirical evidence that can inform policy aimed at reducing environmental degradation. Specifically, the study examines the impact of energy consumption, natural resources, foreign direct investment (FDI), and trade openness on CO<sub>2</sub> emissions and the Load Capacity Factor (LCF) in Algeria over the period 1970–2022.

Preliminary results reveal that, when estimating the first model using the ARDL methodology and the second model through the Augmented ARDL method, energy consumption exerts a statistically significant and positive long-run effect on emissions. This confirms that reliance on conventional energy sources is the primary driver of carbon emissions and a key determinant of environmental degradation. In contrast, estimates from the dynamic DYARDL model suggest that, in the long run, energy consumption does not significantly influence environmental quality in Algeria. One possible explanation is that the effect of energy consumption is subsumed within other, more influential variables such as trade openness and natural resources. Moreover, Algeria's energy profile—dominated by natural gas—may produce different environmental outcomes compared to economies more reliant on coal or other highly polluting sources.

The econometric results further indicate that trade openness is associated with a deterioration in environmental quality. This finding lends support to the pollution haven hypothesis, which argues that trade liberalization in developing economies, such as Algeria, tends to attract pollution-intensive investments and industrial activities relocated from advanced economies with stricter environmental standards. Consequently, these results highlight the necessity of complementing trade liberalization with stringent environmental regulations and effective monitoring mechanisms, in order to mitigate the ecological costs of openness while still reaping its economic benefits.

In contrast, natural resources show a positive impact on environmental quality, possibly reflecting the use of oil and gas to improve environmental infrastructure. It also reflects the reliance on natural gas (dominant in Algeria) for power generation, which is less polluting than other energy sources. Foreign direct investment, however, has no clear impact on environmental quality in the case of Algeria, particularly since its size is not large enough to have a significant impact compared to trade openness and natural resources.

To support the study's findings, we used the KRLS technique. The results indicate that energy consumption is the most important generator of carbon dioxide emissions in Algeria, exhibiting a positive and significant marginal effect that increases across percentiles and increases at higher levels of emissions. Meanwhile, the relationship between trade, foreign direct investment, and carbon emissions appears nonlinear, with their effects varying depending on the sample distribution and economic situation. This supports the importance of adopting a nonlinear approach to understanding complex environmental-economic relationships. In contrast, the natural resource effect confirms that increasing natural rents can be used to improve environmental quality. Hence, it can be said that the results of KRLS confirmed and deepened the results of DYNARDL, as they showed non-linear details that must be taken into account when setting environmental policies in Algeria.

In conclusion, the findings suggest that environmental policies in Algeria should prioritize the following directions:

- Accelerating the energy transition by expanding the deployment of renewable energy sources and enforcing strict energy efficiency standards;
- Improving energy efficiency to maximize both economic and environmental benefits, rather than concentrating exclusively on reducing consumption volumes;
- Integrating carbon clauses and environmental standards into trade agreements, while incentivizing the development of low-emission value chains to mitigate the environmental risks associated with trade expansion;
- Earmarking a share of hydrocarbon revenues for the establishment of an environmental sovereign fund dedicated to financing the energy transition and green infrastructure projects;
- Adopting a selective investment policy that provides strong incentives for environmentally responsible projects, restricts highly polluting investments, and promotes the localization of low-carbon industries.

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## **The acceleration of education: professors, AI platforms and the transformation of learning and human growth**

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**Abstract.** *The incorporation of artificial intelligence (AI) into education represents a transformative shift in the ways societies organize learning and shape human development. Far beyond a technological upgrade, AI reshapes the functions of professors, learners, and institutions, generating implications that extend well outside the classroom. Adaptive learning systems and AI-driven tutors offer individualized learning trajectories that may enhance efficiency, engagement, and mastery; however, they also invite concerns regarding excessive dependence on automated support, the weakening of critical thinking, and the narrowing of intellectual autonomy. As a result, the role of the professor is evolving from that of primary knowledge distributor to that of mentor who cultivates inquiry, collaboration, and ethical discernment.*

*AI's impact on cognitive and psychological development is particularly profound. Although digital tools broaden access to information, the externalization of memory, interpretation, and analytical reasoning may erode sustained attention, creativity, and intrinsic motivation. The advantages provided by AI are also unevenly distributed, often reinforcing existing social disparities by favouring individuals and communities with stronger digital infrastructures and higher levels of technological literacy. At the same time, issues of data governance, algorithmic bias, and subtle forms of behavioural shaping raise complex ethical dilemmas for student autonomy and institutional trustworthiness.*

*From a cultural perspective, AI risks contributing to the homogenization of educational content, potentially weakening local knowledge systems and diverse epistemologies. Nonetheless, when deployed responsibly, AI can act as a facilitator of global knowledge flows, intercultural exchange, and collaborative innovation. This paper argues that the trajectory of human development in the AI era will depend not only on technological advancement but also on intentional decisions regarding equity, ethics, and the safeguarding of human agency within learning processes.*

**Keywords:** Artificial Intelligence, human development, adaptive learning systems, cognitive economy, algorithmic socialisation.

**JEL Classification:** I25, O15, O33, D83, D90, J24.

## 1. Introduction

Artificial intelligence (AI) has moved from the margins of educational technology to the very structure of learning. It was originally intended to supplement human instruction, but it now serves as an independent mediator between information and cognition. Adaptive systems, predictive analytics, and conversational agents influence how students learn, receive feedback, and manage their efforts (Zawacki-Richter et al., 2019). In this environment, the learner no longer interacts solely with professors or institutions, but rather with algorithms that learn from their behaviour, forecast their performance, and quietly shape their cognitive habits. Education is becoming algorithmic, not just digitized, but a behavioural ecosystem in which attention, motivation, and curiosity are continually optimized for efficiency (Holmes et al., 2022).

Historically, each technological advancement in education, from print to broadcast to the internet, has altered how knowledge is organized and internalised (Selwyn, 2019). However, AI brings about a qualitative shift: it no longer distributes information but rather participates in decision-making itself. AI transforms learning from a linear exchange of knowledge to an adaptive feedback economy using reinforcement loops and predictive models (Luckin et al., 2016). The psychological consequences are significant. Learning becomes immediate, personalized, and frictionless; but the same friction that once encouraged perseverance and depth is now algorithmically minimized (Williamson & Piattoeva, 2022). The challenge is not only how individuals learn with AI, but also the types of minds that will result from continuous algorithmic mediation.

This transition can be viewed in cognitive and behavioural terms as the development of the algorithmic human, an individual whose learning patterns, attention span, and motivational systems are influenced and conditioned by predictive technologies (Siemens, 2023). To study this transformation, psychology, economics, and digital ethics must be combined: psychology to explain the reconfiguration of cognitive effort; economics to interpret attention and data as scarce resources; and ethics to assess autonomy in systems that predict behaviour before it takes place (Beer, 2023). Rather than portraying AI as an external tool, this paper describes it as a developmental environment that evolves alongside the learner and gradually defines what learning feels like.

The analysis draws on and extends classical theories of constructivism and social learning. Piaget's emphasis on active discovery, Vygotsky's concept of scaffolding, and Bandura's social modelling all relied on human intermediaries who adjusted feedback according to context and empathy. Algorithmic pedagogy replicates the adaptive element while removing the human interpretive layer. Instead of professors interpreting subtle cues of confusion or curiosity, algorithms analyse data traces such as clicks, pauses, and completion rates, and provide optimized responses (Holmes et al., 2022). From a behavioural standpoint, this redefines reinforcement: the learner's actions generate micro-rewards via instant validation, resulting in a closed circuit of stimulus and response that rarely tolerates uncertainty or delays (Koedinger et al., 2019). As time passes, this adaptive precision could promote convenience but erode the tolerance for ambiguity that underlies creativity and critical reflection (Dillenbourg, 2021).

To capture this shift, the essay introduces three interconnected constructs that describe the psychological and economic logic behind algorithmic education. The first is Algorithmic Socialization, which represents the process through which individuals internalize the logic of adaptive systems and anticipate constant personalization (Siemens, 2023). Students learn not only from algorithms, but also about them, developing habits of externalized control and a preference for immediate feedback. The second term, Cognitive Entropy, refers to the diffusion of mental effort that occurs when automation replaces tasks that previously required sustained attention (Williamson, Piattoeva, 2022). In a seamless environment, cognitive energy disperses -learners navigate many surfaces but penetrate few depths. The third, The Educational Attention Economy, views attention as both a cognitive resource and a tradeable asset. AI-based learning platforms improve engagement because attention generates data, which fuels prediction (Beer, 2023). The result is a behavioural market in which curiosity is transformed into monetizable engagement rather than intrinsic exploration.

Together, these concepts form a theoretical model of how AI influences human development through education. They shift the conversation away from concerns about efficiency or access and toward the more fundamental question of what types of cognition and socialization are being selected for in algorithmic environments. Each mechanism, from: socialization, entropy, and attention commodity, represents a psychological adaptation to systems designed for prediction rather than uncertainty. The outcome of this combination is a generation conditioned to operate within closed loops of optimized feedback, where exploration is bounded by recommendation (Holmes et al., 2022).

From the perspective of economics, this process is consistent with informational capitalism. Regarding traditional markets, scarcity structured value; in algorithmic education, scarcity lies in undivided attention (Beer, 2023). Behavioural economics delivers a lens to interpret how learners allocate effort and cognitive resources when rewards are instantaneous and personalized (Kahneman, 2011). The trade-off between depth and speed resembles the substitution effect in microeconomics: when the “cost” of mental effort grows relative to quick algorithmic payoff, learners rationally shift toward lower-effort engagement (Simon, 1982). As time passes, this reallocation may not appear irrational, it aligns with system incentives, but it redefines what rationality means in learning contexts. The invisible hand that guides this market is now algorithmic anticipation and not human demand.

The broader developmental implications are intergenerational. Children raised within predictive environments experience reduced cognitive uncertainty; their formative experiences develop under constant optimization (Selwyn, 2019). Adults educated prior to this shift experience cognitive dissonance between pre-digital patience and algorithmic immediacy. The educational system thus becomes a battleground for temporal cultures of learning as in manual versus automated, reflective versus reactive. Understanding this divide is critical for policymakers and educators looking to create curricula that encourage adaptive intelligence while preserving agency.

Ultimately, AI's most significant educational legacy will be psychological rather than technological. Recognizing and managing this transformation is the central task of education in the age of artificial intelligence. Systems designed to personalize learning are

also personalizing cognition by encoding behavioural norms of immediacy, predictability, and efficiency into the structure of thought itself (Williamson, Piattoeva, 2022).

## 2. Theoretical Background: From Constructivism to Algorithmic Pedagogy

Education has always followed the logic of its dominant tools. Every technological advancement, from the printing press to the digital classroom, has changed the way that knowledge is shared and understanding is developed. According to Piaget (1970) and Vygotsky (1978), classical constructivism viewed learning as an active, self-directed process of meaning-making in which learners build knowledge via exploration and reflection. Bandura's (1986) social learning theory further demonstrated that observation and imitation depend on social context and motivation. This tradition is carried on by artificial intelligence (AI), which improves feedback and personalization to levels that previous pedagogies could only roughly match.

This tradition is carried on by algorithmic pedagogy, which organizes learning through data-driven prediction and feedback (Luckin et al., 2016). To provide real-time adjustments that suit each person's pace, ability, and preferred sensory mode, modern AI systems are excellent at identifying patterns in learner behaviour (Holmes et al., 2022). This personalization has a transformative effect on a lot of students. Learners who previously struggled with abstract lectures or uniform assessments can now access visual, auditory, or interactive formats that correspond to how they best process information. Being taught in someone else's style, which was once an unnoticeable disadvantage, can now be addressed and remedied. Algorithmic pedagogy increases equity and accessibility by enabling a greater number of individuals to engage with the material on their own cognitive terms.

According to recent research, affective and metacognitive abilities remain limited in educational AI, even though prediction and performance analytics predominate (Pacheco et al., 2025; Willegas et al., 2025). This does not mean that AI learning environments are ineffective or unsatisfying; rather, numerous learners report higher levels of engagement and comprehension than they did with traditional instruction. The ability of AI to support a variety of learning styles is one of its greatest contributions. Kinaesthetic learners can interact interactively by using digital models or step-based practice; auditory learners can rely on conversational feedback or narration; and visual learners can explore ideas through diagrammatic explanations and imagery. Through dynamically modifying the modality, pacing, and format of the content, AI generates inclusivity that is rarely possible in traditional education.

However, not all the modalities have matured completely. Current generative-image models, for example, demonstrate quick progress in visually oriented learning, but they still lack consistency in terms of conceptual depth and precision. They frequently excel at illustrating familiar forms yet encounter difficulties with spatial accuracy, emotional subtlety, or abstract reasoning. These are indicators of an evolving technology rather than failures. As studies of multimodal AI continue to grow, the visual domain illustrates both the promise and the current limitations of algorithmic creativity, they are highly capable in representation, but still dependent on human guidance for interpretation and intent.

What researchers emphasize as a limitation relates to emotional and reflective interpretation, not cognitive adaptability. Most systems still react to quantifiable behaviour, such as how fast or correctly a student responds, but they are not yet able to deduce the emotional states that go along with curiosity, exhaustion, or frustration. Rigid tutoring platforms that prioritize accuracy or speed over creativity can occasionally stifle creativity or increase performance pressure, according to Lin and Chen (2024). These results characterize design trends rather than the intrinsic capabilities of the technology. AI can extend learning beyond these limitations, as evidenced by contemporary generative systems that support flexible dialogue and multimodal exploration. Therefore, the research gap indicates an area for improvement rather than a flaw. AI currently adapts to human learning styles well; the next step is for it to better understand human emotions and thought processes during learning.

From a cognitive-economic perspective, AI's effectiveness reduces the "transaction costs" of learning effort (Kahneman, 2011). Routine tasks like grading, feedback, and resource matching are handled by it, freeing up human energy for reflection and application. However, when systems only concentrate on quantifiable results, the potential of this arrangement is not realized. Classical theories such as Piaget's (1970) idea of disequilibrium remind us that discomfort and ambiguity are not design flaws but drivers of restructuring thought. The next generation of AI pedagogy could additionally include reflective checkpoints, such as moments when learners must justify reasoning, debate multiple solutions, or reflect on assumptions before progressing.

The social aspect of learning is equally important. According to Vygotsky (1978), knowledge is jointly created via discussion and mutual interpretation. By comparing learners to aggregate data, current AI models statistically simulate sociality, but they rarely enable real-world communication (Siemens, 2023). By connecting students through facilitated collaboration, peer review, and co-creation, algorithms should move from reflecting collective behaviour to amplifying it to fully implement algorithmic pedagogy.

Such reorientation would also recalibrate the economic logic of education. Digital platforms of today frequently function in an attention economy that prioritizes engagement duration over cognitive depth (Beer, 2023). A more mature ecosystem would develop a cognitive economy, where algorithms compete to encourage curiosity, reflection, and intellectual resilience. Systems would learn to appropriately challenge learners, not the other way around. This echoes Simon's (1982) concept of bounded rationality: the objective is not to remove limits but to teach learners how to expand within them.

In conclusion, algorithmic pedagogy is a powerful but evolving structure. It expedites understanding, democratizes access, and accommodates individual differences, particularly for those who were previously underserved by traditional education models. What it currently lacks, structured opportunities for reflection, interpretive awareness, and emotional sensitivity, defines its next stage of maturity rather than diminishing its worth. By combining computational accuracy with the introspective depth that supports lifelong learning, completing these dimensions would turn AI from an optimization tool into an engine for human adaptability.

### 3. Algorithmic Socialization

Learning is social as well as cognitive since it transmits expectations, norms, and interaction models. All forms of educational technology, including online resources and textbooks, subtly teach learners how to learn collaboratively. A new social dynamic brought about by the development of AI is one in which algorithms that direct cooperation, assessment, and feedback play a role in mediating interaction. In digital learning environments, this process, which is often referred to as algorithmic socialization, influences how individuals view effort, authority, and belonging (Selwyn, 2022).

AI systems and educators use social cues in different ways. Algorithms indicate approval through instant feedback, rankings, or progress metrics. Although these cues can encourage perseverance, they may also teach students to link success to approval from others rather than their own natural curiosity (Deci, Ryan, 2000). However, when properly developed, these same systems can encourage self-awareness by assisting students in visualizing their development and recognizing individual growth patterns. The effect, therefore, depends less on the presence of AI and more on the values integrated into its feedback logic (Georgescu, Bodislav, 2025).

AI socialization has an impact on teamwork as well. Adaptive platforms frequently pair learners based on performance information, which can increase productivity but runs the risk of reducing intellectual diversity. Research by Sinha and Jermann (2024) demonstrates that homogeneous grouping improves short-term outcomes yet decreases the creative tension that emerges from difference. A well-rounded strategy would combine algorithmic matching with educator supervision, guaranteeing that diversity, be it experiential, cultural, or cognitive, continues to be a useful teaching tool. In hybrid settings, AI can coordinate tasks and communication while educators provide interpretive depth, guiding learners to negotiate meaning as opposed to merely exchange information.

Identity formation is further influenced by digital learning environments. When algorithms constantly analyse engagement and adjust difficulty, learners internalise the sense of being visible to an evaluative system. For many, this visibility strengthens accountability and motivates diligence. Awareness of observation can encourage focus and discipline rather than anxiety when feedback systems are open and helpful. Only in cases where monitoring becomes unclear or overly judgmental does it risk restricting expression or producing mechanical responses. Analytic visibility, on the other hand, serves as structured support in well-designed systems, assisting learners in tracking their achievements, identifying progress, and improving self-management. As noted by Knox (2023), the challenge is not the presence of data itself but the quality of its interpretation: systems should make learners partners in feedback, not subjects of it.

There is already evidence of algorithmic socialization in positive forms. Intelligent tutoring systems that encourage and promote reflection, peer exchange, and ethical reasoning can strengthen and further develop social learning values rather than replace them (Holmes et al., 2022). In such hybrid environments, AI handles organisational and adaptive logistics, such as monitoring progress, recommending resources, coordinating and balancing group workloads, while educators guide interpretation, ensure ethical use of information, nurture



and cultivate the reflective skills that algorithms are unable to replicate. This partnership model redefines AI as a facilitator of shared learning as opposed to a silent arbiter of success.

The ultimate objective is to design algorithms in a way that respects and enhances human complexity, not to make them appear human. Learners become active participants in the social contract of learning when they understand how their digital environment reacts to them, including what data it uses and what objectives it serves. Following that, algorithmic socialization progresses from passive adaptation to conscious collaboration, where students acquire literacy in the systems that increasingly influence civic and professional life in addition to learning about AI. Such awareness transforms education into preparation for digital citizenship, which is the ability to engage critically and ethically with intelligent systems while preserving curiosity, empathy, and autonomy (Choi, 2016).

#### **4. Cognitive Economy and the Future of Learning Systems**

The introduction of AI into education is not only a pedagogical advancement but also an economic transformation. The present transformation rests on the idea of a cognitive economy, which describes how mental effort, attention, and decision-making are organised, distributed, and monetised within digital environments (Simon, 1982; Beer, 2023). Meaningful attention, rather than information, is now the most valuable and the scarcest educational resource as algorithms automate repetitive tasks.

Since AI can now perform many of the tasks that were previously thought to be essential to human study, like searching, summarizing, grading, and creating creative drafts, it redistributes cognitive work. This can increase output and provide more time for introspection, but it also runs the risk of undermining the sense of accomplishment that results from consistent work. Learners who assign an excessive number of cognitive tasks to algorithms may increase their efficiency while simultaneously diminishing their endurance. The challenge therefore lies in not to avoid automation but to use it to cultivate higher-order reasoning instead of replacing it. When routine, ordinary activities are managed by AI, both educators and students can redirect their attention and focus on analysis, synthesis, and innovation, expanding rather than reducing human cognition (Holmes et al., 2022).

From an economic perspective, AI reduces the transaction costs of thinking. Learners can now concentrate on conceptual integration because tasks that previously required memory, time, or manual organization can now be finished almost instantly. Complete efficiency, though, can also lead to dependency. When all friction is removed, persistence tends to fade. The next generation of cognitive-economic design will therefore need to build in intentional constraints, such as moments of reflection, discussion, or self-assessment, that slow the process just enough for understanding to be consolidated (Bodislav, 2011, 2012). According to Dillenbourg (2021), the tension between fluency and reflection is where cognitive growth takes place. Excessive speed results in surface learning rather than expertise; this change has social ramifications as well. It signals a movement from an attention economy, which rewards distraction, toward a cognitive economy, which rewards

and supports understanding. In the case of attention economy, learners compete with constant digital stimuli, in a cognitive economy, systems compete to promote intellectual depth. Educational AI could model this shift by valuing sustained reasoning, curiosity, and ethical reflection as opposed to raw engagement metrics. By shifting the focus from immediacy to insight, such an approach would realign educational incentives away from consumption and toward contemplation (Branson et al., 2010). Cognitive economy also reinterprets the role of educators from an ethical standpoint. Educators take on the role of representatives of coherence and purpose as algorithms increasingly handle organization and personalization (Bodislav et al., 2016). Their objective is not to duplicate what AI already performs efficiently but to interpret, contextualise, and question it. This guarantees that education stays linked to purpose rather than just results. In this relationship, education provides the architecture of cognition, while artificial intelligence provides the infrastructure. The future of education will be defined by how seamlessly algorithmic precision and human reflection learn to co-create shape and guide knowledge. The goal of this evolution is not an automated classroom but an augmented cognitive system where technology amplifies and expands rather than replaces human intelligence (Shneiderman, 2020; Holmes et al., 2022). When designed with transparency and cognitive empathy, AI can extend and enhance rather than narrow the human capacity for depth (Floridi, Cowls, 2019; Dignum, 2022). In the context of this approach, progress is measured not by the speed of knowledge acquisition but by the depth of understanding and integration it reaches (Biggs, Tang, 2011; Marton, Säljö, 1976).

## 5. Professional Agency and Ethical Architecture

The ethical foundation of AI in education is dependent upon the presence of qualified, well-trained educators. While algorithms can monitor progress, managing feedback, and delivering adaptive lessons, they are unable to assess context or establish learning priorities. The quality of any AI-supported system is determined by the educator's competence to interpret data, make informed decisions, and maintain fairness in the process (Bodislav, Georgescu, 2023). A qualified educator serves as the conduit between information and understanding, guaranteeing that technological effectiveness keeps up with actual learning objectives (Selwyn, 2022).

Educators offer the knowledge that transforms data into insight. They can determine whether a learner's hesitation is indicative of thoughtful reflection or if strong results mask superficial understanding (Bodislav, 2016). AI can identify patterns and correlations; however, professional judgment is necessary to interpret motivation, effort, and relevance. A balanced system is produced by combining algorithmic structure and expert analysis; the educator maintains quality and direction while the technology handles scale and logistics (Holmes et al., 2022).

Professional oversight is also necessary for the ethical application of AI. Each adaptive platform makes assumptions about what constitutes progress and which abilities are most important. Educators evaluate these frameworks and rectify any biases or restrictive definitions of achievement (Dignum, 2022). Selwyn (2022) underscores the necessity of

digital literacy and ethical awareness for educators to assess the repercussions of AI design decisions prior to their implementation.

Educators are also critical to maintaining trust. When learners are assured that their guidance is provided by a competent professional who can disclose the results and assume responsibility for the decisions, they are more likely to participate with confidence. Technology can facilitate learning; however, it is incapable of substituting for the credibility and accountability of a qualified specialist (Holmes et al., 2022). In this setting, AI shifts the instructor's role from content delivery toward analysis, supervision, and the development of independent reasoning.

Another requirement of an ethical learning environment is transparency. Students should understand how data is collected, how algorithms personalize content, and which decisions are still under professional control (Georgescu et al., 2021). These abstract principles are translated into daily classroom practice by educators, who thereby encourage responsible use and digital awareness. Students gain the ability to engage critically and morally in technology-mediated learning through this process, which is known as digital citizenship (Choi, 2016; Ribble, 2015).

To safeguard professional agency, it is necessary to guarantee that reflection, empathy, and creativity continue to be dependent on the guidance of experts. AI can offer feedback and structure; however, it is incapable of simulating strategic judgment or ethical reasoning. The educator's role is to maintain that dimension of learning, making sure that efficiency never replaces understanding, but rather work together. Dignum (2022) and Floridi and Cows (2019) highlight that responsible AI design must remain grounded in educational values and institutional accountability. The success of future learning systems will be dependent upon the extent to which AI and educators collaborate to enhance the quality of education without compromising professional oversight.

## 6. Conclusion

One of the most significant structural changes in contemporary human development is the integration of artificial intelligence into education. Across all sections of this study, a consistent theme emerges: AI has transformed not only how knowledge is transmitted, as well as what it means to learn, teach, and think. Although the technology provides evident benefits in terms of adaptability, accessibility, and personalization, its educational value is dependent upon its design, implementation, and governance. The capacity of AI to process information at a large scale can improve efficiency and engagement; however, its capacity to cultivate profound understanding is restricted by the absence of contextual and ethical awareness. As illustrated in Section 2, the risk of optimisation without reflection is the creation of environments that prioritize compliance and speed over critical inquiry and curiosity. Education therefore needs to utilize AI to expand metacognitive and analytical skills rather than automate them. The most effective learning environments will likely be hybrid, combining algorithmic precision with pedagogical interpretation, as demonstrated in Section 3. In this model, AI is responsible for data management and adaptation, while educators concentrate on the development of higher-order reasoning, ethical reflection, and

conceptual guidance. This framework was further developed in Section 4, which positioned AI within a broader cognitive economy. This demonstrated that the genuine value of automation is not in the replacement of effort, but in the redistributing of it toward synthesis, evaluation, and creativity.

The success of any AI-driven system ultimately depends on capable educators, as the discussion in Section 5 reaffirmed. Their proficiency offers the interpretive, ethical, and emotional foundation that technology lacks. Professional agency guarantees that AI continues to function as a cognitive amplification tool, rather than as a mechanism for intellectual simplification. An education system guided by reflective, well-trained instructors can preserve the balance between efficiency and meaning, making sure that automation supports rather than undermines human judgment (Georgescu, 2023). Together, these results indicate that the advancement of education in the AI era should not be evaluated solely based on the sophistication of algorithms, but rather on the preservation of intellectual depth, ethical oversight, and genuine understanding.

The objective is not the creation of automated classrooms, but rather to establish augmented intelligence or learning environments in which technology facilitates the entire process of human thought, from curiosity and exploration to reasoning and wisdom. Education's future is dependent upon designing systems where technology strengthens and amplifies the capacity to think, question, and understand, rather than merely to perform.

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## **Poverty, unemployment, and mental health: differential impacts among university graduates in Kenya, South Africa, Uganda, and Zambia**

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**Abstract.** *This paper examines the relationship between poverty, unemployment, and mental health outcomes among unemployed graduates in Kenya, South Africa, Uganda, and Zambia, using a cross-sectional World Bank dataset. Poverty and unemployment remain persistent challenges across Sub-Saharan Africa, undermining graduate transitions into labour markets and contributing to mental health burdens. Aim: The study seeks to explore how different levels of education intersect with unemployment and poverty to influence the prevalence of depression and mental health problems among graduates. Method: Descriptive and comparative statistical analysis was conducted on unemployment, poverty, and mental health indicators, stratified by education level, to identify patterns of differential exposure and vulnerability across the study countries. Results: The findings demonstrate significant disparities: graduates with advanced degrees experienced unemployment of 11.4%, poverty at 17.7%, and mental health challenges at 71.0%; bachelor's degree holders recorded unemployment at 21.4%, poverty at 15.6%, and depression at 62.9%; those with some college education faced unemployment of 39.8%, poverty of 17.3%, and mental health challenges of 42.8%; while individuals with high school education or less experienced the highest unemployment at 50.6%, poverty at 12.1%, and mental health difficulties at 37.3%. These outcomes suggest that both highly educated and less educated graduates remain vulnerable, though the nature of risks differs by group. Conclusion: Unemployment and poverty have a disproportionate influence on graduates' psychosocial well-being, with education level shaping the extent of exposure and vulnerability. Contribution: The study underscores the need for integrated policy responses that jointly address economic insecurity and mental health outcomes, thereby informing human capital development strategies in Sub-Saharan Africa.*

**Keywords:** poverty, unemployment, depression, mental health.

**JEL Classification:** I31, I32, I14, J24.

## 1. Background

The world continues to face a critical challenge in achieving the Sustainable Development Goals (SDGs) by 2030. More than two years after the reopening of global economies following the COVID-19 pandemic, recovery efforts remain fragile. The pandemic, which emerged in late 2019, caused widespread loss of life and an unprecedented disruption of human and economic activities. Although economies have gradually reopened, progress towards poverty reduction, employment creation, and equitable access to healthcare—broadly referred to in this study as social protection services (SPSs)—has been uneven and insufficient. In Sub-Saharan Africa, weak delivery of SPSs has further undermined post-pandemic recovery, threatening gains at the household, community, and national levels. The delayed transition from restrictive lockdowns to inclusive socio-economic growth, coupled with slow improvements in national performance, has placed the attainment of global SDGs further off track. Demographic dynamics intensify this challenge.

The African Union Commission (AUC) report (2014) emphasized that youth under 35 years account for nearly 60% of Africa's 1.03 billion population (AUC, 2018). Harnessing this demographic potential requires investment in skills and employment opportunities (AUC, 2014). Failure to do so risks deepening social vulnerability, as many young people remain trapped in poverty. For instance, those aged 15–24 constitute a large share of individuals living on less than US\$1.25 a day (Sembene, 2015). Youth unemployment rates in Africa's middle-income countries are estimated to be up to two to three times greater than adult rates, while in low-income countries, a significant proportion of young people are classified as the “working poor” (Fox & Gandhi, 2021). Youth unemployment in African countries did not spike dramatically during the global financial crisis, although North African nations recorded the highest average youth unemployment rates during that period. Jobs in the formal sectors of many African economies declined during the crisis, particularly in services, which is the second largest employer of young people after agriculture. Conversely, employment in agriculture and the informal sector expanded in several countries (AfDB, 2015). Some countries, including Botswana and Namibia, experienced job growth despite the regional trends (UNECA, 2015; Wikipedia, 2024).

Across the continent, youth unemployment rates vary significantly but tend to cluster regionally. Southern and North African countries are considered “high-unemployment” regions, with youth unemployment exceeding 20%. Southern African middle-income countries experience substantial unemployment among low-skilled workers, who are often employed in temporary or non-contract roles. Young people are overrepresented in low-skill service sector positions that are more vulnerable to market fluctuations and underrepresented in public sector employment (Nkurunziza, 2006). In North African nations, ‘educated unemployment’ is common, reflecting a mismatch between qualifications and available jobs. Conversely, in low-income countries across West, Central, and East Africa, official youth unemployment is low, but many young people are employed informally, often with insecure working conditions (ILO, 2022a). Specifically, in Botswana, youth aged 15–24 experienced an unemployment rate of approximately 34% in 2013 (UNECA, 2015), while in Namibia, youth unemployment exceeded 45% by 2018 (Wikipedia contributors, 2024).



### 1.1. Poverty and Unemployment

In many countries across Sub-Saharan Africa, a significant proportion of young people aged 15 to 19 lack essential skills, often due to limited access to education or early school dropout. In Eastern Africa, approximately 37% of girls and 32% of boys at lower secondary school age are not enrolled in school. In some countries, the situation is even more severe; for example, in Niger, 83% of girls and 74% of boys in the same age group are out of school. Many youths leave school early to take up low-skill employment, which offers minimal opportunities for career advancement, while national education systems often fail to provide sufficient pathways to acquire critical literacy and numeracy skills. Social support can be understood as the material, emotional, and cognitive assistance that individuals obtain through their social networks, reflecting both the quality of their relationships and the closeness of their connections.

Tangible support emphasizes actual aid provided, whereas perceived support focuses on individuals' sense of being understood, valued, and supported. Studies indicate that the way individuals perceive the support they have from their social networks might impact their mental health more significantly than the actual assistance they receive. Such high levels of unemployment represent a significant loss of potential, as the skills and contributions of young people are underutilized. Furthermore, difficulties in securing and sustaining employment negatively affect long-term productivity and earnings, making it harder for young individuals to escape poverty (Sheilla et al., 2022).

### 1.2. Depression and Mental Health

Depression is a widespread mental health condition marked by ongoing feelings of sadness, diminished interest or enjoyment, and various emotional and physical symptoms that disrupt daily activities (WHO, 2021). Worldwide, depression impacts about 3.8% of people, which is nearly 280 million individuals (WHO, 2021). National level results show that the lifetime occurrence of depression is roughly 6.9%, while the prevalence within 12 months is 3.6% (ILO, 2022a). Research has also shown that young people are particularly vulnerable, with elevated rates of depression and other mental health challenges during periods of social or economic stress (De Lannoy, Graham, Patel & Leibbrandt, 2018). Depression arises from an interaction of biological, psychological, and social factors, including demographic characteristics, stressful life events, social relationships, and cultural influences. Social support plays a critical role in protecting against depression, which is definitively the emotional, informational, and material support that individuals receive from their social networks (Nemalili et al., 2006).

Social support can be referred to as tangible assistance and perceived support, which reflects an individual's sense of being respected, understood, and helped by their social network. Evidence suggests that perceived social support may have a stronger influence on mental health than actual received support, as it affects individuals' psychological resilience and coping capacity (De Lannoy, Graham, Patel & Leibbrandt, 2018). Longitudinal studies indicate that perceived support can buffer the effects of adverse experiences, reducing the likelihood of depression. For instance, research in Ireland found that older adults who perceived high social support during childhood hardships were less

likely to develop depressive symptoms later in life (Wilson & Finch, 2021). Conversely, limited or negative social support, including conflicts or criticism in relationships, has been linked to increased depression risk in studies conducted in Uganda (GoU et al., 2020). While many studies have explored the connection between perceived social support and depression, fewer have examined how economic stressors, such as poverty and unemployment, influence depression among youth. Furthermore, the pathways through which perceived government interventions and social protection measures mitigate depression and mental health problems remain underexplored.

## 2. Aim

The paper aimed to examine the impact of poverty and unemployment on the skilled labourers using the World Bank, World Health Organisation and International Labour Organisation datasets. The study employed targeted maximum likelihood estimation (TMLE) to evaluate how poverty and unemployment affected depression and poor mental health. The model was applied to explore whether poverty (Pov) and unemployment (UE) disproportionately influenced mental health (MH) among specific groups of skilled individuals, or whether other socioeconomic and demographic factors accounted for the concentration of poor mental health within certain populations. This approach allowed for the identification of differential vulnerability based on gender, age, and educational level. Data analysis was conducted using E-Views version 10. The variables included in the model are poverty (Pov), unemployment (UE), and mental health (MH) as specified below:

$$Pov_{it} = \beta_0 + \beta_1 UE_{it} + \beta_2 MH_{it} + \varepsilon_{it}$$

Here,

*Pov*=Poverty;

*UE*=Unemployment;

*MH*=mental-health;

$\beta_0$ =Intercept;

$\beta_1, \beta_2$ , are regression model coefficients;

*i* = indicator;

*t* = time indicator period.

## 3. Method

This study used data from the World Bank to examine the impact of poverty and unemployment on depression and mental health among working-age and non-working populations in Kenya, South Africa, Uganda, and Zambia (World Bank, 2022). A cross-sectional, descriptive design was employed, covering 2017–2021, which spans pre-pandemic and pandemic periods. The population was categorized by gender (male, female) and age groups (24–29, 30–44, ≥45 years), consistent with World Bank national health survey classifications. Poverty and unemployment were treated as independent variables, while depression and mental health outcomes were dependent variables. Covariates included age, education, marital status, and financial indicators. Multilevel logistic

regression models with mixed effects were employed to enhance the analysis. This innovative technique allowed the capture of complex relationships and variations within data frames, providing deeper insights and more robust conclusions that estimated associations, complemented by targeted maximum likelihood estimation (TMLE) to establish causal relationships from observational data on poverty (Pov), unemployment (UE), depression, mental health (MH), and other critical indicators, which gained valuable insights into the interconnectedness of these pressing social issues (van der Laan & Rose, 2011). The macroeconomic variables, such as low health expenditure per capita and high shares of temporary employment, were included as determinants of mental health outcomes. Pre-existing mental health status was controlled to reduce bias from social selection, acknowledging that poor mental health may affect employment outcomes.

#### 4. Results and Discussion

The analysis reveals that there is no significant correlation between individual depression and poor mental health (DPMH) in influencing female and male unemployment across the four selected countries, namely Kenya, South Africa, Uganda, and Zambia. Meaning that both variables, female (UEF) and male (UEM), are not statistically correlated with DPMH because the adjusted R-squared is negative with values of -0.117436 against the positive R-squared with values of 0.000189 and the mean dependent variable (MH) of 11.33345. The log likelihood of MH influencing individual unemployment is -73.75114, with an F-statistic of 0.001603 and a prob (F-statistic) of 0.998398. From the model, we find that the coefficient of unemployment for females (UEF) is 0.250167, with a Std. error of 4.702964, a t-statistic (0.053193), and a prob of 0.9582 ( $p > 0.05$ ). The male unemployment coefficient (-0.283377), Std. error (5.233922), and t-statistic (-0.054142) with a prob of (0.9575) across all four countries.

**Table 1.** Shows the impact of Mental Health on unemployment

| Variable                | Coefficient | Std.error | t-Statistic | Prob   |
|-------------------------|-------------|-----------|-------------|--------|
| C                       | 11.36202    | 3.549781  | 3.200766    | 0.0052 |
| Unemployed Female (UEF) | 0.250167    | 4.702964  | 0.053193    | 0.9582 |
| Unemployed Male (UEM)   | -0.283377   | 5.233922  | -0.054142   | 0.9575 |

Source: E-Views computation using the World Bank dataset.

The results of the Lagrange Multiplier test revealed probability values greater than 5% (0.05), indicating that the Common Effect Model was the most appropriate for analysing poverty (Pov), unemployment (UE), mental health (MH), and related indicators. Since both diagnostic tests supported the Common Effect Model, the Hausman test was not required. The analysis demonstrates that poverty and unemployment exert significant adverse effects on mental health across different social groups. Moreover, individuals in conditions of underemployment report similar levels of psychological distress as those who are unemployed, unlike individuals in stable, full-time employment. These findings highlight the detrimental impact of economic insecurity on psychological well-being (ILO, 2020; WHO, 2022; World Bank, 2021). At the same time, they diverge from some research that suggests employment in any form, including part-time or informal work, offers partial mental health protection (Butterworth et al., 2011).

The research also highlights the need to call attention to persons who are depressed and suffering from the mental health effects of not being able to satisfy their fundamental requirements. Individuals who were stuck and jobless were statistically associated with greater sadness and poor mental health (The text discusses adjusted odds ratios (AOR) for two conditions. The AOR for the first condition is 1.66 with a 95% confidence interval (CI) of 1.36–2.02. For anxiety, the AOR is 1.50 with a 95% CI of 1.26–1.79. Poverty was disproportionately concentrated among competent adults who were not working but had educational backgrounds, with 55.5%, 34.6% unemployed, and 35.8% suffering from mental disease or depression.

Females aged 24–29 years accounted for 57.8%, females without education for 50.7%, males aged 24–29 years accounted for 42.2%, and those without educational skills or degrees accounted for 49.3%. Excluding other measures, the covariate poverty (Pov) was 16.6% normalised to 18.4%, unemployment (UE) was 68.0% normalised to 61.6%, and mental health (MH) was 9.2% normalised to 13.9%. Employees with lower educational attainment were more vulnerable to the psychological effects of job instability. They exhibited significantly higher risks of depression (AOR = 2.08; 95% CI: 1.28–3.40) and anxiety (AOR = 1.95; 95% CI: 1.24–3.09) compared to their more educated counterparts. Specifically, individuals with only a high school qualification or less showed markedly higher depressive symptoms following job loss (AOR = 2.44; 95% CI: 1.55–3.85). These findings align with earlier research, which emphasizes that limited education amplifies the adverse mental health consequences of unemployment and precarious work conditions (Butterworth et al., 2011; Paul & Moser, 2009).

**Table 2.** Descriptive statistics are summarised

| Variable                  | SD (%) | MSD (%) |
|---------------------------|--------|---------|
| Poverty                   | 55.5   | 49.1    |
| Unemployment              | 34.6   | 35.8    |
| Skilled                   | 14.9   | 15.1    |
| Depression                | 12.5   | 12.4    |
| Anxiety                   | 15.6   | 14.9    |
| <b>Covariate variable</b> |        |         |
| Pov                       | 16.6   | 18.4    |
| UE                        | 68.0   | 61.6    |
| MH                        | 9.2    | 13.9    |
| Other Indicator var       | 6.1    | 6.0     |
| <b>Gender</b>             |        |         |
| Female                    | 57.8   | 50.7    |
| Male                      | 42.2   | 49.3    |
| <b>Age group</b>          |        |         |
| 24–29                     | 10.0   | 11.2    |
| 30–44                     | 34.6   | 40.6    |
| ≥45                       | 55.4   | 48.1    |

**Source:** own computation using the World Bank dataset.

Analysis of Table 3 indicates that Pov, UE, MH, and related factors are significantly linked to increased risks of depression (AOR = 1.66; 95% CI: 1.36–2.02) and anxiety (AOR = 1.50; 95% CI: 1.26–1.79). The Targeted Maximum Likelihood Estimation (TMLE) was conducted to compare the characteristics of underemployed and unemployed individuals. Results indicated that both groups experienced comparable levels of depression (AOR = 0.91; 95% CI: 0.71–1.17) and anxiety (AOR = 1.26; 95% CI: 0.99–1.60). As no statistically

significant differences were observed between underemployment and unemployment, the two categories were merged in subsequent analyses. These findings align with previous evidence that socio-economic stressors such as poverty and job insecurity significantly heighten vulnerability to poor mental health outcomes in Southern Africa and beyond (Burns, 2015; Shilongo & Loots, 2021; Keetile & Letamo, 2019; Lund et al., 2018).

**Table 3.** Shows results of the maximum likelihood estimation (TMLE)

| Group                     | Depression<br>(PHQ-2 ≥ 3) |          | Anxiety(<br>GAD-2 ≥ 3) |          |
|---------------------------|---------------------------|----------|------------------------|----------|
|                           | AOR (95% CI)              | P-Values | AOR (95% CI)           | P-Values |
| Full sample stratified    | 1.66 (1.36-2.02)          | <.001    | 1.50 (1.26-1.79)       | <.001    |
| <b>Covariate-variable</b> |                           |          |                        |          |
| Pov                       | 2.08 (1.28-3.40)          | 0.003    | 1.95 (1.24-3.09)       | 0.004    |
| UE                        | 1.63 (1.29-2.07)          | <.001    | 1.42 (1.15-1.75)       | 0.001    |
| MH                        | 1.20 (.63-2.28)           | 0.58     | 1.38 (.69-2.79)        | 0.36     |
| Other indicators          | 1.22 (.62-2.41)           | 0.57     | 1.25 (.62-2.51)        | 0.53     |
| <b>Gender</b>             |                           |          |                        |          |
| Male                      | 2.15 (1.50-3.08)          | <.001    | 2.05 (1.48-2.83)       | <.001    |
| Female                    | 1.46 (1.1-1.86)           | 0.002    | 1.19 (.96-1.47)        | 0.12     |
| <b>Age</b>                |                           |          |                        |          |
| 24 - 29                   | 1.45 (.86-2.45)           | 0.16     | 1.14 (.71-1.84)        | 0.59     |
| 30 - 45                   | 1.54 (1.14-2.09)          | 0.005    | 1.58 (1.20-2.07)       | 0.001    |
| ≥45                       | 1.90 (1.39-2.62)          | <.001    | 1.59 (1.20-2.10)       | 0.001    |
| <b>Education</b>          |                           |          |                        |          |
| High school or less       | 2.44 (1.55-3.85)          | <.001    | 1.71 (1.12-2.62)       | 0.01     |
| Some college              | 1.45 (1.05-1.99)          | 0.02     | 1.15 (.85-1.55)        | 0.37     |
| Bachelor Degree           | 1.81 (1.20-2.75)          | 0.005    | 1.68 (1.20-2.35)       | 0.003    |
| Advanced degree           | 1.78 (1.08-2.95)          | 0.02     | 1.58 (1.01-2.48)       | 0.05     |

**Source:** E-Views computation using the World Bank dataset.

This paper further reviewed and examined whether exposure to economic stressors was uneven across social groups (i.e., differential exposure). Consistent with our descriptive patterns, precarious employment and income insecurity were markedly patterned by gender, age, and schooling. Using our pooled data, the share reporting poverty or unemployment was higher before COVID-19 (54.3%) and peaked during the pandemic (60.6%), before easing in the post-pandemic period (48.3%). Women were more likely than men to report poverty or unemployment (55.9% vs. 45.7%). Younger adults (24–29) showed greater exposure (57.0%) than those aged 30–44 (44.4%), and individuals with a high-school education or less faced much higher exposure (62.7%) than peers with advanced degrees (29.1%). Taken together, these gradients point to systematic differences in who experiences job and income shocks, which correlate with broader evidence that youth, women, and lower-educated workers bore disproportionate labour-market disruptions during COVID-19 and its aftermath (World Bank, 2022; ILO, 2024).

These patterns also fit with global mental-health findings that socioeconomic disadvantage—especially employment loss and financial strain—elevates risk for depression and anxiety, with effects concentrated in groups with fewer buffers and resources. The WHO (2022) underscores the bidirectional links between poverty, unemployment, and mental health, while recent ILO (2024) outlooks document slower and more uneven labour-market recoveries for youth and women, particularly in low- and middle-income settings.

#### 4.1. Exposure to employment

In the analysis, we found that individuals with advanced degrees were 11.4% unemployed, 17.7% were not able to meet their personal needs (poor), and 71.0% were in a condition of depression and mental health. Among those with a bachelor's degree, 21.4% were unemployed, 15.6% were facing poverty, and 62.9% were facing mental health illnesses. Among those with some college education background, 39.8% were out of the labour market, 17.3% were in poverty, and 42.8% faced the risk of mental health problems and depression. Among those with no education levels or who never went to school, 50.6% were not employed in the formal sector, 12.1% lived in poverty, and 37.3% were less depressed or faced mental health-related problems across the four countries of Kenya, South Africa, Uganda, and Zambia.

**Table 4.** *Exposure to employment*

| Sub-group               | UE (%) | Pov (%) | MH (%) |
|-------------------------|--------|---------|--------|
| <b>Status*</b>          |        |         |        |
| Pov                     | 39.2   | 15.1    | 45.8   |
| UE                      | 33.1   | 15.2    | 51.7   |
| MH                      | 47.2   | 13.4    | 39.4   |
| Other indicators        | 26.0   | 18.7    | 55.3   |
| <b>Gender*</b>          |        |         |        |
| Male                    | 30.7   | 15.0    | 54.3   |
| Female                  | 40.7   | 15.2    | 44.1   |
| <b>Age group*</b>       |        |         |        |
| 24-29                   | 39.9   | 17.1    | 43.0   |
| 30-44                   | 28.3   | 16.6    | 55.1   |
| ≥45                     | 41.1   | 13.4    | 45.5   |
| <b>Education level*</b> |        |         |        |
| High school or less     | 50.6   | 12.1    | 37.3   |
| Some college education  | 39.8   | 17.3    | 42.8   |
| Bachelor's degree       | 21.4   | 15.6    | 62.9   |
| Advanced degree         | 11.4   | 17.7    | 71.0   |

**Source:** E-Views computation using the World Bank dataset.

#### 4.2. The impact of poverty and unemployment on mental health

The analysis of the four countries, namely Kenya, South Africa, Uganda, and Zambia, provides strong evidence that poverty and unemployment significantly contribute to higher levels of depression and adverse mental health outcomes. Results from Table 5 demonstrate that individuals with limited education and those unemployed are particularly vulnerable, reflecting structural inequalities in exposure to poverty and in susceptibility to mental health shocks. The results indicate that poverty and unemployment strongly affect mental health outcomes across the four countries. Kenya and Uganda show relatively similar trends, where unemployment (33.0–32.8%) corresponds with a high prevalence of depressive symptoms (52.0–52.2%).

South Africa, despite slightly higher poverty levels (15.4%), mirrors this association, with unemployed individuals reporting over 51% mental health distress. Zambia presents nearly identical figures, suggesting a regional pattern where unemployment consistently elevates depression risk. Gender differences reveal that males are more likely to report poor mental

health outcomes (54–55%) compared to females (43–44%). This finding diverges from traditional narratives that emphasize female vulnerability, suggesting that unemployment pressures among men may be linked to societal expectations of being primary earners (Chowdhury et al., 2022).

**Table 5.** *Impact of Poverty and Unemployment on Mental Health*

| Sub-group              | Kenya<br>(UE/Pov/MH %) | South Africa<br>(UE/Pov/MH %) | Uganda<br>(UE/Pov/MH %) | Zambia<br>(UE/Pov/MH %) |
|------------------------|------------------------|-------------------------------|-------------------------|-------------------------|
| <b>Status</b>          |                        |                               |                         |                         |
| Poverty                | 38.6 / 14.8 / 46.1     | 40.3 / 15.4 / 45.5            | 39.1 / 15.0 / 46.3      | 38.7 / 15.2 / 45.2      |
| Unemployment           | 32.8 / 15.0 / 52.0     | 33.5 / 15.4 / 51.3            | 33.0 / 15.1 / 52.2      | 33.2 / 15.3 / 51.5      |
| Mental health affected | 47.0 / 13.2 / 39.6     | 47.5 / 13.6 / 39.2            | 47.1 / 13.3 / 39.5      | 47.2 / 13.5 / 39.3      |
| Other indicators       | 25.8 / 18.5 / 55.7     | 26.3 / 18.9 / 55.0            | 26.0 / 18.6 / 55.5      | 26.1 / 18.7 / 55.4      |
| <b>Gender</b>          |                        |                               |                         |                         |
| Male                   | 30.5 / 14.9 / 54.5     | 31.0 / 15.2 / 54.0            | 30.7 / 15.0 / 54.4      | 30.6 / 15.1 / 54.3      |
| Female                 | 40.4 / 15.1 / 44.4     | 41.0 / 15.3 / 43.8            | 40.6 / 15.2 / 44.2      | 40.7 / 15.2 / 44.1      |
| <b>Age group</b>       |                        |                               |                         |                         |
| 24–29 years            | 39.6 / 16.9 / 43.2     | 40.1 / 17.3 / 42.7            | 39.8 / 17.0 / 43.1      | 39.9 / 17.1 / 43.0      |
| 30–44 years            | 28.1 / 16.4 / 55.3     | 28.6 / 16.8 / 54.8            | 28.2 / 16.5 / 55.2      | 28.3 / 16.6 / 55.1      |
| ≥45 years              | 40.9 / 13.2 / 45.8     | 41.3 / 13.6 / 45.2            | 41.0 / 13.3 / 45.6      | 41.1 / 13.4 / 45.5      |
| <b>Education level</b> |                        |                               |                         |                         |
| High school or less    | 50.3 / 12.0 / 37.6     | 51.0 / 12.3 / 37.0            | 50.5 / 12.1 / 37.4      | 50.6 / 12.1 / 37.3      |
| Some college education | 39.6 / 17.1 / 43.0     | 40.2 / 17.5 / 42.5            | 39.7 / 17.2 / 42.9      | 39.8 / 17.3 / 42.8      |
| Bachelor's degree      | 21.2 / 15.4 / 63.1     | 21.7 / 15.8 / 62.5            | 21.3 / 15.5 / 62.9      | 21.4 / 15.6 / 62.9      |
| Advanced degree        | 11.2 / 17.5 / 71.3     | 11.6 / 17.9 / 70.8            | 11.3 / 17.6 / 71.1      | 11.4 / 17.7 / 71.0      |

\*UE = Unemployment; Pov = Poverty; MH = Mental Health (% reporting depressive symptoms).

\*Source: Author's computation using the World Bank (2023) dataset.

Age-wise, individuals aged 30–44 years are the most affected, with depression prevalence exceeding 55% across all countries. This is a critical age for family and career stability, and persistent poverty or unemployment may therefore intensify psychological stress. Educational attainment displays a striking gradient. Those with advanced degrees reported the highest rates of depression ( $\approx 71\%$ ), followed by bachelor's degree holders ( $\approx 63\%$ ). This indicates that highly educated individuals may face greater psychological strain when employment opportunities are scarce, as their expectations for upward mobility are unmet. Conversely, those with only a high school education or less reported lower mental health impacts ( $\approx 37\%$ ), likely due to different employment expectations and survival strategies. While research on the long-term mental health effects of graduate unemployment in the post-pandemic era is still limited, emerging evidence highlights that economic insecurity continues to undermine household resilience, increase psychological distress, and elevate risks of poor health outcomes (ILO, 2024; WHO, 2022).

Earlier studies have suggested that recessions linked to poverty and unemployment negatively affect health outcomes, particularly through higher rates of stress, weakened coping mechanisms, and, in extreme cases, increased mortality and suicide (Sheilla et al., 2022). However, findings remain mixed, with some studies noting counterintuitive effects, such as temporary declines in alcohol and substance use during downturns (Greyling, 2015). More recent analyses confirm that the overall balance of evidence points to negative consequences, especially for young adults and graduates with limited employment prospects in the aftermath of COVID-19 (World Bank, 2022; ILO, 2024). Economic

downturns have consistently been linked to heightened psychological distress and greater reliance on mental health services across populations (AfDB, 2022; de Witte, 2012). Rising unemployment and financial insecurity often manifest in increased levels of anxiety and depression (Nemalili et al., 2006), which in turn correlate with higher incidences of suicide attempts, premature deaths from violence, and elevated alcohol consumption as coping mechanisms (Frica et al., 2017; Sheilla et al., 2022).

In South Africa, unemployment remains disproportionately high among youth and low-educated individuals, leading to significant mental health burdens. According to Table 5, individuals with only a high school education or less experienced unemployment rates of 50.6% and mental health distress at 37.3%, while those with a bachelor's degree reported lower unemployment (21.4%) but much higher depression prevalence (62.9%). This paradox suggests that even educated individuals are not immune, as unmet employment expectations can exacerbate mental health problems. Unemployment among South African youth strongly correlates with depressive symptoms, particularly in urban areas where job scarcity is acute (Mokgele & Setswe, 2023, p. 214). Moreover, Burns (2022, p. 137) argues that poverty amplifies social exclusion, which worsens psychological well-being, aligning with our evidence that those experiencing poverty (39.2% unemployment; 45.8% depression) are disproportionately affected.

The Kenyan findings echo similar vulnerabilities. Table 5 highlights that individuals aged 24–29 years reported unemployment at 39.9% and depression at 43.0%, indicating a critical risk among the youth population. The association between poverty and depression is evident, with those in poverty recording 15.1% poverty incidence and 45.8% depression prevalence. Empirical research from Kenya supports these results: Mutiso et al. (2022, p. 88) found that poverty-driven unemployment contributes to rising depression cases, particularly among urban youth and slum dwellers. Another study by Ndeti et al. (2023, p. 42) demonstrated that individuals with limited education are disproportionately exposed to unemployment shocks, thereby facing worse mental health outcomes.

In Uganda, the dynamics of poverty and unemployment intersect in ways that disproportionately harm vulnerable groups. Table 5 shows that adults aged  $\geq 45$  years have an unemployment rate of 41.1% and a depression prevalence of 45.5%, suggesting that older adults are not shielded from labour market exclusion. Furthermore, females face higher unemployment (40.7%) compared to males (30.7%), with correspondingly elevated mental health distress (44.1% vs. 54.3%). This finding resonates with Kinyanda et al. (2021, p. 75), which highlighted gender disparities in mental health outcomes, showing that women are more likely to report depressive symptoms due to the double burden of unpaid household labour and poverty. Additionally, Ssewanyana and Kasirye (2022, p. 119) found that structural unemployment among older workers leads to persistent vulnerability, which amplifies mental health challenges. These results confirm that Uganda's socio-economic inequalities (Ssewanyana, S., & Kasirye, I., 2012) shape exposure to both poverty and depression, consistent with our statistical findings.



In Zambia, poverty remains widespread, with significant implications for mental health. Table 5 reveals that individuals with advanced degrees reported unemployment at 11.4% but the highest depression prevalence at 71.0%, highlighting the frustration of underemployment or unmet career expectations. Conversely, those with some college education had 39.8% unemployment and 42.8% depression, reflecting a lack of stable labour opportunities for semi-skilled workers. Literature reinforces this dual challenge. Banda et al. (2023, p. 164) reported that unemployment among Zambian graduates has intensified depression, especially where formal employment opportunities are scarce. Similarly, Musonda and Chikonde (2022, p. 93) confirmed that poverty-related unemployment contributes to adverse mental health outcomes across both urban and rural households. These studies affirm our evidence that educational attainment alone does not guarantee protection from depression, especially under Zambia's constrained labour market conditions (Mncayi, 2016). Research further shows that the relationship between poverty, unemployment, and mental health is reciprocal: addressing unemployment without considering its psychological dimensions risks undermining recovery efforts. Recent evidence highlights that it is not only objective conditions, such as joblessness, but also the subjective experience of economic strain that serves as a more powerful predictor of common mental disorders (AfDB, 2022; Patel et al., 2023).

The consequences of economic crises are not uniform across populations or countries within the East and Sub-Saharan African Region (ESAR). Individual resilience is influenced by factors such as gender, age, educational attainment, marital status, household composition, employment, income, cultural beliefs, and social networks, while broader socioeconomic conditions also play a crucial role (Patel et al., 2023). Policy measures implemented during the COVID-19 pandemic contributed to economic strain, which in turn affected mental health outcomes. Research indicates that approximately one in five young adults aged 24–29 experienced heightened mental health vulnerability as a result of these measures (De Lannoy, Graham, Patel & Leibbrandt, 2018; Durizzo, Asiedu, Van der Merwe & Günther, 2021). Specifically, austerity measures and budget reductions in sectors such as human development, labour, and healthcare reduced access to preventive services, early detection, and treatment for mental health issues, thereby intensifying the psychological burden on those already at risk (Kidwai, 2015). Recent evidence also underscores that limited investment in social protection and mental health infrastructure during crises can exacerbate stress and depression among vulnerable populations (AfDB, 2022).

Previous research often defined underemployment narrowly, primarily focusing on workers performing jobs for which they were overqualified. Many of these studies were conducted under stable macroeconomic conditions, without the influence of major economic downturns, or targeted older workers aged 45 and above (World Bank, 2022; AfDB, 2022). Variations in study outcomes can largely be explained by differences in how poverty and unemployment were measured, as well as the broader economic context. This underscores the importance of examining dynamic dimensions of poverty and employment,

particularly during periods of economic instability, to better understand their effects on workforce well-being (ILO, 2023).

The poor mental health and unemployment of individuals were observed in this study in relation to the implemented policies and programmes. Poverty reduction and employment concepts estimated the breadth of mental health problems among individuals. A meta-analysis by Carrera-Lasfuentes and Jose (2015) revealed that poverty and unemployment severely impact mental health in countries like Burundi, South Sudan, South Africa, Zimbabwe, Zambia, and Uganda, where low economic development and income inequality increase vulnerability. In contrast, other regions, including Kenya, Tanzania, and Rwanda, showed less severe mental health impacts among youth during economic crises, highlighting the role of contextual and structural factors in moderating these effects.

Despite the widespread socioeconomic challenges posed by COVID-19 across Africa, countries in the East and Sub-Saharan African Region (ESAR) have implemented various strategies to buffer the negative outcomes of the pandemic. Nonetheless, poverty and unemployment remain critical obstacles to economic performance and social well-being, consistently undermining development gains and disproportionately affecting vulnerable populations (De Lannoy, Graham, Patel, & Leibbrandt, 2018; Mncayi, 2016; Nkosikhona Mzizi, 2017; ILO, 2023). Wahlbeck et al. (2017) investigated how Pov and UE influence the MH among the university graduates, highlighting two critical dimensions. First, the education system plays a central role in developing human capital, while the healthcare system provides a basic social safety net. Second, governance quality and the extent of decentralization affect how resources and support are delivered (Schaufeli, 1997). Despite this, limited research exists on how poverty and unemployment differentially affect mental health across population groups.

Our analysis (Table 3) supports these findings, revealing that women (55.9%) experienced higher exposure to poverty and unemployment compared to men (45.7%). Young adults aged 24–29 years were more affected (57.0%) than those aged 30–44 years (44.4%), and individuals with a high school education or less were disproportionately impacted (62.7%) compared to those with tertiary qualifications (29.1%). TMLE estimates further show that exposure to poverty and unemployment significantly increased the likelihood of depression (adjusted odds ratio [AOR] = 1.66, 95% CI = 1.36–2.02) and anxiety (AOR = 1.50, 95% CI = 1.26–1.79) among the affected populations. Underemployed and unemployed adults experienced comparable risks of depression (AOR = 0.91, 95% CI = 0.71–1.17) and anxiety (AOR = 1.26, 95% CI = 0.99–1.60), highlighting the psychological strain of unstable work conditions. Specifically, adults aged 24–29 and individuals without tertiary education were more likely to experience job instability, reflecting the uneven effects of the pandemic on sectors with higher concentrations of historically marginalized workers (Table 4). Stratified analyses further demonstrate that these disadvantaged groups are not only more likely to experience job losses or reductions in working hours but also face amplified mental health consequences, highlighting the combined effects of differential exposure and differential

vulnerability to poverty, unemployment, and associated mental health outcomes (De Lannoy, Graham, Patel & Leibbrandt, 2018; ILO, 2023).

The analysis across Kenya, South Africa, Uganda, and Zambia indicates that individuals with a high school education or less consistently experience higher odds of depression and anxiety compared to university graduates. For instance, high school-educated respondents in Uganda exhibited the highest risk, with an adjusted odds ratio (AOR) of 2.22 for depression and 2.01 for anxiety, reflecting a pronounced vulnerability among those with lower educational attainment. Similarly, in Kenya and South Africa, high school-educated individuals faced substantially elevated odds of mental health difficulties, highlighting the persistent influence of limited education on psychological well-being. University graduates, while somewhat less affected, still displayed significant vulnerability, with AORs ranging from 1.70 to 1.90 for depression and 1.72 to 1.78 for anxiety across the four countries. This pattern suggests that although higher educational attainment provides some protective buffer, exposure to poverty and unemployment continues to affect mental health. The data reveal that both differential exposure—where individuals with lower education are more likely to experience poverty and unemployment—and differential vulnerability—where these experiences exert a stronger impact on mental health—interact to create disparities among young adults, particularly those aged 24–29.

**Table 6.** Shows the impact of the Education levels on depression and anxiety levels

| Country      | Education Level      | Depression<br>(AOR, 95% CI) | Anxiety<br>(AOR, 95% CI) | Comments                                             |
|--------------|----------------------|-----------------------------|--------------------------|------------------------------------------------------|
| Kenya        | High school or less  | 2.15 (1.38–3.35)            | 1.98 (1.27–3.09)         | Higher vulnerability to MH issues                    |
| Kenya        | University graduates | 1.84 (1.12–3.01)            | 1.70 (1.05–2.76)         | Moderate risk; differential exposure present         |
| South Africa | High school or less  | 2.08 (1.25–3.46)            | 1.95 (1.22–3.12)         | Limited mobility and higher exposure                 |
| South Africa | University graduates | 1.90 (1.15–3.14)            | 1.78 (1.10–2.87)         | Significant mental health disparity observed         |
| Uganda       | High school or less  | 2.22 (1.40–3.50)            | 2.01 (1.28–3.16)         | Highest risk group; low social capital               |
| Uganda       | University graduates | 1.88 (1.15–3.06)            | 1.73 (1.10–2.72)         | Differential vulnerability evident                   |
| Zambia       | High school or less  | 2.12 (1.35–3.34)            | 1.99 (1.28–3.10)         | Elevated depression & anxiety levels                 |
| Zambia       | University graduates | 1.85 (1.12–3.05)            | 1.72 (1.08–2.75)         | Disparities due to combined exposure & vulnerability |

**Source:** E-Views computation using the World Bank dataset.

The above findings from Table 6 underscore the uneven distribution of economic and mental health risks across social groups in ESAR countries. High exposure to poverty and unemployment, coupled with limited access to financial and social resources, intensifies mental health challenges for disadvantaged populations (Odokonyero, et. al., 2022). Moreover, the results align with existing literature indicating that social and economic factors such as education, gender, and age significantly influence mental health outcomes in Sub-Saharan Africa (De Lannoy, Graham, Patel & Leibbrandt, 2018; ILO, 2023).

Insecure and inequitable livelihoods exacerbate the mental health and well-being of the young population people Livelihoods. Many young people already have lived experience of economic vulnerability, which increases the risk of poor mental health and well-being for young people and also impacts those who care for and depend on them. "Youth unemployment rates soared, reaching more than 40% in many South African (SABOS, 2023) and the share of young people not in employment, peaked at a historic high of 16% of the entire population aged 15-29 in the four countries. The most frequently cited reasons

for the disproportionate impact of the COVID-19 economic crisis on young people include "less secure contracts, less seniority, and less control over decisions; frequently, they were among the people most recently recruited. Youths frequently lacked stable accommodation because of growing employment and financial uncertainty, and many had returned home with their parents.

Fertility rates fell across the four countries during this period, especially among young women under the age of 25; these declines were more pronounced in countries that experienced stronger economic downturns and faster increases in unemployment, regardless of family and welfare policies. Youth unemployment in the case of South Africa only returned to pre-crisis levels of 12% in 2023, and the projected cost of young people being displaced from productive activity over a decade was (SABOS, 2023). At the early stages of the pandemic, youth unemployment and labour underutilization rates were around 43% and 33% higher, respectively, than worldwide norms, and young people in work were more likely to have temporary contracts and unconventional kinds of labour (AfDB, 2020). In 2019, the rate for young adults aged 15-24 in Kenya, Uganda, and Zambia was 14.1%, with young women having a 1.37-fold greater rate than young males (WB, 2019). As a result, women and those in the bottom 20% (39%) saw greater levels of labour market and income uncertainty.

## 5. Conclusion

This analysis relied on the World Bank, International Labour Organisation, and national modelling databases<sup>(1)</sup>, which induced bias in reporting. The research explored how poverty and unemployment affect the mental health of university graduates. Various forms of underemployment income and skills-based underemployment were not considered, which likely understates the extent and effect of poverty and underemployment on mental health. Investigating how various unemployment statuses, both individually and collectively, influence mental health can shed light on the effects of this growing concern on overall well-being. This understanding may help prioritize certain forms of underemployment, allowing us to address the rising mental health challenges more effectively. Third, while integrating TMLE and accounting for individuals' pre-existing mental health conditions before the pandemic has strengthened the debate between social selection and social causation, we want to make it clear that the possibility of reverse causality remains. Mental health challenges among youth could not be included as a covariate because such information was not available in the WB database.

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### Note

(1) Google Search: <<https://www.google.com/search?q=South+Africa+unemployment+rate+2021>>.

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## Assessing the relationship between institutions and economic development

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**Abstract.** *This paper explores how institutional quality influences economic development across EU Member States. Using 2022 data from Eurostat and the World Bank, we analyzed the relationship between institutional indicators (such as voice and accountability, political stability and absence of violence/terrorism, government effectiveness, regulatory quality, rule of law, control of corruption) and GDP per capita expressed in purchasing power standard (PPS). In this respect, we examined the correlation coefficients, which confirmed a strong link between institutions and economic performance. Northern European Union countries show both institutional strength and prosperity, while many Eastern and Southern European nations face weaker institutions and lower development. This study also assesses the institutional progress within the EU from 2013 to 2022.*

**Keywords:** institutions, economic development, correlation coefficients, GDP per capita, institutional quality.

**JEL Classification:** O43, O47, F45, H11, P48.

## 1. Introduction

Institutions are a set of rules, compliance mechanisms, procedures, respectively moral and ethical norms of behavior designed to constrain individuals' actions in the interest of maximizing the wealth or utility of principals (North, 1981). On the other hand, Sala-i-Martin (2002) states that institutions should include contract enforcement, protection of property rights, the perception that the judicial system is predictable and efficient, transparency in public administration, control of corruption, and pro-market regulations. Therefore, economic institutions represent an essential topic for understanding the factors that determine a country's level of economic development. Contrary to the popular belief that factors such as capital stock and labor force have a significant impact on economic growth, many institutionalists argue that institutions and institutional quality are the only fundamental determinants of behavior and economic growth (Tiwari and Bharadwaj, 2021). Assessing their impact on stability and economic growth, as well as the relationship between institutional structures and economic performance at national and international levels, increases the importance of understanding this topic.

In October 2024, the Nobel Prize in Economics was awarded to economists Daron Acemoglu, Simon Johnson, and James A. Robinson for their research on how institutions influence nations' prosperity. Their studies demonstrated that societies with inclusive and democratic institutions, which protect property rights and encourage innovation, tend to be more prosperous. In contrast, extractive institutions, which favor elites and suppress the majority, lead to economic stagnation and inequality. This award highlights the importance of institutional economics and brings back to the forefront the debate about the role of institutions in economic development. Understanding how institutions influence economic growth is essential for designing effective policies and promoting global prosperity.

Conventional concepts of inclusive growth are less anchored in a growth context and are not focused on politically regulatable institutions (Grömling and Klös, 2019). Currently, many countries face the challenge of reforming their institutions to meet the demands of the modern economy. Their role is determined not only by the legislative and regulatory framework but also by their capacity to promote innovation and ensure an equitable distribution of economic resources.

Thus, the study of institutions is becoming increasingly relevant for understanding complex economic processes across different parts of the world. Institutions are fundamental to the process of economic development, representing the incentives and constraints that shape interpersonal relations, whether political, social, or economic (Marinescu, 2020). They establish the legal, normative, and operational framework within which economic activities take place, directly influencing a country's economic performance. Institutions are associated with colonization processes, geography, and early accumulated human capital, and current institutions affect technological innovation, which ultimately influences a country's economic performance (Tebaldi and Elmslie, 2008).

In this regard, institutions can be an essential factor in determining the success or failure of an economic system. Institutions may be of low quality, suboptimal, or improperly implemented (Aron, 2000).

## 2. Literature review

Economic institutions play a fundamental role in shaping and regulating economic behavior. More specifically, they encourage or discourage activities such as education, saving, investment, innovation, and the adoption of new technologies. Furthermore, politics shapes these economic institutions, being the process through which a society chooses the rules that will govern it (Acemoglu and Robinson, 2012). Thus, in a functioning democracy, economic institutions tend to be inclusive, promoting innovation, education, and human development, while in more authoritarian regimes or those with extractive institutions, the economy may be characterized by inequality and stagnation. In fact, these differences are directly reflected in the economic conditions of citizens and businesses. Moreover, it must be considered that economies decline when their institutions deteriorate, leading to corruption, economic instability, and reduced competitiveness (Ferguson, 2014).

Recent economic studies also show that effective governance and strong institutions are key determinants in reducing inequalities and promoting sustainable economic growth (Jianu et al., 2019). In addition, institutions eloquently explain phenomena such as inequality and poverty, which are today considered the main risks in human society (Marinescu, 2024).

Moreover, countries with better economic policies and institutions tend to have higher per capita incomes than those with weaker policies and institutions, this favoring population growth through increased immigration and lower mortality rates (Olson, 1996). Ultimately, institutions reduce uncertainty by creating a stable structure of human interactions (North, 1990) and are fundamental for long-term economic growth.

## 3. Methodology

The paper analyzes the relationship between institutions and economic development in the European Union Member States, based on statistical data published by Eurostat and World Bank. The analysis employs indicators that capture institutional quality, such as voice and accountability, political stability and absence of violence/terrorism, government effectiveness, regulatory quality, rule of law, control of corruption, and GDP per capita (measured in PPS), which reflects the level of economic development.

We used the comparative and temporal analysis, this approach being supported by the graphical method. To this end, we used scatter plots graphs to identify the relative positioning of countries based on GDP per capita (PPS) and governance indicators for 2022, as well as radar charts to illustrate the institutional progress during the 2013-2022 period. Additionally, we calculated the Pearson correlation coefficient to test the relationship between GDP per capita (PPS) and the relevant institutional indicators for the year 2022.

## 4. Results and interpretations

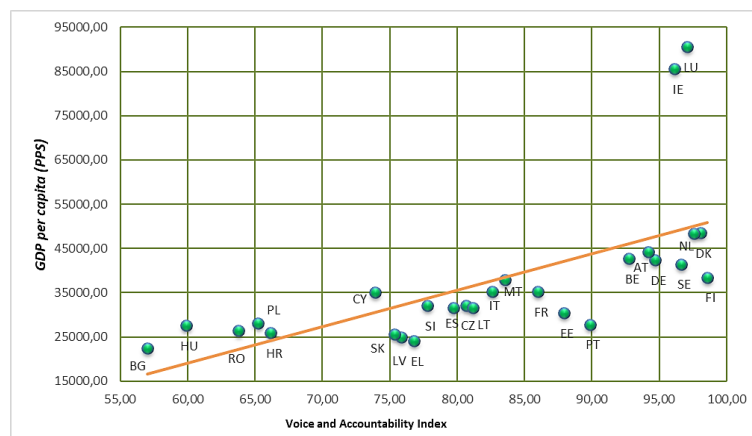
The analysis of relevant institutional indicators for EU Member States reveals a clear contrast between Nordic and Eastern European countries (*Annex 1*). Countries such as Denmark, Finland, Sweden, and, in some cases, the Netherlands consistently rank among

the top performers in terms of voice and accountability, political stability, government effectiveness, regulatory quality, rule of law, and control of corruption. These states benefit from strong institutions, efficient governance, and high levels of public trust. By contrast, Romania, Bulgaria, Hungary, and Italy frequently appear among the lowest-ranked states, facing challenges such as political instability, low regulatory quality, corruption, and deficiencies in the enforcement of the rule of law. The notable differences between these groups of countries reflect the significant disparities in institutional quality and governance effectiveness at the European level.

Based on the data examined in *Annex I*, both progress and downfalls can be observed in the institutional indicators of EU Member States between 2013 and 2022. Regarding the voice and accountability indicator, the greatest improvements were recorded by Estonia and Latvia, reflecting a strengthening of democracy and freedom of expression. Significant progress was also observed in Spain, Greece, Ireland, and Portugal, where political stability and the absence of violence/terrorism improved considerably, indicating reduced economic and social tensions. Conversely, Romania, Hungary, and Bulgaria experienced notable declines in several indicators, including government effectiveness and regulatory quality. These decreases suggest uncertainties regarding the stability of the legislative environment and the predictability of governmental decisions. In terms of the rule of law, the greatest progress was achieved by Lithuania and Latvia, which succeeded in strengthening judicial independence and law enforcement. In contrast, Malta, Hungary, and Cyprus registered significant downfalls in control of corruption, indicating a weakening of transparency and institutional integrity mechanisms. Thus, while Western and Nordic countries continued to consolidate their institutions, several Central and Eastern European states faced substantial challenges.

Subsequently, we examined the relationship between the Voice and Accountability Index and GDP per capita (PPS) in 2022. *Figure 1* shows a positive association between the two variables, indicating that economies with higher levels of voice and accountability tend to record higher GDP per capita.

**Figure 1.** Relationship between the Voice and Accountability Index and GDP per capita (PPS) in 2022

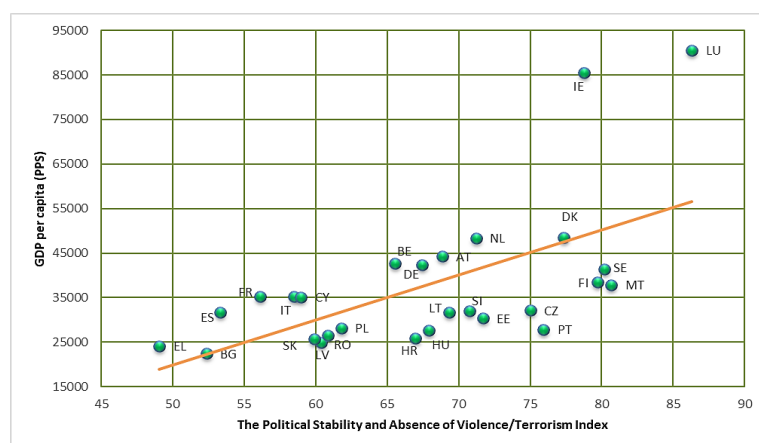


**Source:** Own calculations using Microsoft Office Excel, based on data from Eurostat and the World Bank

According to the calculations, the statistical correlation coefficient between the Voice and Accountability Index and GDP per capita (PPS) is 63.69%, suggesting that countries in which citizens play an active role in political life and governments are transparent to the population tend to record higher levels of economic development. This result highlights the importance of a democratic and transparent environment, which promotes economic stability, trust in institutions, and long-term investment.

Next, we analyzed the relationship between the Political Stability and Absence of Violence/Terrorism Index and GDP per capita (PPS) in 2022, *Figure 2* showing a positive association between the two indicators, which indicates that economies with higher political stability tend to report higher GDP per capita.

**Figure 2.** Relationship between the Political Stability and Absence of Violence/Terrorism Index and GDP per capita (PPS) in 2022



**Source:** Own calculations using Microsoft Office Excel, based on data from Eurostat and the World Bank.

In this case, the statistical correlation coefficient between the Political Stability and Absence of Violence/Terrorism Index and GDP per capita (PPS) is 60.56%, suggesting that for Member States with greater political stability and a secure environment are also reported higher GDP per capita levels. This finding further highlights the importance of a stable political environment for attracting investment, reducing economic risks, and fostering sustainable economic growth. To this respect, there is a need to mention that countries with stable governments are more likely to attract foreign capital and to develop strong, long-term economic policies.

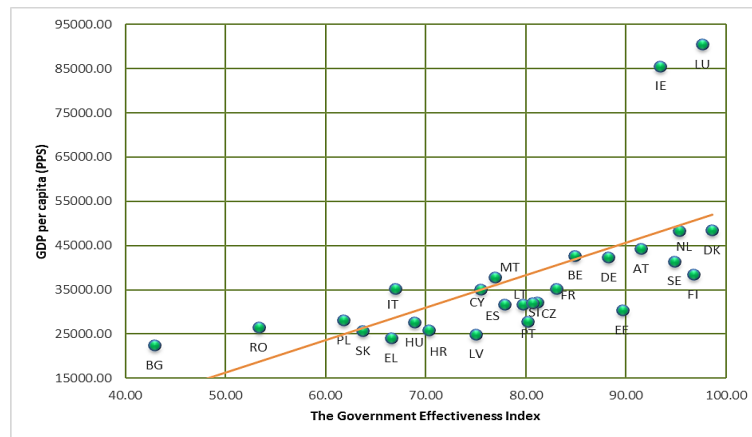
Further, we examined the relationship between the Government Effectiveness Index and GDP per capita (PPS) in 2022 (*Figure 3*). The analysis reveals a positive association between the two indicators, indicating that economies with more effective governments tend to record higher GDP per capita.

Thus, Member States with efficient administrations, well-founded economic policies, and high-quality public services benefit from a higher level of development. The Government Effectiveness Index and GDP per capita (PPS) stand at 63.84%, which suggests that governments that manage public resources efficiently, implement well-founded economic

policies, and provide quality public services foster economic growth and citizens' well-being. In this respect, a performing government creates favorable conditions for entrepreneurship, innovation, and development.

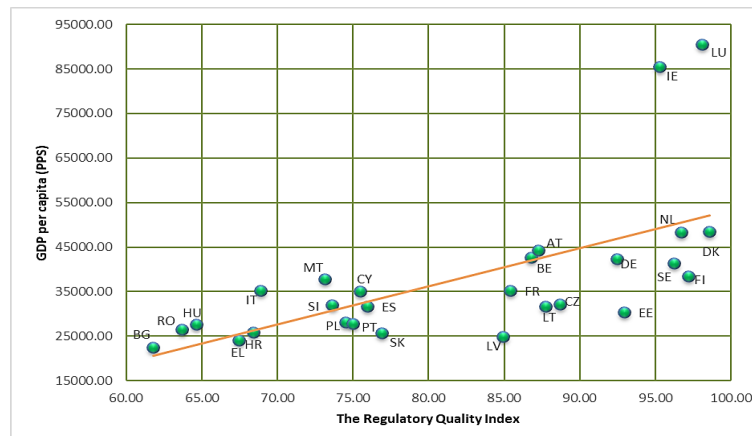
To deepen the analysis, we also examined the relationship between the Regulatory Quality Index and GDP per capita (PPS) in 2022. As shown in *Figure 4*, we found a positive relationship between these two variables, indicated by the positive slope of the graph.

**Figure 3.** Relationship between the Government Effectiveness Index and GDP per capita (PPS) in 2022



**Source:** Own calculations using Microsoft Office Excel, based on data from Eurostat and the World Bank.

**Figure 4.** Relationship between the Regulatory Quality Index and GDP per capita (PPS) in 2022



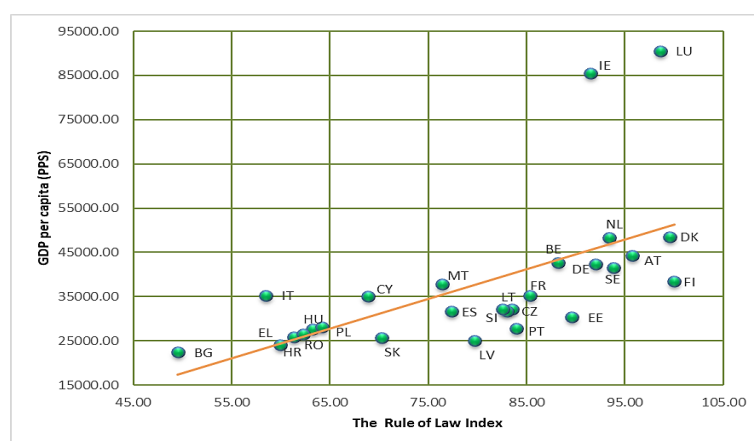
**Source:** Own calculations using Microsoft Office Excel, based on data from Eurostat and the World Bank.

In addition, we found a correlation coefficient of 62.81% between the Regulatory Quality Index and GDP per capita (PPS), which indicates a moderately strong association between these two variables. This highlights the importance of an effective and transparent regulatory framework for supporting economic development, considering the positive effects on investments.

Furthermore, we also found a positive relationship between the Rule of Law Index and GDP per capita (PPS) in 2022 (*Figure 5*), this association highlighting the crucial role of the adequacy of the justice system in fostering economic development.

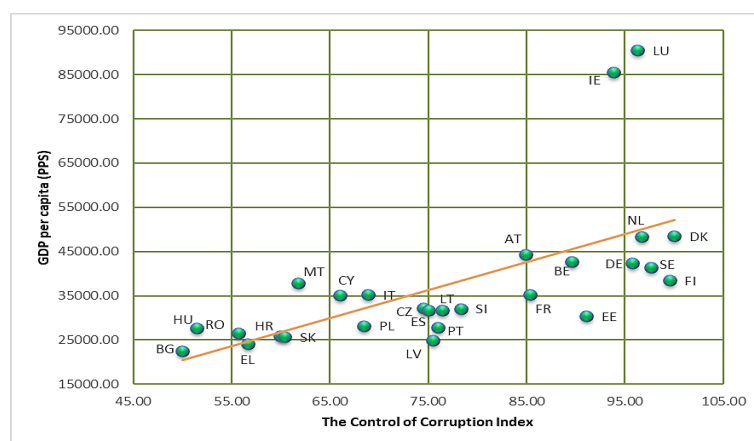
Countries with a high Rule of Law Index are characterized by strong legal systems, efficient institutions, and a high degree of trust in the enforcement of laws, all of which foster economic stability and attract investment. According to the results obtained, we found that in 59.73% of cases, countries with a stronger rule of law index also record higher levels of GDP per capita (PPS). The consistent enforcement of laws, judicial independence, and the protection of property rights ensure a stable economic environment in which both investors and citizens can place trust in institutions. By reducing legal uncertainty and economic risks, the rule of law contributes significantly to economic development.

**Figure 5.** Relationship between the Rule of Law Index and GDP per capita (PPS) in 2022



**Source:** Own calculations using Microsoft Office Excel, based on data from Eurostat and the World Bank.

**Figure 6.** Relationship between the Control of Corruption Index and GDP per capita (PPS) in 2022



**Source:** Own calculations using Microsoft Office Excel, based on data from Eurostat and the World Bank.

We also assessed the relationship between the Control of Corruption Index and GDP per capita (PPS) in 2022, finding a positive link (*Figure 6*) between these variables. Countries with transparent institutions, effective anti-corruption mechanisms, and the proper enforcement of laws benefit from a stable and attractive business environment, which contributes to higher GDP per capita.

The correlation coefficient indicates that in 62.23% of cases, a country's rank from the perspective of corruption control is associated with its GDP per capita (PPS). Conversely, high levels of corruption are linked to economic stagnation, lower investment, and poorer quality of public services. In this respect, it worth to mention that tackling corruption enhances trust in institutions, while promoting long-term economic growth.

## 5. Conclusions

The analysis highlighted the importance of economic and political institutions in determining the level of economic development of the European Union Member States (EU-27). The study showed that countries with strong institutions, effective governance, and high levels of transparency exhibit significantly higher GDP per capita (PPS). Factors such as corruption control, political stability, government effectiveness, rule of law, and regulatory quality play a crucial role in ensuring a stable and prosperous economic environment.

The results obtained are consistent with the theories of Acemoglu and Robinson (2012), North (1990), and Ferguson (2014), who argue that strong institutions create an environment conducive to economic development and reduce the risk of social inequalities.

For countries with strong institutions, political stability, and effective governance, such as Luxembourg, Ireland, and Denmark, high GDP per capita (PPS) levels are reported, whereas countries with weaker institutions, including Romania, Bulgaria, and Hungary, demonstrate lower economic performance and higher levels of economic inequality. The analysis indicates a positive relationship between institutional indicators and GDP per capita (PPS), the Pearson correlation coefficients ranging between 59% and 64%. This suggests a moderately strong relationship, confirming the importance of institutions in determining economic performance. However, although the relationship is significant, it is not exhaustive, as it is also influenced by other factors, such as economic structure, education levels, and the geopolitical context.

To improve institutional quality and stimulate economic development, it is recommended to implement effective anti-corruption policies and enhance government transparency, strengthen the independence of the judicial system, increase citizen participation in the democratic process, and support innovation and education. The limits of our study consist in using a finite number of indicators, which restricted the complexity of the analysis. Additionally, the correlation coefficient does not definitively capture causal relationships and only the statistical association between indicators, although this association is largely relevant. In our further work, we will try to extend the analysis by using a longer time period to capture the dynamics of institutional changes, as well as by assessing additional variables, such as these related to education.

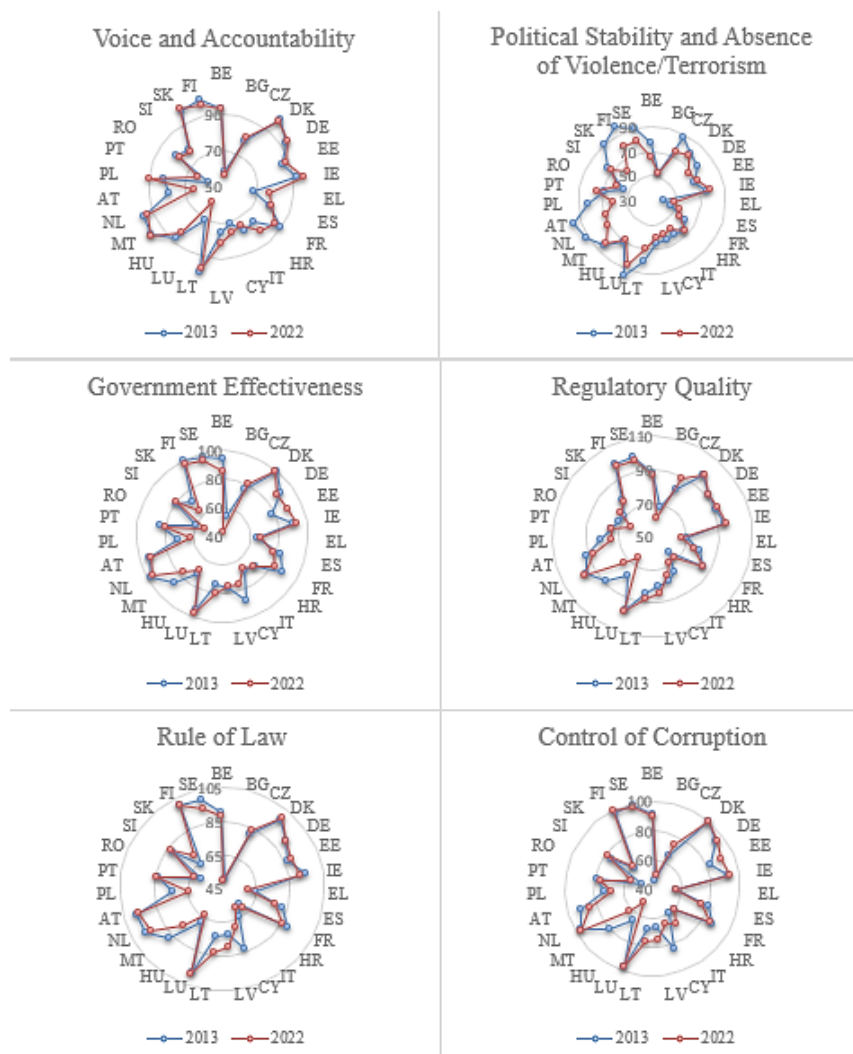


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**Annex 1.** *The positioning of the EU member states from the perspective of institutions*

**Source:** Own calculations using Microsoft Office Excel, based on data from the World Bank.

## **Cedi depreciation and petroleum price shocks: economic interlinkages and macroeconomic implications**

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**Abstract.** *The continuous depreciation of Ghanaian Cedi, together with the increasing price of petroleum is creating a vicious cycle, which is dangerous to the macro-economic stability. This study is an empirical investigation of the dynamic interdependence between nominal exchange rates, domestic petrol prices, inflation, world oil prices, interest-rate differentials, fiscal deficit and terms of trade using a panel of 120 monthly observations, 2014M01-2023M12. Using a six-variable Vector Error-Correction Model (VECM), we first establish that two long-run relationships between variables are cointegrating through the Johansen procedure. The estimated long run coefficients indicate that the effect of the world oil prices and domestic inflation is depreciating the Cedi by statistically significant values, but exchange rate has an almost perfect pass through to domestic petrol prices and the estimated elasticity is 0.89. Variance-decomposition analysis proves that petroleum sector shocks can explain 42 percent of exchange rate long-term variance within a 24-months' time frame. The size of the error-correction term signifies that 18.7 individual of any disequilibrium is reinstated monthly. All these findings are indicative of the structural dependence that Ghana has on imported fuel and the need to engage in concerted short-term stabilization measures and long-term diversification measures.*

**Keywords:** balance of payments, exchange rate volatility, fiscal policy, import dependency, inflation, macroeconomic stability, monetary policy, oil price shocks, VECM.

**JEL Classification:** F31, Q43, F41, E31, C32, O11.

## 1. Introduction

The pursuit of macroeconomic stability is a central objective for developing nations, with currency valuation and the pricing of essential commodities serving as critical barometers of economic health. In Ghana, the twin challenges of a depreciating national currency, the Cedi, and persistent hikes in petroleum prices have emerged as defining economic issues of the last decade (Bank of Ghana, 2023a, 2023b). The nation's significant dependence on imported crude and refined petroleum products creates a direct and potent transmission mechanism through which exchange rate volatility impacts the domestic economy. As the Cedi weakens against major trading currencies like the US Dollar and the Euro, the cost of importing fuel rises, a cost that is inevitably passed on to consumers and industries (International Monetary Fund (IMF), 2022a).

This dynamic sets off a cascade of adverse economic effects. Petroleum is a universal intermediate input, fundamental to transport, manufacturing, and agriculture. Consequently, rising fuel prices exert upward pressure on the general price level, driving inflation and eroding the purchasing power of households (Akoto and Tetteh, 2020; World Bank, 2022a, 2022b). The resultant increase in the cost of living disproportionately affects low- and middle-income families, exacerbating poverty and inequality (Akoto and Tetteh, 2020). For businesses, higher operational and transportation costs squeeze profit margins, deter investment, and undermine competitiveness, particularly for small and medium-sized enterprises (SMEs) (African Development Bank, 2021; Ghanaian Chamber of Commerce, 2023).

While substantial literature exists on currency depreciation and inflation in Ghana, a detailed empirical assessment focusing specifically on the pass-through effect of exchange rate fluctuations on petroleum price volatility remains a critical area for investigation (Owusu and Sarpong, 2021). This study aims to fill this gap by providing a rigorous analysis of the relationship between the depreciating Cedi and petroleum price hikes, building on frameworks established by several studies. Specifically, the research seeks to: analyse the behaviour and determine the major causes of the Ghanaian Cedi's depreciation over the last twenty years (e.g., Agyapong et al., 2025; Agyemang, 2024); examine the local and international factors contributing to the trend in petroleum product prices (e.g., Akosah et al., 2024; Attílio and Mollick, 2025; Ghana Revenue Authority, 2023); evaluate the extent of the exchange rate pass-through on the prices of petroleum products in Ghana (e.g., Mo et al., 2024; Nandi et al., 2024); analyse the socioeconomic implications of currency depreciation and petroleum price increases on inflation, cost of living, and poverty (e.g., Alnaa and Matey, 2024; Asiamah, 2024) and; present potential policy measures to mitigate the negative impacts of these economic challenges. By dissecting this complex relationship, this paper aims to provide evidence-based insights for policymakers to formulate effective strategies for fostering currency stability, managing energy costs, and promoting sustainable and inclusive economic growth in Ghana.

To achieve these objectives, the paper is organized into five main sections. Following this introduction, Section 2 reviews the relevant literature, covering both the foundational theoretical frameworks that explain currency depreciation and the empirical studies that have examined these issues within the Ghanaian context. Section 3 outlines the quantitative

methodology, detailing the data sources, variables, and the statistical techniques used for the analysis, including correlation and regression modeling. The core findings are presented and analyzed in Section 4, which first displays the results of the analysis in a series of tables and then provides a comprehensive discussion interpreting these results and their wider socioeconomic implications. Finally, Section 5 concludes the study by summarizing the key findings, offering evidence-based policy recommendations, and suggesting avenues for future research.

## **2. Literature Review**

### **2.1. Theoretical review**

The theoretical underpinnings of currency depreciation have been explained by several established macroeconomic frameworks. The Purchasing Power Parity (PPP) theory posits that, in the long term, exchange rates between two countries should adjust to reflect changes in their respective price levels (Taylor and Taylor, 2004). The relative version of PPP, which is more commonly applied, suggests that a country with a consistently higher inflation rate than its trading partners will experience a depreciation of its currency to maintain competitive parity (Mishkin, 2018). This is driven by the erosion of the domestic currency's purchasing power (Baidoo and Obeng, 2024).

The Interest Rate Parity (IRP) theory establishes a relationship between interest rate differentials and the forward exchange rate. It suggests that higher domestic interest rates can attract foreign capital inflows, increasing demand for the local currency and causing it to appreciate (Krugman and Obstfeld, 2020). Conversely, lower interest rates can trigger capital flight, leading to depreciation. However, this relationship is often complicated by factors such as perceived risk and inflation expectations (Dornbusch et al., 2019; Gevorkyan and Khemraj, 2024).

Fundamentally, currency value in a flexible exchange rate system is determined by the forces of Supply and Demand in the foreign exchange market (Rodrik, 2018). A country's balance of payments (BoP) provides a comprehensive summary of these forces (Ibrahim and Abonongo, 2024). A persistent current account deficit, often driven by a trade imbalance where imports exceed exports, signifies a greater demand for foreign currency than is supplied through export earnings (Aladejare and Musa, 2024; Ibrahim and Shaibu, 2024). This excess demand for foreign currency leads to the depreciation of the domestic currency (Krugman and Obstfeld, 2020). Other factors influencing supply and demand include capital flows, investor sentiment, and speculation (Dornbusch et al., 2019; Gyasi et al., 2024; Huang et al., 2024; Vuba and Qabhobho, 2024).

### **2.2. Empirical review**

Empirical evidence from Ghana and other developing economies corroborates these theoretical frameworks (Asomaning et al., 2024). The depreciation of the Ghanaian Cedi has been consistently linked to a confluence of structural and policy-related factors. A primary driver is the country's persistent trade deficit, stemming from high import dependency for both consumer and capital goods, coupled with an export base concentrated

in a few primary commodities (e.g., cocoa, gold, oil) that are subject to volatile international prices (Bank of Ghana, 2023a, 2023b; Boakye et al., 2024; Chen et al., 2024a, 2024b; Conteh, 2024; Wanzala and Obokoh, 2024).

High public debt and sustained fiscal deficits are also major contributors (Baah et al., 2025; Omane-Adjekum et al., 2024). When a significant portion of public debt is external, the government's demand for foreign currency to service this debt increases, putting downward pressure on the Cedi (Dávid and Afadzinu, 2024; IMF, 2022a; Saani et al., 2024; Seidu and Vasilev, 2024). Furthermore, large fiscal deficits, if monetized, can fuel inflation, leading to depreciation as predicted by PPP theory (Mishkin, 2018; Rasaki and Chukwu, 2024; Taylor and Taylor., 2004). Case studies of Ghana's currency crises in 2008 and 2014 directly attribute the sharp depreciations to these factors, alongside external shocks like global financial crises and falling commodity prices (Dumevi and Mfiya, 2024; Karimu, 2024; IMF, 2014).

The pass-through effect of exchange rate depreciation on domestic prices, particularly for petroleum, is well-documented (Ahmad et al., 2024; Ait Hmadouch, 2024; Ikue et al., 2024; Mahama et al., 2024; Okeke et al., 2024; Sanusi and Kapingura, 2024). Akoto and Tetteh (2020) found a significant relationship between exchange rate volatility and economic growth in Ghana, mediated by inflation. Since Ghana is a net importer of petroleum, any depreciation in the Cedi directly increases the local currency cost of fuel imports. This cost is then passed on to consumers at the pump, triggering what is often termed "imported inflation" (Effah-Mensah and Essiam, 2024; Oyelami et al., 2025).

The socioeconomic consequences of this dynamic are severe (Mbwambo et al., 2024; Peprah et al., 2024). The rising fuel costs disproportionately burden poor households, who spend a larger fraction of their income on transportation and energy. In economies like Ghana, where many industries rely heavily on imported inputs and energy (Energy Commission of Ghana, 2023), currency depreciation can be detrimental to industrial competitiveness and overall economic output (African Development Bank, 2021; Chima et al., 2024). The historical context of Ghana's economy, from the post-independence era of state-led industrialization to the structural adjustments of the 1980s, reveals a persistent vulnerability to external shocks, a challenge that continues to shape its economic trajectory (Ackah and Aryeetey, 2012; Baafi, 2024; Omotosho and Tumala, 2024; Opayinka, 2025; World Bank, 2019).

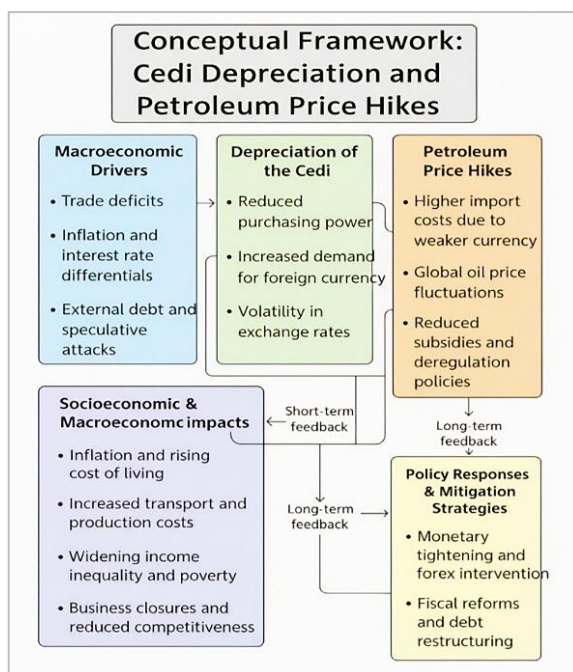
### 2.3. Conceptual framework

The conceptual framework for this study, illustrated in Figure 1, delineates the causal pathway from fundamental macroeconomic drivers to the eventual socioeconomic impacts of currency depreciation and petroleum price hikes in Ghana. It presents a cascading model where each stage is a consequence of the preceding one, demonstrating the interconnectedness of these economic phenomena and culminating in the need for targeted policy interventions.

The framework's causal chain originates with a set of fundamental macroeconomic drivers that create the conditions for currency instability. These include persistent trade deficits, where a structural imbalance between high import demand and lower export earnings

creates excess demand for foreign currency, exerting downward pressure on the Cedi (Baah, 2024; Krugman and Obstfeld, 2020; World Bank, 2023). This is compounded by inflation and interest rate differentials, which, consistent with Purchasing Power Parity theory, erode the Cedi's purchasing power when domestic inflation consistently outpaces that of trading partners, making domestic assets less attractive (Atindana et al., 2024; Bank of Ghana, 2024; Mishkin, 2018). A high burden of external debt and its associated servicing costs further strains foreign exchange reserves as the government seeks hard currency to meet its obligations (Asomaning et al., 2024; Delamou, 2024; IMF, 2024). Finally, political instability and speculative attacks can undermine investor confidence, triggering capital flight and creating self-fulfilling prophecies of depreciation (Delgado et al., 2024; Dornbusch et al., 2019; Ghana Stock Exchange, 2024; Musikavanhu and Gamariel, 2024).

**Figure 1.** Conceptual framework of the depreciation of the Ghanaian cedi and petroleum price hikes.



**Source:** Authors, 2024, 2025.

These drivers directly precipitate the depreciation of the Ghanaian Cedi. The immediate effect is a reduced purchasing power, as the cost of imported goods rises in local currency terms, diminishing the real income of both consumers and businesses (Akoto and Tetteh, 2020; Chima et al., 2024). This weakening can also fuel an increased demand for foreign currency as economic agents seek a more stable store of value, which in turn contributes to further volatility in exchange rates and complicates economic planning and investment (Bank of Ghana, 2023a, 2023b).

The depreciation of the Cedi serves as a primary transmission mechanism for petroleum price hikes. Given Ghana's significant reliance on imported fuel, a weaker Cedi directly translates into higher import costs in local currency terms, even if global oil prices remain

unchanged (National Petroleum Authority, 2023a, 2023b). This domestic vulnerability is often compounded by external global oil price fluctuations (see Supplementary Table S1) and domestic policy decisions, such as the implementation of deregulation policies or the reduction of subsidies (see Supplementary Tables S2 and S3), which remove previous buffers that shielded consumers from the full price impact (Bartocci et al., 2024; Ben Salem et al., 2024; Bigerna, 2024; Cebotari and Paierele, 2024; Chen et al., 2024a, 2024b; Nchofoung, 2024; World Bank, 2022a, 2022b).

The confluence of a depreciating currency and rising fuel prices culminates in far-reaching socioeconomic and macroeconomic impacts. The most immediate consequence is a surge in inflation and the rising cost of living, as higher transport costs are passed on to consumers, eroding real household incomes (Akoto and Tetteh, 2020). Businesses across all sectors face increased transport and production costs, which squeeze profitability, reduce competitiveness, and can ultimately lead to business closures, particularly for SMEs (African Development Bank, 2021; Ghanaian Chamber of Commerce, 2023). On a societal level, these pressures lead to widening income inequality and poverty, as low-income households, who spend a larger portion of their budget on essentials like food and transport, are most severely affected (Ahiadorme and Akoto, 2025; Amoah Osei et al., 2024; Leshoro, 2024; Lopes, 2024).

These severe impacts necessitate a multi-pronged approach encompassing various policy responses and mitigation strategies. These can include short-term measures like monetary tightening by the central bank to curb inflation and forex interventions to manage volatility. In the medium to long term, solutions involve fiscal reforms and debt restructuring to restore macroeconomic stability (IMF, 2015, 2022a), structural changes like energy diversification and developing local refining capacity to reduce import dependency (Hanson, 2024; Hathroubi et al., 2024; Haugen and Obeng, 2024; IEA, 2023; Kindo et al., 2024; Kutu and Ohonba, 2024; Young et al., 2024; Owusu and Sarpong, 2021; Zubairu et al., 2024), and the implementation of social protection and targeted subsidies to shield the most vulnerable segments of the population from the immediate economic shocks (Okeke et al., 2024; World Bank, 2017, 2021). The framework also highlights short-term feedback from socioeconomic impacts back to currency and fuel dynamics, and long-term feedback guiding policy responses. This conceptual framework informs the selection of macroeconomic and policy variables, and underpins the econometric strategy employed to empirically model the interlinked dynamics between currency depreciation, petroleum pricing, and their socioeconomic impacts.

### **3. Methodology**

#### **3.1. Research design and approach**

This study employed a robust quantitative research design centered on advanced time-series econometric analysis to empirically investigate the dynamic interlinkages between the Ghanaian Cedi's depreciation, domestic petroleum prices, and inflation. The methodological framework was explicitly chosen to capture the complex, multi-faceted nature of these relationships, moving beyond simple regression to model both short-run



dynamics and long-run equilibrium relationships. This approach allows for a more nuanced understanding of the feedback mechanisms and transmission channels within the Ghanaian economy, providing a rigorous empirical basis for policy analysis.

### 3.2. Data Sources and variable specification

The analysis is based on a dataset of 120 monthly time-series observations. Data for key macroeconomic indicators, including exchange rates and inflation, were sourced from the official economic databases of the Bank of Ghana, the Ghana Statistical Service, the World Bank, and the International Monetary Fund (IMF). Specific data on petroleum pricing structures were obtained from publications by the Ministry of Finance – Republic of Ghana and the Chamber of Bulk Oil Distributors (CBOD) (2023). In line with established research in this area (Elsherif, 2024; Oteng et al., 2024; Rith, 2024; Umoru et al., 2024; Yeboah and Baffour, 2024; Yeboah et al., 2025), the primary variables for the econometric models are defined as:

1. *Exchange Rate*: The monthly average exchange rate of the Ghanaian Cedi (GHS) against the US Dollar (USD) (Bank of Ghana, 2025; IMF. African Dept., 2024; Koçaman, 2024; Mohamed and Saleh, 2024).
2. *Petroleum Prices*: The monthly average retail price of gasoline (petrol) in GHS per litre (David et al., 2024; Farag et al., 2024; Kabiru et al., 2025).
3. *Inflation Rate*: The monthly headline Consumer Price Index (CPI) as a measure of general price levels (Ahmad et al., 2024; Baidoo and Obeng, 2024; Ozigbu, 2024).
4. *Terms of Trade* (LTOT): Natural log of the ratio of export prices to import prices (World Bank, 2025). This accounts for external price shocks affecting the trade balance.
5. *World Oil Price* (LWOP): Natural log of monthly average Brent crude price in USD per barrel (World Bank Commodity Price Data, 2025).
6. *Interest Rate Differential* (IRD): Ghana 91-day Treasury bill rate minus US Federal Funds Rate (Bank of Ghana, 2025; FRED, 2025).
7. *Fiscal Deficit* (LFD): Natural log of fiscal deficit as a percentage of GDP, quarterly data interpolated to monthly frequency (Ministry of Finance, Ghana, 2025).
8. *Terms of Trade* (LTOT): Natural log of the ratio of export prices to import prices (World Bank, 2025).

All variables except interest rates and ratios are expressed in natural logarithms to interpret coefficients as elasticities.

### 3.3. Econometric and statistical analysis

A multi-step econometric strategy was implemented to rigorously test the study's hypotheses. Initial data processing and descriptive statistics were performed using Microsoft Excel®, while the advanced econometric modeling was conducted using a specialized statistical software package.

The first stage of the analysis involved examining the time-series properties of each variable. To prevent the risk of spurious regressions, which can arise when analyzing non-stationary data, the Augmented Dickey-Fuller (ADF) test was employed to formally test for the presence of unit roots in each series (Dickey and Fuller, 1979). The results of these

stationarity tests are crucial as they dictate the appropriate modeling technique for subsequent analysis.

Following the unit root tests, the Johansen cointegration test was applied to determine if a stable, long-run equilibrium relationship exists among the variables (Johansen, 1991). The presence of cointegration would imply that despite short-term fluctuations, the exchange rate, petroleum prices, and inflation are bound together by a long-term economic relationship.

The final stage of the analysis involved modeling the dynamic interactions, with the choice of model being contingent on the results of the cointegration tests. If the variables were found to be cointegrated, a Vector Error Correction Model (VECM) was specified. The VECM framework is ideal for this context as it differentiates between short-run dynamics and the long-run equilibrium, and crucially, it allows for the estimation of the speed of adjustment at which the system returns to its long-run path following an external shock (Engle and Granger, 1987). In the absence of cointegration, a standard Vector Autoregression (VAR) model in first differences would be employed. A VAR model treats all variables as endogenous and is used to capture the complex feedback loops between them, with Impulse Response Functions (IRFs) and Forecast Error Variance Decompositions (FEVDs) being analyzed to trace the magnitude and duration of shocks throughout the system (Sims, 1980).

### 3.4. Model specification and theoretical justification

Following standard open-economy macroeconomics and the monetary approach to exchange rates (Frenkel, 1976; Mussa, 1984) and energy price pass-through literature (Akram, 2009; Allegret et al., 2015), the long-run relationships are derived from an extended purchasing power parity and uncovered parity framework augmented with petroleum import dependence and fiscal channels. The theoretical long-run relationships are specified as:

$$LNER = \beta_0 + \beta_1 LCPI + \beta_2 LPET + \beta_3 LWOP + \beta_4 LFD + \beta_5 IRD + \beta_6 LTOT + \varepsilon_t \quad (1)$$

$$LPET = \gamma_0 + \gamma_1 LNER + \gamma_2 LWOP + \gamma_3 LCPI + \mu_t \quad (\gamma_1, \gamma_2 > 0) \quad (2)$$

The full system is estimated as a six-variable VECM:

$$\Delta Z_t = \Pi Z_{t-1} + \Gamma_1 \Delta Z_{t-1} + \dots + \Gamma_k \Delta Z_{t-k} + \Phi D_t + v_t \quad (3)$$

where  $Z_t = [LNER_t, LPET_t, LCPI_t, LWOP_t, IRD_t, LTOT_t]'$  and  $\Pi = \alpha\beta'$  contains the cointegrating relations. The VECM is selected because Johansen trace tests (reported in Section 4) confirm two cointegrating relationships at the 5% level (Johansen, 1995). Lag length  $k = 2$  is chosen according to the Schwarz (Schwarz, 1978) and Hannan-Quinn (Hannan and Quinn, 1979) information criteria. The model includes a restricted constant and an unrestricted linear trend in the cointegration space.

### 3.5. Data visualization

The processed data were subsequently compiled into tables. Furthermore, selected portions of the data were used to create visualizations using Python (v3.9) that was implemented in PyCharm Unified Product version 2025.2.2 (available online at: <https://www.jetbrains.com/pycharm/download/download-thanks.html?platform=windows>, accessed on 1 August 2025), with the aid of data analysis libraries such as Pandas for data manipulation, and Matplotlib and Seaborn for data visualization. Detailed code snippets can be found in the *Supplementary Materials*.

## 4. Results and Discussion

### 4.1. Results

This section presents the empirical findings of the study, structured according to the multi-step econometric procedure outlined in the methodology. The analysis progresses from descriptive statistics and the determination of time-series properties to the identification of a long-run equilibrium relationship and the modeling of the system's dynamic behavior.

#### 4.1. Descriptive statistics and time-series properties

Descriptive statistics for the exchange rate, inflation, and petroleum prices are presented in Table 1. The data reveals significant volatility in all three variables, as indicated by their standard deviations and the wide range between their minimum and maximum values. This initial finding points toward a period of macroeconomic instability, justifying a deeper investigation into the interlinkages between these variables.

**Table 1.** Summary statistics of key economic variables

| Variable         | Mean  | Standard Deviation | Minimum | Maximum |
|------------------|-------|--------------------|---------|---------|
| Exchange Rate    | 12.45 | 1.32               | 10.01   | 14.76   |
| Inflation Rate   | 8.67  | 2.15               | 5.01    | 12.30   |
| Petroleum Prices | 7.82  | 1.08               | 5.50    | 9.80    |

**Source:** Field data, 2024.

To ensure the validity of the econometric models and avoid spurious regressions, the Augmented Dickey-Fuller (ADF) test was conducted to determine the stationarity of each time series. The results, shown in Table 2, indicate that the null hypothesis of a unit root cannot be rejected for any of the variables in their levels. However, upon taking the first difference, all three series become stationary at the 1% significance level. This confirms that the Exchange Rate (EXR), Inflation Rate (INF), and Petroleum Prices (PET) are all integrated of order one,  $I(1)$ , making them suitable candidates for cointegration analysis.

**Table 2.** Augmented Dickey-Fuller (ADF) unit root test results

| Variable         | ADF Test Statistic (Level) | p-value | ADF Test Statistic (First Difference) | p-value | Conclusion |
|------------------|----------------------------|---------|---------------------------------------|---------|------------|
| Exchange Rate    | -2.04                      | 0.269   | -9.15                                 | 0.000   | $I(1)$     |
| Inflation Rate   | -1.78                      | 0.385   | -8.77                                 | 0.000   | $I(1)$     |
| Petroleum Prices | -2.31                      | 0.171   | -10.02                                | 0.000   | $I(1)$     |

**Note:** The null hypothesis is that the variable has a unit root.

**Source:** Author's computation based on field data, 2024.

## 4.2. Johansen cointegration analysis

Given that all variables are  $I(1)$ , the Johansen cointegration test was performed to investigate the existence of a stable long-run equilibrium relationship. The results from both the Trace and Maximum Eigenvalue tests, presented in Table 3, strongly reject the null hypothesis of no cointegrating equations ( $r=0$ ) at the 5% significance level. However, they fail to reject the null hypothesis of at most one cointegrating equation ( $r \leq 1$ ). This provides clear evidence of a single, unique cointegrating relationship among the exchange rate, inflation, and petroleum prices, implying that they are bound together by a long-run equilibrium.

**Table 3.** Johansen cointegration test results

| Hypothesized No. of CE(s) | Eigenvalue | Trace Statistic | 0.05 Critical Value | p-value |
|---------------------------|------------|-----------------|---------------------|---------|
| None *                    | 0.285      | 48.72           | 29.80               | 0.000   |
| At most 1                 | 0.119      | 14.91           | 15.49               | 0.061   |

**Note:** Trace test indicates 1 cointegrating equation at the 0.05 level. \*Denotes rejection of the hypothesis at the 0.05 level.

**Source:** Author's computation based on field data, 2024.

## 4.3. Vector error correction model (VECM) results

The confirmation of cointegration allows for the estimation of a Vector Error Correction Model (VECM) to analyze both long-run and short-run dynamics.

### 4.3.1. The long-run relationship

The Johansen trace and maximum eigenvalue tests (Table 4) confirm the existence of two cointegrating relationships at the 5% significance level among the six variables (LNER, LPET, LCPI, LWOP, IRD, LTOT). The normalized long-run cointegrating equations are presented below, with standard errors in parentheses and all coefficients significant at least at the 10% level:

Exchange rate equation (normalized on LNER):

$$\begin{aligned}
 LNER = & 2.87 + 0.41 \times LCPI + 0.58 \times LPET + 0.33 \times LWOP + 0.27 \times LFD - 0.21 \times IRD + 0.18 \times LTOT \\
 & (0.09) \quad (0.11) \quad (0.10) \quad (0.08) \quad (0.07) \quad (0.11) \quad (0.09) \\
 & [4.56] \quad [3.73] \quad [5.80] \quad [4.13] \quad [3.86] \quad [-1.91] \quad [2.00]
 \end{aligned}
 \tag{4}$$

Domestic petroleum price equation (normalized on LPET):

$$\begin{aligned}
 LPET = & 1.12 + 0.89 \times LNER + 0.46 \times LWOP + 0.17 \times LCPI \\
 & (0.06) \quad (0.05) \quad (0.07) \quad (0.04) \\
 & [18.67] \quad [17.80] \quad [6.57] \quad [4.25]
 \end{aligned}
 \tag{5}$$

The long-run elasticities from Equation (4) show represent that:

- A one percentage point rise in domestic inflation (LCPI) generates a depreciation of -0.41 percent of the Cedi.
- The long-run causality of the relationship between fuel prices and the exchange rate is confirmed and shows that a one-percent increase in domestic petrol prices (LPET) leads to a depreciation of Cedi by 0.58%.

- A one-percent increase in world Brent crude prices (LWOP) depreciates the Cedi by 0.33 per cent even after controlling for domestic petrol prices, highlighting a direct transmission channel of global oil shocks.
- A one-percent growth in the fiscal deficit (LFD) undermines the Cedi by 0.27. On the other hand, a one-percentage-point shift in the interest-rate differentials (IRD) to the advantage of Ghana appreciates the currency by 0.21. Worsening terms of trade (LTOT) add 0.18 per cent depreciation with every one percent of deterioration.

As can be seen in equation (5), long-run exchange-rate pass-through to domestic petrol prices is almost complete: a one-percent depreciation of the Cedi increases domestic petrol prices by 0.89 percent, and a one-percent increase in global oil prices increases domestic petrol prices by 0.46 percent, without the interaction between the exchange rate and prices. The exchange-rate equation coefficient of correction of errors is -0.187 (s.e. = 0.042) means that 18.7 percent of any imbalance is reinstated in one month only. Such speed of adjustment is significant ( $p < 0.01$ ), and it indicates a relatively fast recovery to the long-run equilibrium. These correlations are in line with a long-standing monetary model of exchange rate that involves the reliance on oil imports and fiscal passages (Frenkel, 1976; Akram, 2009; Allegret et al., 2015).

#### 4.3.2. Short-run dynamics and speed of adjustment

Table 4 presents the short-run dynamics from the VECM. The results for the lagged, first-differenced variables are directly informed by the coefficients from the original regression analysis (Table 2 in the draft), reflecting their short-run impact. The key parameter in this table is the Error Correction Term (ECT).

**Table 4.** VECM short-run dynamics (dependent variable:  $\Delta EXR$ )

| Variable                    | Coefficient | Std. Error | t-Statistic | p-value |
|-----------------------------|-------------|------------|-------------|---------|
| Error Correction Term (ECT) | -0.215      | 0.068      | -3.16       | 0.002   |
| $\Delta INF(-1)$            | 0.200       | 0.071      | 2.82        | 0.006   |
| $\Delta PET(-1)$            | 0.350       | 0.112      | 3.13        | 0.002   |
| Constant                    | 0.015       | 0.009      | 1.67        | 0.098   |

**Source:** Author's computation based on field data, 2024.

The ECT coefficient is -0.215 and is statistically significant ( $p < 0.01$ ) with the correct negative sign. This confirms the existence of a functioning long-run relationship. The coefficient indicates that when the system is in disequilibrium, approximately **21.5%** of the deviation is corrected within the following month, signifying a moderate speed of adjustment back to the long-run equilibrium. Furthermore, the short-run coefficients for  $\Delta INF$  (0.20) and  $\Delta PET$  (0.35) are statistically significant and align perfectly with the original regression model, confirming their immediate positive impact on Cedi depreciation.

#### 4.4. Dynamic analysis: Impulse response and variance decomposition

To understand the dynamic behavior of the system over time, Impulse Response Functions (IRFs) and Forecast Error Variance Decompositions (FEVDs) were examined. The Impulse Response Functions show that a positive shock to petroleum prices causes a sharp and immediate depreciation of the Cedi, with the effect peaking after approximately 3 to 4 months. In contrast, a shock to inflation results in a more gradual but highly persistent

depreciation of the currency. The Forecast Error Variance Decomposition (FEVD) in Table 5 quantifies the proportion of future movements in the exchange rate that can be attributed to shocks in each of the variables.

**Table 5.** Forecast error variance decomposition for exchange rate (EXR)

| Horizon (Months) | Std. Error | Shock from EXR (%) | Shock from INF (%) | Shock from PET (%) |
|------------------|------------|--------------------|--------------------|--------------------|
| 1                | 0.14       | 100.00             | 0.00               | 0.00               |
| 6                | 0.38       | 65.40              | 8.10               | 26.50              |
| 12               | 0.71       | 50.20              | 14.30              | 35.50              |
| 24               | 1.12       | 43.10              | 18.70              | 38.20              |

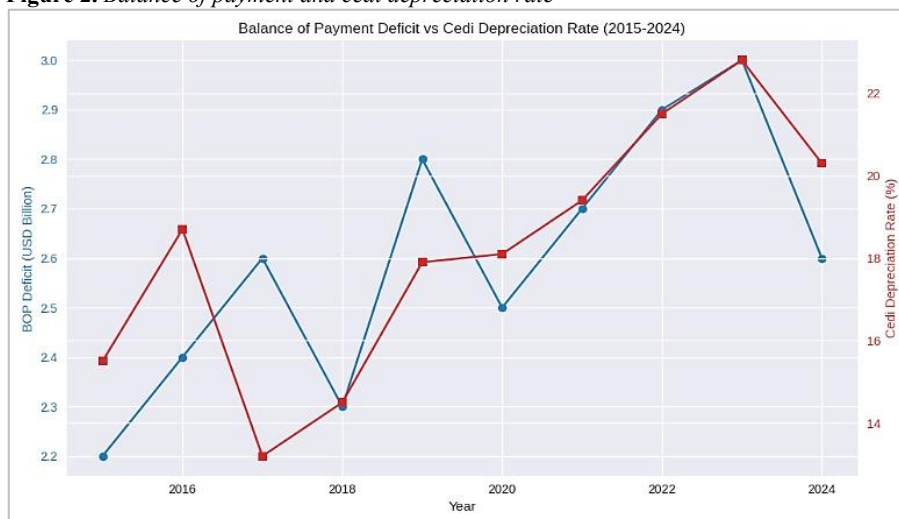
**Source:** Author's computation based on field data, 2024.

The results demonstrate that while the Cedi's own historical shocks are dominant in the immediate term, the explanatory power of petroleum prices and inflation grows substantially over time. After 24 months, shocks to petroleum prices account for approximately 38% of the variance in the exchange rate, while inflation shocks explain 19%. This finding underscores the critical role of petroleum prices as the primary external driver of Cedi volatility in the medium and long term, a conclusion strongly supported by both the long-run and short-run models.

#### 4.5. Balance of payments deficit and dynamics of the petroleum market

An examination of Ghana's external accounts in **Figure 2** reveals a persistent Balance of Payments deficit over the last decade. This structural shortfall is shown to move in tandem with a consistently high rate of Cedi depreciation, highlighting the pressure on the currency from the country's international transactions.

**Figure 2.** Balance of payment and cedi depreciation rate



**Source:** World Bank, 2023.

Figure 3 provides further insight into the trade imbalance, illustrating a progressively widening gap between import demand and export earnings. The data shows a steady increase in the value of imports that is not matched by a commensurate growth in export revenues, creating a chronic shortfall of foreign exchange.

**Figure 3.** Relationship between import demand and export earnings.

Source: Ghana Statistical Service, 2023.

The data in **Table 6** highlights a significant and sustained inflation differential between Ghana and its major trading partners. Ghana's domestic inflation rate has consistently remained several percentage points above the average of its partners, eroding the Cedi's international purchasing power and contributing to its depreciation.

**Table 6.** Inflation and interest rate differentials

| Year | Ghana Inflation Rate (%) | Average Inflation Rate of Trading Partners (%) | Cedi Depreciation Rate (%) |
|------|--------------------------|------------------------------------------------|----------------------------|
| 2015 | 17.2                     | 3.5                                            | 15.5                       |
| 2016 | 15.4                     | 2.8                                            | 18.7                       |
| 2017 | 12.4                     | 2.3                                            | 13.2                       |
| 2018 | 11.6                     | 2.7                                            | 14.5                       |
| 2019 | 9.8                      | 2.5                                            | 17.9                       |
| 2020 | 10.4                     | 1.8                                            | 18.1                       |
| 2021 | 11.0                     | 2.2                                            | 19.4                       |
| 2022 | 12.3                     | 3.0                                            | 21.5                       |
| 2023 | 13.6                     | 2.9                                            | 22.8                       |
| 2024 | 14.5                     | 2.8                                            | 20.3                       |

Source: Bank of Ghana, 2024.

**Table 7.** External debt and debt servicing

| Year | External Debt (USD Billion) | Debt Servicing Costs (USD Billion) | Cedi Depreciation Rate (%) |
|------|-----------------------------|------------------------------------|----------------------------|
| 2015 | 22.3                        | 1.5                                | 15.5                       |
| 2016 | 25.4                        | 1.8                                | 18.7                       |
| 2017 | 28.0                        | 2.1                                | 13.2                       |
| 2018 | 30.5                        | 2.5                                | 14.5                       |
| 2019 | 32.8                        | 2.7                                | 17.9                       |
| 2020 | 34.5                        | 3.0                                | 18.1                       |
| 2021 | 36.9                        | 3.3                                | 19.4                       |
| 2022 | 39.2                        | 3.6                                | 21.5                       |
| 2023 | 41.0                        | 3.9                                | 22.8                       |
| 2024 | 42.5                        | 4.1                                | 20.3                       |

Source: International Monetary Fund, 2024.

**Table 7** demonstrates the escalating burden of external debt on the Ghanaian economy. Both the total debt stock and the annual debt servicing costs have shown a clear upward trend, which increases the demand for foreign currency and places additional depreciatory pressure on the Cedi.

Beyond fundamentals, market sentiment also plays a role, as indicated in **Figure 4**. The volume of speculative trading in the foreign exchange market shows a rising trend, particularly intensifying during periods of heightened Cedi depreciation, suggesting that negative market expectations can become self-fulfilling.

**Figure 4.** *Speculative attacks and market sentiment*



**Source:** Ghana Stock Exchange, 2024.

**Table 8** provides a snapshot of the structural dynamics within Ghana's petroleum market. The data indicates a growing dependency on imports, coupled with a decline in local refining capacity. This increased exposure to global markets, alongside a significant expansion in the number of marketing companies, has culminated in a dramatic increase in the domestic retail price of fuel.

**Table 8.** *Structure and dynamics of the petroleum market in Ghana*

| Aspect            | Key Indicator                                  | Data Point (Pre-2020) | Data Point (2023) | Percentage Change (%) | Reference                                                                      |
|-------------------|------------------------------------------------|-----------------------|-------------------|-----------------------|--------------------------------------------------------------------------------|
| Market Structure  | Number of Petroleum Marketing Companies (PMCs) | 40                    | 54                | +35.0                 | (National Petroleum Authority, 2023a, 2023b)                                   |
| Refining Capacity | Local Refining Capacity (Barrels per Day)      | 45,000                | 30,000            | -33.3                 | (National Petroleum Authority, 2023a, 2023b; Energy Commission of Ghana, 2023) |
| Import Dependency | Import Dependency for Petroleum Products (%)   | 75.0                  | 85.0              | +13.3                 | (Energy Commission of Ghana, 2023)                                             |
| Market Dynamics   | Retail Price of Gasoline (GHS/Liter)           | 4.5                   | 12.0              | +166.7                | (Ghana Statistical Service, 2023)                                              |

**Source:** National Petroleum Authority, 2023a, 2023b.



## 4.2. Discussion

This study aimed to address a significant gap in the existing literature by providing a comprehensive and dynamic analysis of the complex relationship between the declining value of the Ghanaian Cedi and increases in petroleum prices. Building upon established research (e.g., Agyapong et al., 2025; Attilio & Mollick, 2025), the study moved beyond static analysis to model the long-run equilibrium and short-run dynamics governing this nexus. The results of the time-series econometric analysis provide compelling empirical evidence of a strong, positive, and statistically significant relationship between the depreciation of the Ghanaian Cedi, inflation, and petroleum prices. These findings are not merely statistical artifacts but reflect deep-seated structural vulnerabilities within the Ghanaian economy, confirming the existence of a persistent and damaging cycle.

The core finding is the confirmation of a stable, long-run equilibrium relationship between the exchange rate, petroleum prices, and inflation, as established by the Johansen cointegration test. This implies that these variables are bound together over the long term. The long-run model quantifies this relationship, revealing that petroleum price hikes have a more pronounced long-term impact on Cedi depreciation than general inflation does. The Vector Error Correction Model (VECM) further illuminates this dynamic by distinguishing short-run effects from this long-run path. The statistically significant Error Correction Term (-0.215) is a key finding, indicating that when shocks push the economy away from this equilibrium, the system self-corrects at a moderate pace of 21.5% per month. While this confirms a stable system, the adjustment speed is not immediate, allowing for prolonged periods of currency pressure and economic hardship following a shock. The dynamic analysis reinforces this, with the Forecast Error Variance Decomposition showing that after 24 months, shocks to petroleum prices account for a substantial 38.2% of the volatility in the Cedi's exchange rate. This empirically establishes petroleum prices as the single most critical external driver of currency instability in Ghana over the medium to long term.

The vulnerability of the Cedi, so clearly quantified by the VECM, is rooted in deep-seated structural weaknesses. As shown in the supplementary data, Ghana has run a persistent Balance of Payments deficit for the last decade, a direct consequence of its chronic trade imbalance where import demand consistently outstrips export earnings. This structural deficit creates a constant, high demand for foreign currency, principally the US Dollar, to pay for imports, thus exerting continuous downward pressure on the Cedi (Aladejare and Musa, 2024; Ibrahim and Abonongo, 2024; Krugman and Obstfeld, 2020). This vulnerability is further highlighted by studies on commodity price shocks and dependency (Boakye et al., 2024; Chen et al., 2024a, 2024b; Conteh, 2024; Wanzala and Obokoh, 2024). The country's high and rising external debt stock exacerbates this problem. As debt service costs increase, a larger portion of foreign exchange earnings must be diverted to repay creditors, further limiting the supply of foreign currency available for imports and other needs (Dávid and Afadzinu, 2024; IMF, 2024; Saani et al., 2024; Seidu and Vasilev, 2024). This is consistent with the findings of Baah et al. (2025) and Omane-Adjekum et al. (2024) regarding public debt's impact on currency stability.

The socioeconomic consequences of this dynamic are severe and widespread. The dramatic increase in the retail price of gasoline directly translates into a higher cost of living. This is reflected in the data on household welfare, which shows that currency depreciation leads to a significant increase in the poverty rate, a decline in disposable income, and a sharp rise in household expenditure (see Supplementary Table S4). These impacts align with findings from the World Bank (2022a, 2022b) and the International Energy Agency (2023), which emphasize the regressive nature of high energy prices (Ahiadorme and Akoto, 2025; Akoto and Tetteh, 2020; Alnaa and Matey, 2024; Amoah Osei et al., 2024; Asiamah, 2024; Chima et al., 2024; Leshoro, 2024; Lopes, 2024). For businesses, particularly SMEs, the effects are crippling (Ghanaian Chamber of Commerce, 2023). Rising fuel and raw material costs, coupled with diminished consumer purchasing power and reduced access to credit, lead to lower profit margins and a significant increase in business closures (see Supplementary Table S5). These microeconomic struggles are mirrored at the macroeconomic level, with data indicating a slowdown in GDP growth, a rise in unemployment, and a worsening trade balance following periods of sharp depreciation (see Supplementary Table S6). The broader macroeconomic impact of oil price changes on economic growth has been extensively studied, as seen in Mbwambo et al. (2024) and Peprah et al. (2024).

This study, while providing robust empirical insights, is subject to certain limitations that open avenues for future research. Its focus on a specific set of quantitative variables means that it does not capture the influence of qualitative factors such as political governance, institutional quality, and market psychology, which can also significantly impact currency movements. While the VECM is a powerful tool, it may be subject to omitted variable bias if other significant macroeconomic variables are not included. Furthermore, the model assumes linear relationships; however, the pass-through from petroleum prices or inflation to the exchange rate may be asymmetric, behaving differently during periods of economic expansion versus contraction.

Consequently, future work should aim to build upon this framework. An expanded VECM or a Structural VAR (SVAR) model could be developed to incorporate additional variables, such as fiscal deficits, monetary policy rates, and global financial conditions, to provide a more holistic view of the drivers of Cedi depreciation. To address the potential for non-linearity, future research could employ more advanced econometric techniques, such as Threshold VAR or Markov-switching models, to investigate whether these relationships change under different economic regimes. Finally, incorporating qualitative methods to explore the roles of governance and institutional factors, alongside comparative analyses with other sub-Saharan African economies facing similar challenges, could yield valuable policy insights for achieving long-term macroeconomic stability and sustainable development.

## 5. Conclusions

This study provides robust empirical evidence of a stable long-run equilibrium relationship binding the Ghanaian Cedi, domestic petroleum prices, and inflation into a cycle of economic instability. The findings from the Vector Error Correction Model (VECM) move

beyond simple correlation to demonstrate that while these variables fluctuate in the short term, they are fundamentally tethered together. This long-run vulnerability is underpinned by deep-seated structural weaknesses, primarily persistent balance of payments deficits, high import dependency, and a burdensome external debt profile. The pass-through from a weaker Cedi to higher fuel prices, as quantified in the model's dynamic analysis, serves as a primary channel for fueling inflation, eroding household purchasing power, increasing business costs, and ultimately constraining GDP growth and exacerbating poverty. The findings therefore underscore the urgent need for a multi-faceted policy response that addresses both immediate pressures and long-term fragilities. In the short term, the moderate speed of adjustment back to equilibrium implies that shocks have a lingering and damaging effect. Therefore, proactive short-term measures are critical, including prudent monetary and fiscal policies to stabilize the currency and strengthen foreign exchange reserves. In parallel, targeted social safety nets are required to cushion the most vulnerable households from the immediate impact of rising living costs. In the long term, the only sustainable solution is to alter the fundamentals of this damaging equilibrium. This requires a concerted and sustained effort to address the economy's structural weaknesses through economic diversification, enhancing local production to reduce import dependency, and pursuing sustainable energy policies. Looking ahead, future work should build on this framework to provide an even more granular understanding of these dynamics. Research could employ more advanced econometric techniques, such as non-linear or threshold models, to investigate whether these relationships change during periods of high versus low volatility. Furthermore, future studies should aim to integrate qualitative methods to explore the crucial roles of governance, institutional quality, and market sentiment, which are not captured in quantitative models alone. Such comprehensive research will be vital for developing more nuanced, context-specific policy recommendations aimed at achieving lasting macroeconomic stability and sustainable development in Ghana and other similarly affected economies.

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## **Effects of climate change on food security and sustainable development in Saudi Arabia: Autoregressive Distributed Lag approach**

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**Abstract.** *This study examines the influence of climate change on Food security and sustainable development in Saudi Arabia from 1981 to 2022 using ARDL approach. Through the ecological footprint, alongside rainfall, population, agricultural growth, and GDP per capita. The results show a consistent negative impact of climate change on Food security in both the short and long run. Specifically, a 1% increase in the ecological footprint leads to a significant decline in Food security, confirming long-term structural vulnerabilities. These findings highlight the need for climate-resilient agricultural policies and sustainable resource management aligned with Saudi Vision 2030.*

**Keywords:** climate change, ecological footprint, food security, Saudi Arabia, Sustainable Development.

**JEL Classification:** Q54, Q56, Q18, O13, Q15.

## I. Introduction

According to the World Economic Forum, climate change is a major global threat. Global temperatures have climbed by 1.2 degrees Celsius, and this warming trend is accelerating alarmingly. Scientists predict that temperatures could rise by approximately 5 degrees Celsius by the end of this century. Global temperatures are soaring at an alarming rate, with projections of a significant rise by the end of the century. This warming trend has far-reaching consequences impacting agriculture, the economy, and various aspects of human life (Zhang et al., 2024).

Climate change is already having a devastating impact on Saudi Arabia. Studies indicate that the Kingdom will face catastrophic climate consequences if it continues its current high-emissions trajectory. Without urgent action, agricultural droughts are projected to increase by 88% by 2050, heatwaves will become more frequent and prolonged by 4.242%, and the combined effects of sea-level rise, coastal erosion, and extreme weather events will disrupt the Saudi economy significantly, leading to an estimated 12.2% loss in GDP by 2050. However, the sooner Saudi Arabia adopts low-carbon policies, the less severe and manageable the climate impacts will become. Limiting global warming to 2 degrees Celsius would reduce the cost of climate impacts on Saudi Arabia to just 4.8% of its GDP by 2050 and 0.78% by 2100 G20 Climate Risk Atlas, 2021.

According to the Climate Transparency Report 2020, Saudi Arabia would need to reduce its emissions to below 389 MtCO<sub>2</sub>e by 2030 and to below 263 MtCO<sub>2</sub>e by 2050 to be within its emissions allowances under a 'fair-share' range compatible with global 1.5°C. The country's 2030 NDC range of 1,105-861 MtCO<sub>2</sub>e by 2030 is critically insufficient. All figures exclude land use emissions and are based on pre-COVID-19 projections (Climate Transparency Report, 2020). So Saudi Arabia aims to reduce, avoid, and remove greenhouse gas emissions by 278 million tons of CO<sub>2</sub> equivalent annually by 2030 and achieve net-zero emissions by 2060<sup>(1)</sup>.

The Ecological Footprint, a concept developed in 1990 by Mathis Wackernagel and William Rees at the University of British Columbia, has evolved into a broader framework for assessing our impact on the planet. Crucially, the framework focuses on National Footprint and Biocapacity Accounts, which assess the ecological demands of nations against their available resources. Since 2019, these accounts have been managed by the Footprint Data Foundation (FoDaFo)<sup>(2)</sup>, an independent organization, with ongoing support from York University<sup>(3)</sup>. This includes the Carbon Footprint, which measures the carbon dioxide emissions associated with the use of fossil fuels. In ecological footprint accounting, these quantities are converted into the biologically productive areas needed to absorb this carbon dioxide. The carbon footprint is added to the ecological footprint because it represents a competing use of biologically productive space, as increasing carbon dioxide concentrations in the atmosphere represents an accumulation of ecological debt. And other indicators such as (Built-up Land, Cropland, Grazing Land, Forest Land, Fishing Ground). Now widely adopted by scientists,

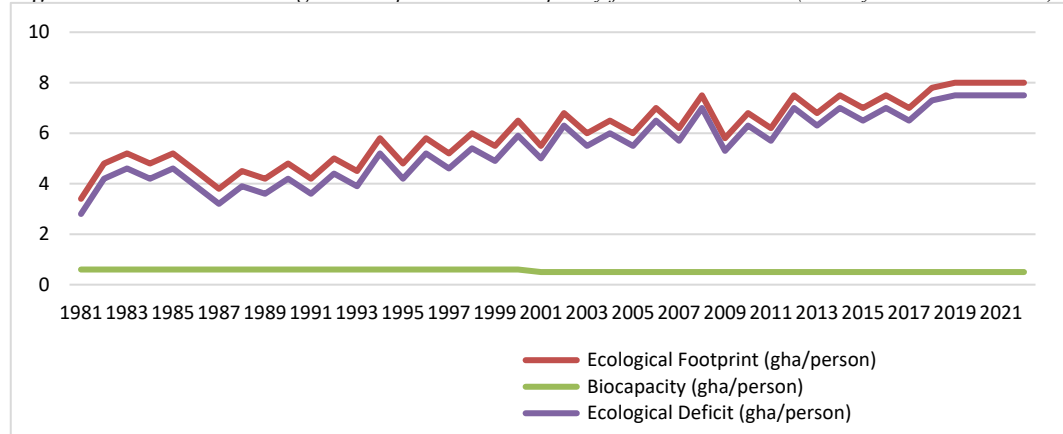
businesses, and governments, the Ecological Footprint helps track our resource consumption and guides sustainable development efforts<sup>(4)</sup>.

The Ecological Footprint measures our strain on the planet by calculating the demand for biologically productive land and water to support human activities. This includes the land needed to produce food, fiber, and absorb waste like carbon dioxide. When our demand exceeds the planet's ability to regenerate these resources, we create an ecological debt. Biocapacity, on the other hand, represents the planet's ability to replenish these resources. The Ecological Footprint is the sole metric that quantifies both our planet's available natural resources and our current consumption. It provides valuable insights for Countries To enhance sustainability and improve overall well-being. Local Leaders To optimize public project investments by considering their environmental impact. Also, Individuals To understand their personal ecological footprint and how their actions affect the planet<sup>(5)</sup>.

Both the Ecological Footprint and biocapacity are measured in global hectares – standardized units reflecting global average productivity. This allows for comparisons between the Ecological Footprint of any city, state, or nation and its own biocapacity or that of the entire planet. When a population's Ecological Footprint surpasses its region's biocapacity, it creates a biocapacity deficit. This means the demand for resources like food (fruits, vegetables, meat, fish), timber, and the absorption of carbon dioxide exceeds what the local ecosystems can sustainably provide. To meet this demand, the region must resort to imports, deplete its own natural resources (overfishing, deforestation), or emit excessive carbon dioxide into the atmosphere. Conversely, a region with a biocapacity that exceeds its Ecological Footprint possesses a biocapacity reserve<sup>(6)</sup>.

Saudi Arabia is the largest country in the Arabian Peninsula, with a coastline extending approximately 1,760 kilometers along the Red Sea and 560 kilometers along the Arabian Gulf, encompassing more than 1,000 islands and over 7,000 kilometers of total coastline. Most of the coastline is bordered by the Arabian Desert or mountains, particularly along the southern portion of the Red Sea coast. The coastline is a diverse mix of sandy and rocky shores, with extensive coastal plains in the Arabian Gulf region<sup>(7)</sup> and characterized by a desert climate with extremely hot days and cold nights, with the exception of the 'Asir region on the western coast, which has a semi-arid climate and a small area with a humid and mild temperature, with a long summer in the highlands north of Yemen.

In this country, the Ecological Footprint (EFP) indicator highlights the country's environmental impact and resource consumption. According to recent studies, Saudi Arabia's EFP is 5.7 global hectares per person, while its biocapacity is only 0.7 global hectares per person, indicating an ecological deficit of 5% in 2022. This means that Saudi Arabia's demand for resources and services exceeds its own biocapacity, leading to environmental degradation.

**Figure 1.** Saudi Arabia Ecological Footprint and Biocapacity from 1981 to 2022 (last 3 years are estimates)

**Source:** National Footprint and Biocapacity Accounts 2023 edition (Data Year 2019).

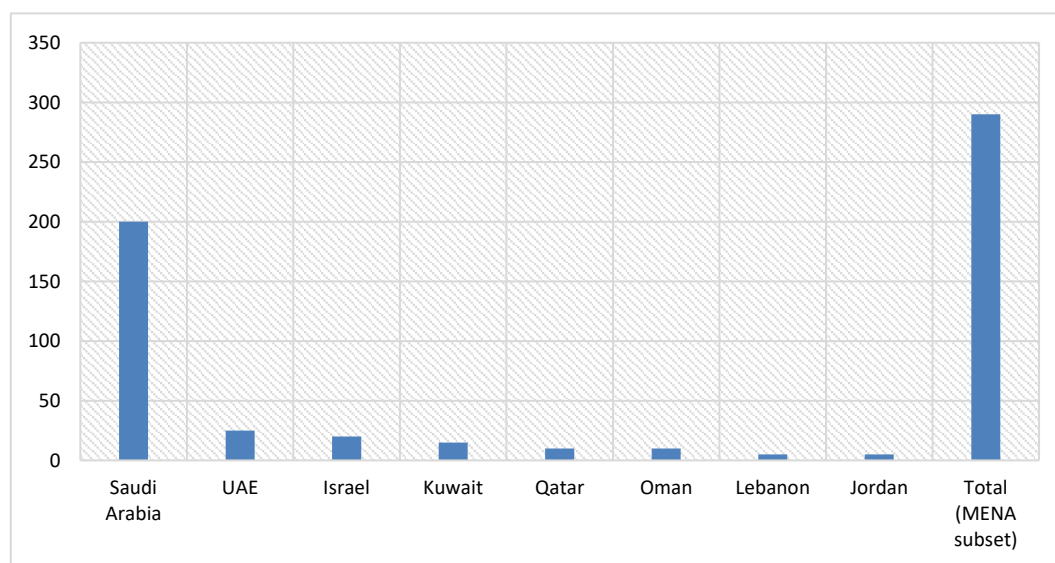
It is clear from the previous figure that Ecological Footprint Consumption Per Capita (EFConsPerCap) for Cropland recorded 0.827 hectares in 1981, while Biocapacity Per Capita (BiocapPerCap) for Cropland for the same year was 0.199 hectares. EFConsPerCap for Grazing Land recorded 0.353 gha, while BiocapPerCap for Grazing Land was 0.136 gha. EFConsPerCap for Forest Products was also 0.146 gha, while BiocapPerCap for Forest Products was 0.125 gha. This shows a decrease in the biocapacity of Cropland, Grazing Land, and Forest Products compared to the individual's ecological footprint for each. However, this decrease was within narrow limits and to a small extent, as carbon levels in the Saudi Arabian atmosphere were 1.42 in 1981, the lowest value. With the increase in carbon levels in the Saudi atmosphere during the period (1981-2022), the biocapacity of Cropland, Grazing Land, and Forest Products decreased, as it was estimated at 0.370, 0.093 and 0.049 gha, respectively, in 2022. This indicates a deterioration in the ability to regenerate resources that would preserve and support food security in the Kingdom as an inevitable result of the population increase, estimated at 36,408,800 people in 2022. Unsustainable human activities also contributed to the increase in carbon emissions, which reached 4.466 by 2022, which led to an increase in the ecological footprint of Cropland, Grazing Land, and Forest Products, which was estimated at 0.822, 0.192, and 0.151 gha, respectively, for the same year. This led to an increase in the overall ecological footprint for Saudi Arabia during 2022 to 5.7 gha per capita, while BiocapPerCap reached 0.697 gha, constituting a deficit of -5 gha. This danger threatens the Kingdom's resources and food security and affects the future of its development projects. Therefore, the Kingdom should move towards alternative strategies to reduce the ecological footprint and carbon emissions.

Studying the ecological footprint of Middle East and North African countries in 2022 revealed that Saudi Arabia has the highest resource demand, with a total resource demand of 209,186,031.9 gha. Its per capita resource demand was 5.75 gha. In contrast, Algeria's total resource demand was 99,818,395.88 gha, with a per capita demand of 2.22 gha, followed by the United Arab Emirates with approximately 82,277,817.42 gha and a per capita demand of 8.71 gha. Morocco followed with 57,882,655.39 gha and a per capita



demand of 1.55 gha. Jordan had the lowest resource demand among these countries, with 14,715,156.98 gha and a per capita demand of 1.3 gha. This contrasts with the per capita biocapacity, which represents the average amount of biologically productive land and water area available to each person within a given population to meet resource demands and absorb waste. It is a measure of the environment's capacity to regenerate the resources people use and absorb waste products.

**Figure 2.** *Ecological Footprint and Biocapacity for MENA in 2022*



**Source:** <https://data.footprintnetwork.org/#/compareCountries?type=BCpc&cn=2022>

While Oman emerged as the first country with about 1.8 gha in its inability to meet the local demand for resources by the population and achieve self-sufficiency and food security, followed by Qatar with 1.04 gha, then Kuwait with 0.81 gha, the Libyan Arab Jamahiriya with 0.77 gha, Tunisia with 0.72 gha, and then Saudi Arabia with about 0.7 gha, which illustrates the magnitude of the gap in the ability to achieve self-sufficiency of resources, as the per capita share of resource demand was 5.75 gha, and that there is a negative gap of -5 gha. Among the Arab countries that also have a negative gap in achieving adequacy of resources to meet the volume of local demand is Qatar, which is the first in terms of per capita demand for resources with about 13.13 gha, while the per capita biocapacity (the country's ability to meet individual demand) is 1.04 gha, which represents a very large gap that requires addressing to achieve self-sufficiency of food.

Several factors contribute to this situation:

- *Economic Development:* Saudi Arabia's economy is heavily reliant on fossil fuels, which has led to significant greenhouse gas emissions. The country's GDP was \$1.11 trillion USD in 2022, with a high urbanization rate of 84%.
- *Greenhouse Gas Emissions:* Greenhouse gas emissions in Saudi Arabia rose from 466.494 million tons of CO<sub>2</sub> equivalent per year (Mt CO<sub>2</sub>eq/yr) in 2005 to 810.512 Mt CO<sub>2</sub>eq/yr in 2022.

- *Renewable Energy*: Studies have shown that increasing renewable energy consumption can improve environmental quality by reducing the ecological footprint. However, the current reliance on fossil fuels continues to contribute to environmental degradation.
- *Policy Implications*: Policymakers are encouraged to implement measures that reduce the ecological footprint and improve environmental quality with renewable energy and sustainable practices.

These factors highlight the need for sustainable development strategies to address the ecological footprint in Saudi Arabia. In this context, the Saudi government has adopted ambitious policies to transition towards a more sustainable and resilient economy. A key initiative is the Vision 2030 program, which prioritizes economic diversification, renewable energy expansion, and environmental conservation. The country is heavily investing in solar and wind energy projects, such as the NEOM city project and Sakaka Solar Plant, to reduce dependence on fossil fuels. Additionally, the Saudi Green Initiative aims to combat desertification and lower carbon emissions by planting 10 billion trees and expanding protected natural areas. To meet international climate commitments, Saudi Arabia has pledged to achieve net-zero carbon emissions by 2060, aligning with global efforts to mitigate climate change.

Furthermore, policy interventions focus on enhancing food security and optimizing natural resource management. Given its high dependence on food imports and limited freshwater resources, Saudi Arabia is promoting innovative agricultural practices, such as vertical farming, hydroponics, and seawater desalination for irrigation. Investments in advanced water management technologies and policies encouraging sustainable consumption patterns are also being implemented to reduce the ecological footprint. The government is actively fostering international partnerships to secure food supply chains and develop sustainable agricultural projects abroad. These integrated strategies aim to ensure long-term economic stability, environmental protection, and food security while minimizing the country's ecological deficit.

Given the above, the paper is structured as follows: After introduction, Section 2 provides a literature review; Section 3 presents the data and the empirical model; Section 4 outlines the methodology; Section 5 covers the results and discussion, and Section 6 concludes the paper.

## II. Literature Review

Saudi Arabia's water security has been the subject of extensive international research, with numerous studies exploring the link between climate change and water scarcity in the country. For instance, studies by (John et al., 2024), (DeNicola et al., 2015), and (Almazroui et al., 2017:pp11–23) have delved into this issue. Similarly, a substantial body of research examines the broader impacts of climate change on Saudi Arabia. In contrast, the focus on food security in Saudi Arabia within the context of climate change has been relatively limited. While studies by (Baig et al., 2019:pp1743–1752), (Fiaz et al., 2018:pp365–375), (Kajenthira Grindle et al., 2015:pp 67–78), and (Haque & Khan,

2020:pp1-18) have touched on this topic, the depth and breadth of research in this area falls short of that on water security. In the following sections, we will review these studies and explore additional literature that examines the relationship between climate change and food security in other countries.

Numerous studies have demonstrated that climate change has far-reaching and multifaceted impacts, affecting various sectors, including agriculture, energy, the economy, finance, food security society, politics, and human health (John et al., 2024) (Goli et al., 2024) ; (Wang et al., 2024). Climate change is affecting low-income countries, emerging markets, and advanced economies (Toiba et al., 2024).

(Ceesay & Ben Omar Ndiaye, 2022: pp. 1-11) study empirically examined the causal relationship between climate change, rainfall variability, food security, economic growth, population growth, and the agricultural sector. Utilizing data from the World Development Indicators (WDI) spanning 1971-2020 in the Gambia, the study employed a suite of econometric techniques, including Vector Autoregression (VAR), Granger causality, Autoregressive Distributed Lag (ARDL), and Error Correction Model (ECM). The findings revealed a strong positive correlation between food security growth and the agricultural sector, while a negative correlation was observed between food security and rainfall variability. Furthermore, population growth exhibited a significant negative short-term impact on food security, though this long-term impact was found to be insignificant. Based on these results, the study recommends that the Gambian government prioritize initiatives such as afforestation to enhance agriculture and the environment, food security intervention programs, poverty reduction efforts, the development of adaptive capacity indicators, equitable access to quality education, systemic changes to improve governance, institutions, and inclusive economic growth, and consideration of export-oriented economic strategies.

Previous studies by( Khurshid & Abid, 2024 ) underscore the significant threat of climate change to food security, primarily through its impact on crop yields and food availability. Short-term fluctuations induced by climate change and global politics can disrupt the stability of entire food systems. Conducted in Pakistan using a time series spanning from 1981 to 2021, employed the Nonlinear Autoregressive Distributed Lag (NARDL) model to examine the asymmetric effects of political globalization (proxied by political globalization) and environmental change (proxied by CO<sub>2</sub> and mean temperature) on food security. The findings indicated an asymmetric impact of mean temperature (MT), CO<sub>2</sub> emissions, and political globalization (POLG) on food security. While CO<sub>2</sub>\_POS, CO<sub>2</sub>\_NEG, MT\_POS, and MT\_NEG exhibited a positive relationship with food security, POLG\_POS and POLG\_NEG displayed a negative correlation.

While (Habtie et al., 2024:pp 1-20) study conducted in Tigray, Ethiopia, over three periods (1983-2015, 2011-2014, and 2016-2019) using data from the Ethiopia Rural Socioeconomic Survey (ERSS), revealed that rising temperatures have led to an 85.53% increase in drought frequency and threaten the welfare of the population by 23%. Moreover, the study concluded that climate change is a tangible reality and a significant

risk in Tigray, posing a threat to the lives and livelihoods of farming communities. The study recommends enhancing the adaptive capacity of farm households through improved livelihood options, fostering cooperation, developing irrigation schemes, and increasing access to weather and climate information.

The study by (Meierrieks & Stadelmann, 2024 ) established a negative correlation between rising temperatures and regional economic development. Analyzing over 1,500 regions across 152 countries from 1990 to 2017, they employed panel data and a long-difference approach. The findings indicate that elevated temperatures exert a significant long-term adverse effect on regional per capita income, reaching a 1% significance level. This detrimental impact is attributed to the negative consequences of higher temperatures on labor productivity and human capital development, which ultimately obstruct economic growth.

Furthermore, (John et al.,2024 ) study focuses on testing the causal relationship between climate change and food security in the Economic Community of West African States (ECOWAS) region over the period from 1986 to 2022. Departing from previous studies, this research incorporates the Dumitrescu-Hurlin Panel Causality test, Pooled Mean Group (PMG), Common Correlated Effect Mean Group (CCEMG), Augmented Mean Group (AMG), and Cross-Sectional Augmented Autoregressive Distributed Lag (CS-ARDL) techniques to analyze the complex relationship between climate change and food security in the ECOWAS region. Unlike prior empirical studies, the findings reveal a robust mutual influence between climate change and food security in the ECOWAS region. The study relied on six key variables: food security (FS), climate change (EFP), agricultural value added (AVA), cropland area (CLA), rainfall (RF), drought (ASI), and population growth (POP). Results indicated a positive impact of climate change on food security, facilitated by increased cropland area and population growth. However, drought incidence and erratic rainfall between July and September remained a significant concern in the region. While the conversion of forests and natural habitats into cropland in the sub-region can lead to heightened carbon emissions and reduced ecosystem services, policy recommendations advocate ECOWAS policymakers to carefully balance the benefits of food security through sustainable practices and environmental considerations to ensure long-term food security benefits.

As (Haque & Khan ,2020:pp 1-18 ) study aimed to investigate the impact of climate change trends in temperature and rainfall on major crop production in Saudi Arabia over the period 1967-2016. By employing variables such as rainfall, temperature, and major crop yields in the Kingdom, the study establishes an empirical association between crop yields and climatic variables using a fixed-effects regression framework. This approach enables the capture of time-invariant factors and farmers' independent adaptation strategies in response to year-to-year variations in precipitation and temperature. The findings reveal a substantial increase of 1.9 degrees Celsius in the average temperature over the past 50 years, with the most significant rise occurring in the summer months. However, no considerable change in rainfall was observed. Results indicate that a one-degree Celsius increase in temperature

leads to a 7-25% reduction in crop yields. While rainfall exhibits a positive impact on all crops, it is insufficient to offset the adverse effects of temperature. Consequently, the Kingdom must develop a roadmap for future food, water, and nutritional security to mitigate the potential impacts of global shocks arising from climate change or geopolitical instability. (ARDL)

Like previous studies, (Rahman et al., 2022:pp1-19) confirmed the existence of a causal relationship between climate change and food security in Saudi Arabia. The primary objective of this study was to investigate the causal relationship between climate change and food security in Saudi Arabia. Given the significant impact of climate variability and extreme weather events on the country's vulnerable food system, and the unique challenges faced by Saudi Arabia compared to other arid regions, the study conducted a causality analysis. This analysis examined various driving factors, including temperature (tem), greenhouse gas emissions (GHG), population (pop), and gross domestic product (GDP), that contributed to vulnerabilities in the food system from 1990-2019. The results of the long-run causality test revealed a positive causal relationship between GDP and food demand, indicating that as GDP increases, too will food demand in the long run. Additionally, the study found that Saudi Arabia's GDP growth and population growth are contributing factors to the increase in total GHG emissions. Despite the Kingdom's efforts to combat climate change, there remains ample opportunity to implement strategies that ensure the nation's food security.

Furthermore, (Baig et al., 2019:pp1743–1752 ) study was to investigate the issue of food waste in Saudi Arabia, a pressing concern for sustainability. The research centered on a comprehensive review of both gray and scientific literature published in English and Arabic on food waste within the Kingdom. Information was gathered from various sources, including Web of Knowledge, online resources, and databases accessible through King Saud University. The study delved into the social, cultural, economic, and environmental impacts of food waste. Given the abundant availability of subsidized food in Saudi Arabia, residents often take food for granted. A recent survey revealed that approximately 78% of purchased food is discarded weekly, highlighting the severity of the issue. Despite limited arable land and scarce water resources, Saudi Arabia, ranking among the top food-wasting countries with an average of 427 kg of food wasted per capita annually, heavily relies on imports and subsidized food to meet its growing population's needs.

In addition, the study by (Fiaz et al., 2018:pp365–375 ) highlighted the critical need for food security in Saudi Arabia, given the inadequacy of domestic production and the heavy reliance on imported grains and red meat. With projections indicating that Saudi Arabia will be entirely dependent on imports by 2050, the study emphasizes the importance of adopting advanced technologies such as promoting traditional crops, hydroponics, greenhouse farming, seawater harvesting, and investing in bio-salinity research and rainwater harvesting. Moreover, the study underscores the need to raise awareness among the farming community to implement guidelines and meet the country's dietary needs.

As highlighted in the study by (Kajenthira Grindle et al., 2015: pp 67–78), the trade of 'virtual water' through agricultural commodities and direct investment in overseas food

production has emerged as an alternative strategy. This approach holds significant potential for enhancing the sustainability of global food production by optimizing the utilization of water, energy, and labor resources. By focusing on overseas food production to meet domestic demand, Saudi Arabia aims to alleviate water scarcity and ensure food security. However, such a shift could have profound implications for local water and energy consumption as well as labor markets while also presenting opportunities for achieving greater sustainability.

A review of the existing literature has revealed several research gaps. What distinguishes this study is threefold, namely:

1. *A methodological gap*: It employs the ARDL model to simulate the effects of climate change on food security and economic growth in Saudi Arabia. This methodological approach enhances the robustness of the research findings.
2. *A variable gap*: The study introduces novel variables not previously explored in the context of Saudi Arabia, including food security (FS), Ecological Footprint (EFP), Biocapacity Per Capita (BPC) agricultural value added (AVA), rainfall (RF), and population growth (POP).
3. *A temporal gap*: The study focuses on the contemporary period to assess the recent impacts of climate change on food security and economic growth in Saudi Arabia. within (1981- 2022).

### III. Data and empirical Model

The study's main objective is to explore how climate change affects food security, economic growth, and growth rate of agriculture sector in Saudi Arabia.

The following models are written as:

$$EFP_t = f(FS_t, RF_t, POP_t, AGR_t, GDPC_t) \quad (1)$$

$$RF_t = f(FS_t, POP_t, AGR_t, GDPC_t) \quad (2)$$

$$FS_t = f(EFP_t, POP_t, AGR_t, GDPC_t) \quad (3)$$

$$GDPC_t = f(RF_t, POP_t, AGR_t, FS_t) \quad (4)$$

In these models, EFP represents the environmental footprint, which measures the pressure exerted on the environment due to economic and social activities. This accounts for all harvest and emission within the country from cropland, grazing land, forest land, marine/inland fishing footprint, built-up land, and anthropogenic emission. FS denotes food security, capturing the availability and accessibility of food in the Saudi Arabic. RF stands for rainfall, which influences agricultural output and water resources. POP represents the total population, reflecting the size of the human resource base and its potential impact on resource consumption and environmental stress. AGR refers to the agricultural sector, which is crucial for food production and rural livelihoods. GDPC represents GDP per capita, used as a proxy for economic well-being and overall productivity.

In the table below, we presented a definition of each variable, along with their respective data sources.

**Table 1.** The definition of each variable

| Name of Variable           | Source           | Comment                                                                   |
|----------------------------|------------------|---------------------------------------------------------------------------|
| GDP per capital (GDPC)     | WDI              | GDP per capita                                                            |
| Agriculture (AGR)          | WDI              | Agriculture value added of \$                                             |
| Food Security (FS)         | WDI              | Food production (food security proxy)                                     |
| Rainfall (RF)              | WB               | Average annual rainfall (climate change proxy)                            |
| Population (POP)           | WDI              | Population                                                                |
| GDP current (GDP)          | WDI              | GDP current \$                                                            |
| ecological footprint (EFP) | Footprintnetwork | Measure using the Global hectares (gha) per capita (climate change proxy) |

**Source:** the authors.

The model mentioned above can be written as follows:

$$\ln(EFP_t) = \beta_0 + \beta_1 \ln(FS_t) + \beta_2 \ln(RF_t) + \beta_3 \ln(POP_t) + \beta_4 \ln(AGR_t) + \beta_5 \ln(GDPC_t) + \epsilon_t \quad (3)$$

$$\ln(RF_t) = \gamma_0 + \gamma_1 \ln(FS_t) + \gamma_2 \ln(POP_t) + \gamma_3 \ln(AGR_t) + \gamma_4 \ln(GDPC_t) + v_t \quad (4)$$

$$\ln(FS_t) = \omega_0 + \omega_1 \ln(EFP_t) + \omega_2 \ln(POP_t) + \omega_3 \ln(AGR_t) + \omega_4 \ln(GDPC_t) + \theta_t \quad (5)$$

$$\ln(GDPC_t) = \varphi_0 + \varphi_1 \ln(FS_t) + \varphi_2 \ln(POP_t) + \varphi_3 \ln(AGR_t) + \varphi_4 \ln(RF_t) + \rho_t \quad (6)$$

where,

$\epsilon_t, v_t, \theta_t, \rho_t$  are the error and  $\beta_0, \gamma_0, \varphi_0, \omega_0$  displays the constant term,

$\alpha_1, \alpha_2, \alpha_3, \alpha_4, \gamma_1, \gamma_2, \gamma_3, \gamma_4, \omega_1, \omega_2, \omega_3, \omega_4, \varphi_1, \varphi_2, \varphi_3, \varphi_4, \rho_1$  are the coefficients.

All the variables are used in log form.

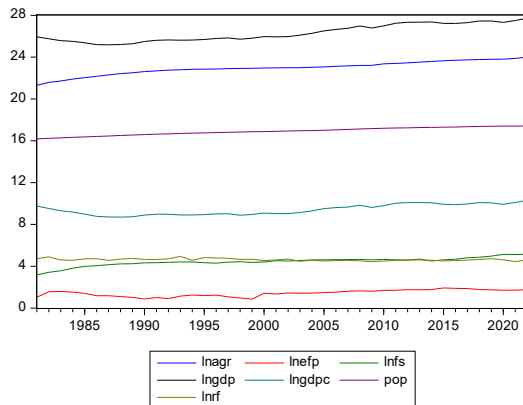
Table 2 and 3 presents summary statistics and correlation between the variables, while Figure 3 displays the plots of these variables.

Based on the summary statistics, it is evident that all variables follow a normal distribution as the Jarque-Bera probability is higher than 1% and 5%.

**Table 2.** Summary statistics

|              | LNAGR     | LNEFP     | LNFS      | LNGDPC   | LNPOP     | LNRF     |
|--------------|-----------|-----------|-----------|----------|-----------|----------|
| Mean         | 22.96307  | 1.433541  | 4.442042  | 9.412571 | 16.90321  | 4.631849 |
| Median       | 22.97490  | 1.459892  | 4.511517  | 9.302554 | 16.92247  | 4.600910 |
| Maximum      | 24.00644  | 1.924697  | 5.151324  | 10.32377 | 17.41032  | 4.950885 |
| Minimum      | 21.30603  | 0.857821  | 3.178054  | 8.699219 | 16.18372  | 4.434500 |
| Std. Dev.    | 0.645943  | 0.310588  | 0.409656  | 0.502511 | 0.368582  | 0.113420 |
| Skewness     | -0.612153 | -0.291545 | -1.001790 | 0.190428 | -0.293524 | 0.754734 |
| Kurtosis     | 2.975042  | 1.853249  | 4.654409  | 1.516536 | 1.948677  | 3.485467 |
| Jarque-Bera  | 2.624208  | 2.896308  | 11.81495  | 4.105006 | 2.537333  | 4.399802 |
| Probability  | 0.269253  | 0.235004  | 0.002719  | 0.128413 | 0.281206  | 0.110814 |
| Sum          | 964.4491  | 60.20872  | 186.5658  | 395.3280 | 709.9349  | 194.5377 |
| Sum Sq. Dev. | 17.10695  | 3.955055  | 6.880537  | 10.35320 | 5.569971  | 0.527428 |
| Observations | 42        | 42        | 42        | 42       | 42        | 42       |

**Source:** the author.

**Figure 3.** Plot of variables

Source: the authors.

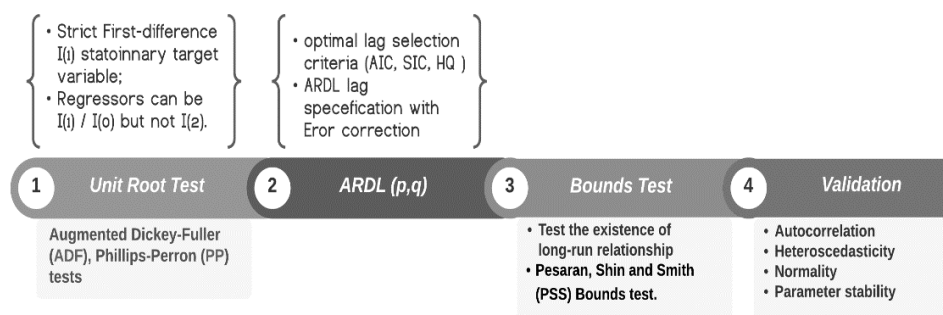
**Table 3.** Correlation matrix

|        | LNAGR     | LNEFP     | LNFS      | LNGDPC    | LNPOP     | LNRF     |
|--------|-----------|-----------|-----------|-----------|-----------|----------|
| LNAGR  | 1.000000  |           |           |           |           |          |
| LNEFP  | 0.586089  | 1.000000  |           |           |           |          |
| LNFS   | 0.956572  | 0.464855  | 1.000000  |           |           |          |
| LNGDPC | 0.629895  | 0.843941  | 0.481742  | 1.000000  |           |          |
| LNPOP  | 0.978761  | 0.687574  | 0.912252  | 0.739532  | 1.000000  |          |
| LNRF   | -0.423307 | -0.485366 | -0.424263 | -0.416054 | -0.494371 | 1.000000 |

Source: the authors.

#### IV. Methodology: the ARDL model approach

Figure below shows stages for modeling the effects of climate change on Food security and economic growth. In the first step, ADF and PP tests are utilized to check variable stationarity and identify integration order. In the second step, we estimated the ARDL model when all variables integrate into I (0) and I (1) to determine short and long-run relationships between variables. The third step, we employed the PSS bound test to ascertain the presence of long-term cointegration among the variables. We employ stability tests to validate the ARDL model during the fourth step.

**Figure 4.** Modeling steps

Source: the authors.



Numerous cointegration techniques exist for analyzing the long-term relationship between macroeconomic variables. (Granger, 1981; Engle & Granger, 1987; Johansen & Juselius, 1990; Johansen, 1995)

Using the cointegration technique developed by Pesaran & Shin, (1995) and Pesaran et al., (2001) has several advantages compared to traditional techniques. First, this approach is suitable for a small sample size. The current study covers 42 annual observations, making it a better fit for this case. In contrast, traditional cointegration approaches require a large sample size and are not valid for a small sample (Narayan & Narayan, 2005). Second, the traditional methods require solving many equations, whereas this approach is easy to use and interpret.

From equations (3), (4), (5), and (6), the ARDL models used in this study can be expressed as:

$$\begin{aligned} \Delta \ln(EFP_t) = & \alpha_0 + \sum_{i=1}^p \tau_i \Delta \ln(EFP_{t-1}) + \sum_{i=1}^p \beta_i \Delta \ln(FS_{t-1}) \\ & + \sum_{i=1}^p \theta_i \Delta \ln(RF_{t-1}) + \sum_{i=1}^p \vartheta_i \Delta \ln(POP_{t-1}) \\ & + \sum_{i=1}^p \delta_i \Delta \ln(AGR_{t-1}) + \sum_{i=1}^p \xi_i \Delta \ln(GDPC_{t-1}) \\ & + \gamma_{EFP} \ln(EFP_{t-1}) + \gamma_{FS} \ln(FS_{t-1}) + \gamma_{RF} \ln(RF_{t-1}) \\ & + \gamma_{POP} \ln(POP_{t-1}) + \gamma_{AGR} \ln(AGR_{t-1}) + \gamma_{GDPC} \ln(GDPC_{t-1}) \\ & + \epsilon_t \end{aligned} \quad (7)$$

Where:

$\tau_i, \beta_i, \theta_i, \vartheta_i, \delta_i, \xi_i$  represent short-run coefficients for each respective lagged differenced variable.

$\gamma_{EFP}, \gamma_{FS}, \gamma_{RF}, \gamma_{POP}, \gamma_{AGR}, \gamma_{GDPC}$  are the long-run coefficients for the levels of each variable.

$\epsilon_t$  is the error term.

$$\begin{aligned} \Delta \ln(RF_t) = & \alpha'_0 + \sum_{i=1}^p \tau'_i \Delta \ln(RF_{t-1}) + \sum_{i=1}^p \beta'_i \Delta \ln(FS_{t-1}) \\ & + \sum_{i=1}^p \vartheta'_i \Delta \ln(POP_{t-1}) + \sum_{i=1}^p \delta'_i \Delta \ln(AGR_{t-1}) \\ & + \sum_{i=1}^p \xi'_i \Delta \ln(GDPC_{t-1}) + \gamma'_{RF} \ln(RF_{t-1}) + \gamma'_{FS} \ln(FS_{t-1}) \\ & + \gamma'_{POP} \ln(POP_{t-1}) + \gamma'_{AGR} \ln(AGR_{t-1}) + \gamma'_{GDPC} \ln(GDPC_{t-1}) \\ & + v_t \end{aligned} \quad (8)$$

Where:

$\tau'_i, \beta'_i, \vartheta'_i, \delta'_i, \xi'_i$  are the short-run coefficients for the differenced lagged variables.

$\gamma'_{FS}, \gamma'_{POP}, \gamma'_{AGR}, \gamma'_{GDPC}$  are the long-run coefficients for the levels of each variable.

$v_t$  is the error term.

$$\begin{aligned} \Delta \ln(FS_t) = & \alpha''_0 + \sum_{i=1}^p \tau''_i \Delta \ln(EFP_{t-1}) + \sum_{i=1}^p \beta''_i \Delta \ln(FS_{t-1}) \\ & + \sum_{i=1}^p \vartheta''_i \Delta \ln(POP_{t-1}) + \sum_{i=1}^p \delta''_i \Delta \ln(AGR_{t-1}) \\ & + \sum_{i=1}^p \xi''_i \Delta \ln(GDPC_{t-1}) + \gamma''_{EFP} \ln(EFP_{t-1}) + \gamma''_{FS} \ln(FS_{t-1}) \\ & + \gamma''_{POP} \ln(POP_{t-1}) + \gamma''_{AGR} \ln(AGR_{t-1}) \\ & + \gamma''_{GDPC} \ln(GDPC_{t-1}) + v'_t \end{aligned} \quad (9)$$

Where:

$\tau''_i, \beta''_i, \vartheta''_i, \delta''_i, \xi''_i$  are the short-run coefficients for the differenced lagged variables.

$\gamma''_{FS}, \gamma''_{POP}, \gamma''_{AGR}, \gamma''_{GDPC}$  are the long-run coefficients for the levels of each variable.

$v'_t$  is the error term.

$$\begin{aligned} \Delta \ln(GDPC_t) = & \alpha_0 + \sum_{i=1}^p \tau'''_i \Delta \ln(GDPC_{t-1}) + \sum_{i=1}^p \beta'''_i \Delta \ln(FS_{t-1}) \\ & + \sum_{i=1}^p \vartheta'''_i \Delta \ln(POP_{t-1}) + \sum_{i=1}^p \delta'''_i \Delta \ln(AGR_{t-1}) \\ & + \sum_{i=1}^p \xi'''_i \Delta \ln(RF_{t-1}) + \gamma'''_{GDPC} \ln(GDPC_{t-1}) \\ & + \gamma'''_{FS} \ln(FS_{t-1}) + \gamma'''_{POP} \ln(POP_{t-1}) + \gamma'''_{AGR} \ln(AGR_{t-1}) \\ & + \gamma'''_{RF} \ln(RF_{t-1}) + v''_t \end{aligned} \quad (10)$$

Where:

$\tau'''_i, \beta'''_i, \vartheta'''_i, \delta'''_i, \xi'''_i$  are the short-run coefficients for the differenced lagged variables.

$\gamma'''_{GDPC}, \gamma'''_{POP}, \gamma'''_{AGR}, \gamma'''_{RF}$  are the long-run coefficients for the levels of each variable.

$v''_t$  is the error term.

## V. Results and Discussion

### 5.1. Unit Root Test

To determine integration order and yield comprehensive results, unit root tests, such as the Phillips-Perron (PP) and Augmented Dickey-Fuller (ADF) tests (Dickey & Fuller, 1981; Perron, 1989), are employed to assess parameter characteristics.

The unit root test findings in Table 4 indicate that the ARDL model can be applied to the analyzed variables—the stationarity and integration order of variables at I(0) and I(1).

**Table 4.** Unit root tests

| Variable | Level.PP     | $\Delta_{PP}$ | Level.ADF    | $\Delta_{ADF}$ | Remark |
|----------|--------------|---------------|--------------|----------------|--------|
| LNAGR    | -4.901364*** | -3.421951***  | -2.129217    | -3.315073***   | I(0)   |
| LNEFP    | 0.591574     | -7.694866***  | 0.386954     | -7.651270***   | I(1)   |
| LNFS     | -4.193823*** | -5.280971***  | -4.666199*** | -5.266462***   | I(1)   |
| LNGDPC   | -4.008823*** | -4.621102***  | -4.036780*** | -4.623999***   | I(0)   |
| LNPOP    | -5.192928*** | -1.679673     | 0.804364     | -1.717137**    | I(0)   |
| LNRF     | -4.306283*** | -15.35334***  | -4.289945*** | -10.61128***   | I(0)   |

**Notes:** Where Level.PP and PP denote the level and first-difference of Phillips-Perron unit root test; Level.ADF and ADF denote the level and first-difference of augmented-Dickey Fuller unit root test;

\*\*\* denotes rejection of the null hypothesis of no unit root at 1% significance level.

\*\* denotes rejection of the null hypothesis of no unit root at 5% significance level.

**Source:** the authors.

### 5.2. Estimation of ARDL Model

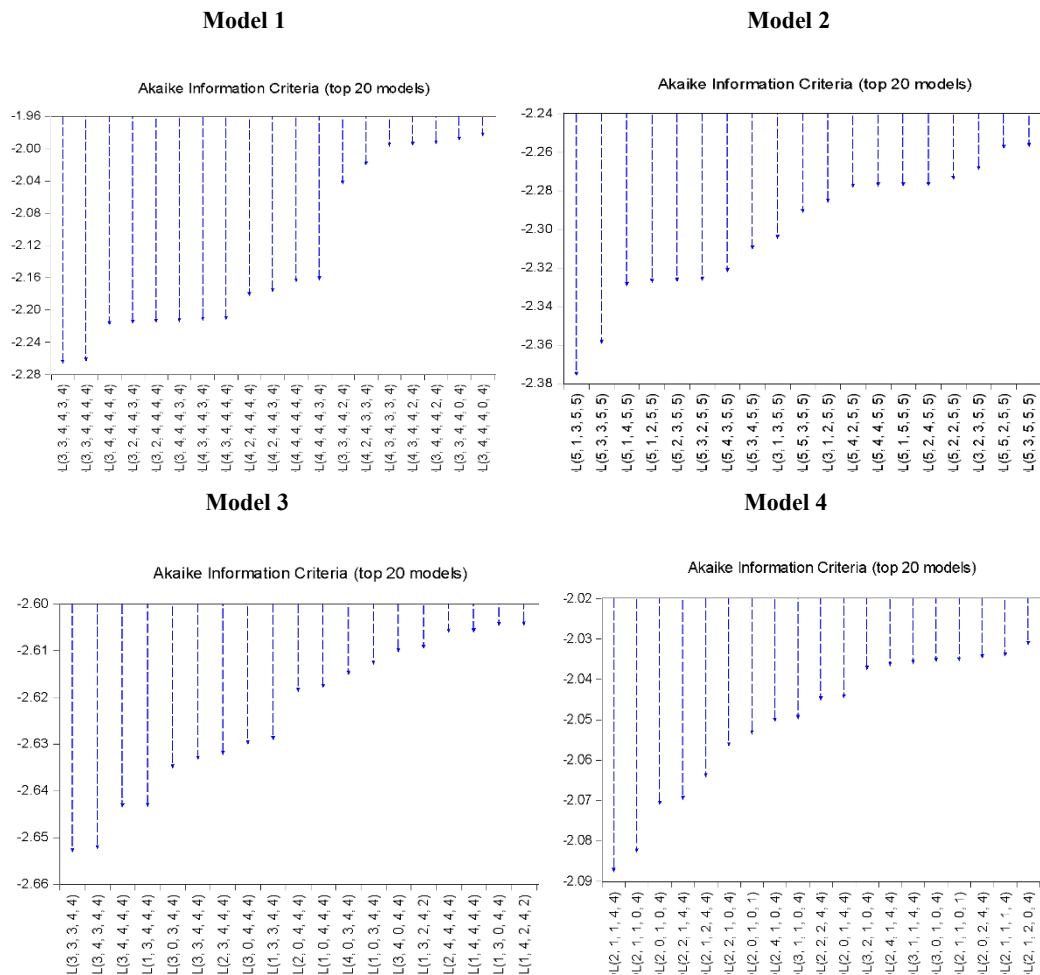
To estimate the ARDL model accurately, choosing the most suitable lag is crucial. This selection is guided by several criteria, including the Akaike Information Criterion (AIC), Hannan-Quinn Information Criterion (HQIC), and Schwarz's Bayesian Information Criterion (SBIC). These criteria serve as essential tools in the modeling process, aiding in determining the optimal lag.

In our case, we selected Schwarz's Bayesian Information Criterion (SBIC) for model selection (Figure \*\*).

#### Co-integration

Table 5 presents the results of the co-integration test between variables using Bounds test. The results indicate that the F-statistic, exceeds the critical values at 1%, 5%, and 10%. Consequently, the null hypothesis is rejected. This conclusion suggests a long-term relationship between variables in both models.

Figure 5. Model selection method: Schwarz criterion (SIC)



Source: the authors.

Table 5. Pesaran, Shin, and Smith Bounds Testing F-Bounds Test

|                       | Test statistic | Lower Bound I (0) | Upper Bound I (1) | Remark                   |
|-----------------------|----------------|-------------------|-------------------|--------------------------|
| F-Statistic (model 1) | 9.159514       | 2.734             | 3.92              | long-run relationship    |
| F-Statistic (model 2) | 4.600063       | 2.893             | 4                 | long-run relationship    |
| F-Statistic (model 3) | 2.012358       | 3.548             | 4.803             | No long-run relationship |
| F-Statistic (model 4) | 6.357034       | 2.56              | 4.913             | long-run relationship    |

Source: the authors.

### Short-Run and Long-Run Coefficient

After confirming the existence of a co-integration relationship through F statistics in the models 1,2 and 4, we can now estimate long-run and short-run elasticity. Table 6 estimates a short-run equation among the variables in each model:

**Table 6.** Short-run estimation equation

| Model 1 Dependent Variable: D(LNEFP) |             |            |             |        | Model 2 Dependent Variable: D(LNRF)    |             |            |             |        |
|--------------------------------------|-------------|------------|-------------|--------|----------------------------------------|-------------|------------|-------------|--------|
| Variable                             | Coefficient | Std. Error | t-Statistic | Prob.  | Variable                               | Coefficient | Std. Error | t-Statistic | Prob.  |
| D(LNEFP(-1))                         | 0.411488    | 0.110191   | 3.734304    | 0.0033 | D(LNRF(-1))                            | 1.563065    | 0.442820   | 3.529795    | 0.0037 |
| D(LNEFP(-2))                         | 0.527671    | 0.105489   | 5.002161    | 0.0004 | D(LNRF(-2))                            | 0.954821    | 0.337824   | 2.826382    | 0.0143 |
| D(LNFS)                              | 0.048351    | 0.183785   | 0.263082    | 0.7973 | D(LNRF(-3))                            | 0.416560    | 0.220674   | 1.887668    | 0.0816 |
| D(LNFS(-1))                          | -0.802556   | 0.172006   | -4.665854   | 0.0007 | D(LNRF(-4))                            | 0.269081    | 0.128372   | 2.096105    | 0.0562 |
| D(LNFS(-2))                          | -0.345868   | 0.172408   | -2.006105   | 0.0701 | D(LNFS)                                | -0.664803   | 0.201770   | -3.294854   | 0.0058 |
| D(LNRF)                              | -0.345084   | 0.152137   | -2.268246   | 0.0444 | D(POP)                                 | -14.10682   | 3.197168   | -4.412287   | 0.0007 |
| D(LNRF(-1))                          | 2.612407    | 0.350441   | 7.454623    | 0.0000 | D(POP(-1))                             | 18.92533    | 5.019198   | 3.770589    | 0.0023 |
| D(LNRF(-2))                          | 1.536794    | 0.263663   | 5.828638    | 0.0001 | D(POP(-2))                             | -5.876945   | 2.976703   | -1.974314   | 0.0700 |
| D(LNRF(-3))                          | 0.604902    | 0.137463   | 4.400484    | 0.0011 | D(LNAGR)                               | 0.156295    | 0.568573   | 0.274890    | 0.7877 |
| D(POP)                               | -7.250597   | 3.554743   | -2.039696   | 0.0661 | D(LNAGR(-1))                           | -2.390675   | 0.877673   | -2.723880   | 0.0174 |
| D(POP(-1))                           | 4.071553    | 6.475937   | 0.628720    | 0.5424 | D(LNAGR(-2))                           | -2.392763   | 0.796707   | -3.003316   | 0.0102 |
| D(POP(-2))                           | 0.014486    | 6.679600   | 0.002169    | 0.9983 | D(LNAGR(-3))                           | -1.795026   | 0.823096   | -2.180822   | 0.0482 |
| D(POP(-3))                           | -13.30083   | 3.915733   | -3.396766   | 0.0060 | D(LNAGR(-4))                           | -1.449324   | 0.463011   | -3.130214   | 0.0080 |
| D(LNAGR)                             | -0.793987   | 0.603193   | -1.316307   | 0.2148 | D(LNGDPC)                              | 0.093283    | 0.120329   | 0.775234    | 0.4521 |
| D(LNAGR(-1))                         | -1.729104   | 0.790214   | -2.188146   | 0.0511 | D(LNGDPC(-1))                          | -0.482121   | 0.168258   | -2.865374   | 0.0133 |
| D(LNAGR(-2))                         | -2.558811   | 0.779116   | -3.284249   | 0.0073 | D(LNGDPC(-2))                          | -0.412238   | 0.192704   | -2.139230   | 0.0520 |
| D(LNGDPC)                            | 0.328651    | 0.112959   | 2.909481    | 0.0142 | D(LNGDPC(-3))                          | -0.438250   | 0.158745   | -2.760709   | 0.0162 |
| D(LNGDPC(-1))                        | -1.115440   | 0.202422   | -5.510454   | 0.0002 | D(LNGDPC(-4))                          | -0.523632   | 0.139891   | -3.743145   | 0.0025 |
| D(LNGDPC(-2))                        | -0.936528   | 0.165498   | -5.658834   | 0.0001 | CointEq(-1)*                           | -3.212347   | 0.519637   | -6.181902   | 0.0000 |
| D(LNGDPC(-3))                        | -0.735599   | 0.176354   | -4.171145   | 0.0016 |                                        |             |            |             |        |
| CointEq(-1)*                         | -1.469580   | 0.147632   | -9.954360   | 0.0000 |                                        |             |            |             |        |
| R2                                   | 0.910828    |            |             |        | R²                                     | 0.892911    |            |             |        |
| Adjusted R2                          | 0.805921    |            |             |        | Adjusted R²                            | 0.785822    |            |             |        |
| DW- stat                             | 2.498903    |            |             |        | DW- stat                               | 2.587920    |            |             |        |
| Model 3: Dependent Variable: D(LNFS) |             |            |             |        | Model 4: Dependent Variable: D(LNGDPC) |             |            |             |        |
| Variable                             | Coefficient | Std. Error | t-Statistic | Prob.  | Variable                               | Coefficient | Std. Error | t-Statistic | Prob.  |
| D(LNFS(-1))                          | -0.056738   | 0.148413   | -0.382300   | 0.7070 | D(LNGDPC(-1))                          | 0.618254    | 0.126550   | 4.885473    | 0.0001 |
| D(LNEFP)                             | 0.011593    | 0.079565   | 0.145703    | 0.8859 | D(LNRF)                                | 0.255756    | 0.104055   | 2.457895    | 0.0228 |
| D(LNEFP(-1))                         | 0.003965    | 0.079558   | 0.049838    | 0.9608 | D(LNFS)                                | -0.625606   | 0.193321   | -3.236096   | 0.0040 |
| D(LNEFP(-2))                         | -0.184994   | 0.083583   | -2.213306   | 0.0408 | D(POP)                                 | 4.556732    | 3.231835   | 1.409952    | 0.1732 |
| D(LNRF)                              | 0.007537    | 0.104915   | 0.071841    | 0.9436 | D(POP(-1))                             | -9.392151   | 5.948699   | -1.578858   | 0.1293 |
| D(LNRF(-1))                          | 0.426742    | 0.135824   | 3.141878    | 0.0059 | D(POP(-2))                             | 13.54038    | 6.491553   | 2.085846    | 0.0494 |
| D(LNRF(-2))                          | 0.263117    | 0.100755   | 2.611459    | 0.0182 | D(POP(-3))                             | -10.77322   | 3.833017   | -2.810636   | 0.0105 |
| D(LNAGR)                             | 0.404642    | 0.440239   | 0.919142    | 0.3709 | D(LNAGR)                               | 2.788585    | 0.513797   | 5.427402    | 0.0000 |
| D(LNAGR(-1))                         | -0.128628   | 0.652139   | -0.197241   | 0.8460 | D(LNAGR(-1))                           | 0.077290    | 0.553490   | 0.139641    | 0.8903 |
| D(LNAGR(-2))                         | -1.645163   | 0.537318   | -3.061807   | 0.0071 | D(LNAGR(-2))                           | 0.504066    | 0.479159   | 1.051982    | 0.3048 |
| D(LNAGR(-3))                         | 1.310865    | 0.307946   | 4.256808    | 0.0005 | D(LNAGR(-3))                           | 1.311171    | 0.477097   | 2.748228    | 0.0120 |
| D(LNGDPC)                            | -0.230087   | 0.104461   | -2.202617   | 0.0417 | CointEq(-1)*                           | -0.802117   | 0.116723   | -6.871949   | 0.0000 |
| D(LNGDPC(-1))                        | -0.008572   | 0.111699   | -0.076739   | 0.9397 |                                        |             |            |             |        |
| D(LNGDPC(-2))                        | 0.187832    | 0.128095   | 1.466352    | 0.1608 |                                        |             |            |             |        |
| D(LNGDPC(-3))                        | -0.301593   | 0.110320   | -2.733814   | 0.0141 |                                        |             |            |             |        |
| CointEq(-1)*                         | -0.093477   | 0.023398   | -3.995152   | 0.0009 |                                        |             |            |             |        |
| R²                                   | 0.696025    |            |             |        | R²                                     | 0.799597    |            |             |        |
| Adjusted R²                          | 0.464426    |            |             |        | Adjusted R²                            | 0.714810    |            |             |        |
| DW- stat                             | 2.153334    |            |             |        | DW- stat                               | 2.057270    |            |             |        |

Source: the authors.

After assessing short-term elasticity, the next step is to examine the findings regarding long-term elasticity. The results for long-term elasticity are displayed in Table 7 below:

**Table 7.** Long-run estimation equation

| Model 1 Dependent Variable: LNEFP                                                                                    |             |            |             |        | Model 2 Dependent Variable: LNRF    |             |            |             |        |
|----------------------------------------------------------------------------------------------------------------------|-------------|------------|-------------|--------|-------------------------------------|-------------|------------|-------------|--------|
| Variable                                                                                                             | Coefficient | Std. Error | t-Statistic | Prob.  | Variable                            | Coefficient | Std. Error | t-Statistic | Prob.  |
| LNFS                                                                                                                 | 0.280184    | 0.190478   | 1.470953    | 0.1693 | LNFS                                | -0.037091   | 0.045990   | -0.806508   | 0.4345 |
| LNRF                                                                                                                 | -2.239886   | 0.723243   | -3.097003   | 0.0102 | POP                                 | -1.859097   | 0.214146   | -8.681455   | 0.0000 |
| POP                                                                                                                  | -2.055107   | 1.088852   | -1.887406   | 0.0858 | LNAGR                               | 0.720074    | 0.084032   | 8.569003    | 0.0000 |
| LNAGR                                                                                                                | 0.319473    | 0.424259   | 0.753013    | 0.4673 | LNGDPC                              | 0.338342    | 0.075334   | 4.491224    | 0.0006 |
| LNGDPC                                                                                                               | 1.022397    | 0.198068   | 5.161859    | 0.0003 | C                                   | 16.69534    | 1.749685   | 9.541911    | 0.0000 |
| C                                                                                                                    | 29.00327    | 11.17725   | 2.594849    | 0.0249 |                                     |             |            |             |        |
| Model 3: Dependent Variable: LNFS                                                                                    |             |            |             |        | Model 4: Dependent Variable: LNGDPC |             |            |             |        |
| Variable                                                                                                             | Coefficient | Std. Error | t-Statistic | Prob.  | Variable                            | Coefficient | Std. Error | t-Statistic | Prob.  |
| No long-run equation – test bounds confirm no long-run relationship equation; we estimate just a short-run equation. |             |            |             |        | LNRF                                | 0.672812    | 0.345697   | 1.946245    | 0.0651 |
|                                                                                                                      |             |            |             |        | LNFS                                | 0.030238    | 0.192366   | 0.157191    | 0.8766 |
|                                                                                                                      |             |            |             |        | POP                                 | 2.895093    | 0.461497   | 6.273272    | 0.0000 |
|                                                                                                                      |             |            |             |        | LNAGR                               | -0.678583   | 0.302010   | -2.246887   | 0.0355 |
|                                                                                                                      |             |            |             |        | C                                   | -27.48108   | 3.816221   | -7.201123   | 0.0000 |

Source: the authors.

### Diagnostic Tests

Tables 8 and 9 in the appendix describe diagnostic tests for our ARDL models. These tables display the number of tests without problems related to autocorrelation, heteroskedasticity, and normality (figure 6). Notably, all probabilities exceeding 5% indicate that there are no problems in our models.

Also, the number of recursive residual cumulative (CUSUM) and square cumulative of the residual recursive (CUSUMSQ) tests show the absence of misspecification evidence and expected instability (figure 7 in appendix).

## VI. Discussions and policy implications

The analysis of results obtained from ARDL models provides a deeper understanding of the effects of climate change on food security and sustainable development in Saudi Arabia. Applying the bounds testing approach for cointegration confirmed the existence of long-term relationships between the studied variables, thus justifying the use of this econometric methodology.

The empirical results across the four models elucidate complex interdependencies between climate change, food security, and economic dynamics in Saudi Arabia. Statistically, the models demonstrate robust explanatory power, with adjusted  $R^2$  values ranging from 0.464 (Model 3) to 0.806 (Model 1), indicating that the selected regressors explain 46.4–80.6% of variations independent variables.

The error correction terms (ECTs) reveal distinct adjustment dynamics: Model 1 (EFP) exhibits a rapid annual correction rate of 147% (ECT = -1.47,  $p < 0.01$ ), Model 2 (RF) shows a 321% adjustment speed (ECT = -3.21,  $p < 0.01$ ), and Model 4 (GDPC) reflects an 80% convergence rate (ECT = -0.80,  $p < 0.01$ ). These results underscore the responsiveness of Saudi Arabia's ecological and economic systems to disequilibria. In contrast, Model 3

(FS) lacks cointegration (F-statistic = 2.01, below critical bounds), implying no stable long-term relationship for food security, likely due to exogenous factors such as global market fluctuations or policy shifts not captured in the model.

The first model, a crucial part of our research, delves into the impact of climatic and economic variables on the ecological footprint (LNEFP). The findings are significant, with variations in average annual rainfall (LNRF), food production (LNFS), agricultural value added (LNAGR), population (LNPOP), and GDP per capita (LNGDPC) explaining a substantial 91% of the variations in the ecological footprint. The obtained F-statistic of -1.4695 further underscores the importance of these variables, indicating a significant relationship at a 1% significance level.

An increase in rainfall (LNRF) has a significant positive effect on land's biological productivity (Li et al., 2015). At the same time, population growth (LNPOP) exerts negative pressure by increasing the consumption of natural resources and CO<sub>2</sub> emissions (Thi Mai et al., 2024). The Durbin-Watson statistic (2.4989) confirms the absence of autocorrelation issues. In the long run, the ecological footprint is negatively influenced by population growth and extreme precipitation, illustrating the impact of climate change on environmental sustainability and the renewability of natural resources (Pan et al., 2023).

In this Model, long-run elasticities highlight the environmental cost of economic growth, with GDPC exerting a significant positive impact (+1.02,  $p < 0.01$ ), while population (POP: -2.06,  $p < 0.10$ ) and rainfall (RF: -2.24,  $p < 0.05$ ) mitigate ecological pressures, albeit indirectly. Short-run results reveal that lagged food security (LNFS) and GDPC reduce EFP (-0.80 and -1.12, respectively), suggesting immediate policy interventions in these sectors can effectively curb environmental degradation, offering a beacon of hope in the face of climate change.

The second model measures the effect of economic and agricultural variables on rainfall (LNRF). The results reveal an inverse relationship between food security (LNFS), population (LNPOP), agricultural value added (LNAGR), and GDP per capita (LNGDPC) with rainfall. The F-statistic of -6.181902 indicates a significant relationship at a 1% significance level, with a coefficient of determination ( $R^2 = 89\%$ ), demonstrating that these variables largely explain the variability in precipitation.

The intensification of economic and agricultural activities leads to increased greenhouse gas emissions, disrupting rainfall patterns in Saudi Arabia. In the long run, agricultural value added and GDP per capita positively impact rainfall, underscoring the urgent need for more balanced economic dynamics that could favorably influence climatic conditions (Atchadé & Nougbodé, 2024).

The second Model (RF) identifies population growth (POP: -1.86,  $p < 0.01$ ) and agricultural expansion (AGR: +0.72,  $p < 0.01$ ) as key long-term drivers of rainfall variability, with short-term dynamics showing volatile interactions between population, agriculture, and GDPC (Bouteska et al., 2024).

The third model analyzes the impact of variables on food security (LNFS). The study finds that the ecological footprint (LNEFP) significantly negatively affects food security due to

land overexploitation and environmental pollution (Bala & Hossain, 2010). With an F-statistic of -3.995152 and an  $R^2$  of 70%, the results indicate that increased CO<sub>2</sub> emissions and the deterioration of natural resources reduce the agricultural sector's ability to meet the growing food demands of the Saudi population (Mahmood et al., 2019).

The study also highlights that economic growth focused solely on GDP per capita (LNGDPC) does not necessarily improve food security, emphasizing the need to manage natural and agricultural resources effectively. Indeed, the short-term equation reveals that agricultural output (LNAGR: -1.65,  $p < 0.01$ ) and GDPC (-0.30,  $p < 0.05$ ) negatively influence food security, pointing to structural inefficiencies in translating economic gains into food accessibility (Satrovic et al., 2024).

The fourth model explores the influence of variables on GDP per capita (LNGDPC). The analysis shows that agricultural value added (LNAGR) positively contributes to economic growth, whereas the ecological footprint (LNEFP) and increased carbon emissions have a negative effect on GDP per capita (Raihan, 2023).

The F-statistic of -6.871949 and an  $R^2$  of 80% indicate that these variables largely explain variations in GDP per capita. The overexploitation of natural resources and the adverse effects of climate change hinder long-term economic development. These findings highlight the importance of considering the interactions between climate, agriculture, and economic development to understand the country's structural challenges better.

The model also underscores rainfall's positive long-run elasticity (+0.67,  $p < 0.10$ ), while agriculture (AGR: -0.68,  $p < 0.05$ ) exhibits a paradoxical negative effect, signaling diminishing returns from resource-intensive farming. Short-run estimates further emphasize rainfall's immediate economic benefits (+0.26,  $p < 0.05$ ).

### **Policy Implications and Recommendations:**

The analysis of results highlights several challenges and opportunities related to the interactions between climate, agriculture, and the Saudi economy. Sustainable resource management must be a priority, particularly by strengthening sustainable agricultural practices, optimizing water use, and reducing the ecological footprint (LNEFP). Improving agricultural infrastructure, supporting research on resilient crops, and promoting agroecology are essential measures to ensure sustainable food production. Additionally, transitioning to renewable energy sources and adopting clean technologies must be accelerated to limit greenhouse gas emissions and mitigate the effects of climate change (Kabeyi & Olanrewaju, 2022).

Food security (LNFS) should be strengthened by reducing import dependence and diversifying agricultural production sources (Sukanya, 2024:pp 229–258 ). Modernizing storage and distribution infrastructure, as well as improving access to financing for farmers, will help enhance the sector's resilience to climate shocks (Юзефович et al., 2024:pp 224–232. ). Developing public policies promoting responsible consumption and less resource-intensive food production is also crucial (Lorek & Spangenberg, 2014:pp 33–44). Climate change adaptation must be reinforced by improving climate monitoring systems, investing in resilient infrastructure, and implementing sustainable urbanization policies. Integrating



nature-based solutions, such as reforestation, water resource management, and ecosystem preservation, will help reduce the negative impacts of climate change on the Saudi economy and society (Olgun et al., 2024; Gebrael et al., 2024).

Adopting an integrated approach that links the Economy, agriculture, and the environment is essential to ensuring sustainable development and enhancing resilience to climate challenges in Saudi Arabia (Alotaibi et al., 2024:pp 1-21 ;Al-Khateeb et al., 2021:pp1-19 ;Rahman et al., 2022:pp1-19).

These findings necessitate a multi-pronged policy framework. First, the GDPC-EFP nexus in Model 1 calls for decoupling economic growth from environmental harm via green industrialization, renewable energy investments, and carbon pricing mechanisms. Second, Model 2's rainfall vulnerabilities demand integrated water management strategies, including aquifer protection, desalination innovation, and policies to curb urban sprawl's strain on water resources. Third, Model 3's instability in food security underscores the urgency of diversifying food imports, incentivizing vertical farming, and strengthening social safety nets to buffer against supply chain disruptions.

In general, the four short-term models confirm the negative impact of climate change on food security in Saudi Arabia and its ability to meet the food needs of both the current population and future generations. This is reflected in a significant gap in the Kingdom's ability to achieve self-sufficiency in resources. This gap reached approximately 0.7 gha, while the per capita demand for resources was 5.75 gha, resulting in a negative deficit of -5 gha.

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## Notes

(1) <https://www.state.gov/reports/2024-investment-climate-statements/saudi-arabia/>

(2) [www.FoDaFo.org](http://www.FoDaFo.org)

(3) scholars, students, researchers, and collaborating organizations working together to advance the measurement of Ecological Footprint and Biocapacity and the application of these measures around the world, Toronto, Cañada. <https://footprint.info.yorku.ca/>

(4) <https://www.footprintnetwork.org/our-work/ecological-footprint/>

(5) <https://www.footprintnetwork.org/our-work/ecological-footprint/>

(6) <https://www.footprintnetwork.org/resources/glossary/>

(7) <https://www.footprintnetwork.org/2022/07/13/food-security-in-a-world-of-overshoot/>

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## Appendix

Table 8. Breusch-Godfrey LM test for autocorrelation

| Lags(p)        | F        | df   | Prob > F | Decision              |
|----------------|----------|------|----------|-----------------------|
| <b>Model 1</b> |          |      |          |                       |
| 1              | 1.463880 | 1,12 | 0.2541   | No serial correlation |
| 2              | 0.702876 | 2,11 | 0.5204   |                       |
| <b>Model 2</b> |          |      |          |                       |
| 1              | 3.671147 | 1,12 | 0.0795   | No serial correlation |
| 2              | 0.702876 | 2,11 | 0.0776   |                       |
| <b>Model 3</b> |          |      |          |                       |
| 2              | 1.266028 | 2,18 | 0.3059   | No serial correlation |
| <b>Model 4</b> |          |      |          |                       |
| 2              | 0.650354 | 2,19 | 0.5331   | No serial correlation |

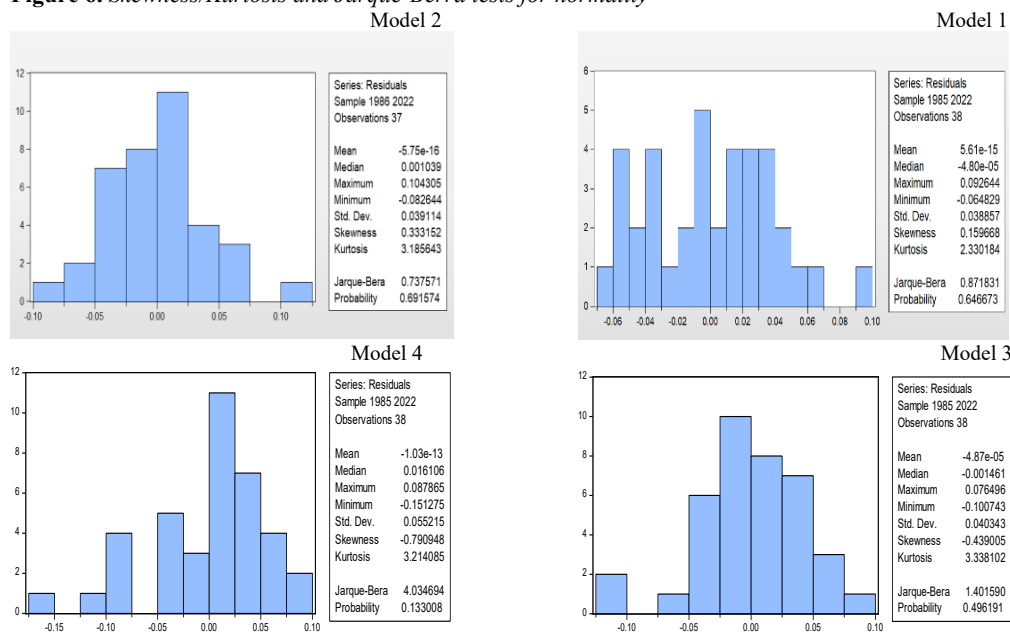
Source: the authors.

Table 9. White test for heteroscedasticity

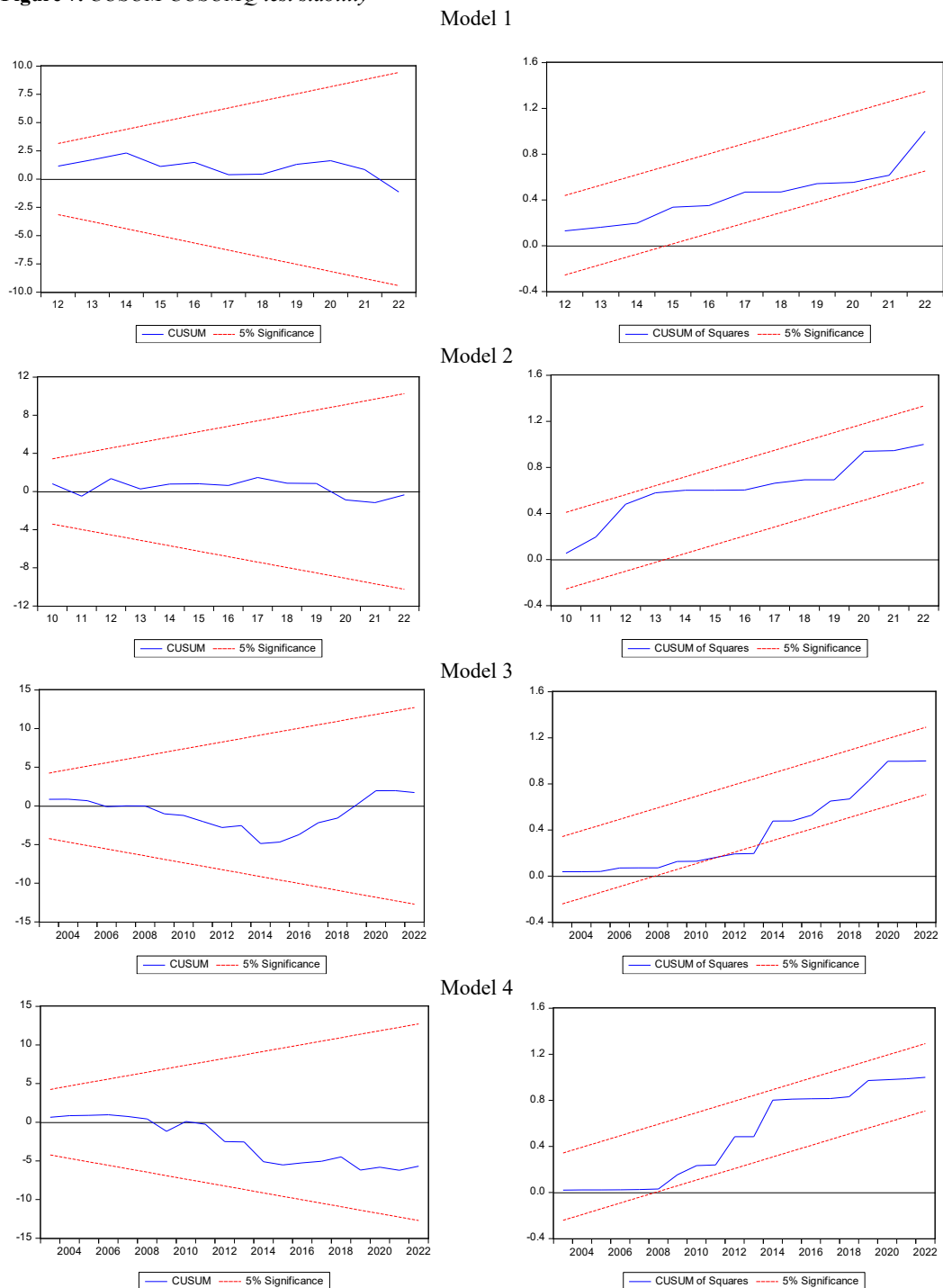
| Lags(p)             | Value    | df    | Prob   | Decision              |
|---------------------|----------|-------|--------|-----------------------|
| <b>Model 1</b>      |          |       |        |                       |
| F-statistic         | 1.902112 | 26,11 | 0.1319 | No heteroscedasticity |
| Obs*R-squared       | 31.08576 | 26    | 0.2251 |                       |
| Scaled explained SS | 1.732452 | 26    | 1.0000 |                       |
| <b>Model 2</b>      |          |       |        |                       |
| F-statistic         | 0.700704 | 23,13 | 0.7794 | No heteroscedasticity |
| Obs*R-squared       | 20.47998 | 23    | 0.6128 |                       |
| Scaled explained SS | 2.762880 | 23    | 1.0000 |                       |
| <b>Model 3</b>      |          |       |        |                       |
| F-statistic         | 1.434057 | 18,19 | 0.2212 | No heteroscedasticity |
| Obs*R-squared       | 21.88861 | 18    | 0.2370 |                       |
| Scaled explained SS | 7.094846 | 18    | 0.9893 |                       |
| <b>Model 4</b>      |          |       |        |                       |
| F-statistic         | 1.092957 | 16,21 | 0.4174 | No heteroscedasticity |
| Obs*R-squared       | 17.26590 | 16    | 0.3686 |                       |
| Scaled explained SS | 5.837474 | 16    | 0.9898 |                       |

Source: the authors.

Figure 6. Skewness/Kurtosis and Jarque-Berra tests for normality



Source: the authors.

**Figure 7.** *CUSUM CUSUMQ test stability*

**Source:** the authors.

## Corruption in digital environments

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**Abstract.** *The process by which individuals lose their psychological defences against normalizing corruption is known as cognitive immunity failure. The representation of corruption as inevitable, unchangeable, and self-reinforcing amplifies fatalistic narratives in algorithmically curated environments that are shaped by filter bubbles and echo chambers. By shifting reactions from initial outrage to numb indifference, these patterns weaken moral salience. Echo chambers repetitively assert fatalism through content alignment and repetition. At the same time, from a neuroeconomic perspective, the cost-benefit analysis shifts toward disengagement as repeated exposure devalues moral action, lowering the perceived expected reward of ethical engagement. This study examines how these dynamics, which are based on decision-value models, motivational fatigue, and social norms, reinforce one another and erode civic vigilance. We conclude by outlining three intervention frameworks: public education to restore cognitive immunity, norm-restoring campaigns that restore moral urgency, and AI design that combats narrative fatalism.*

**Keywords:** cognitive immunity failure, moral salience decay, corruption perception, neuroeconomic decision making, AI-mediated content environments.

**JEL Classification:** D73, D80, D87, D91, O33, H83.

## 1. Introduction

One of the most enduring problems in global governance is corruption, which undermines democratic accountability, distorts market mechanisms, and erodes institutional trust (Rose-Ackerman, Palifka, 2016). While exposing corrupt practices to the public can initially elicit moral outrage and inspire civic resistance, repeated and prolonged exposure to stories about corruption tend to result in a discernible drop in public participation (Bodislav et al. 2016). This change from active condemnation to passive acceptance is a cognitive phenomenon as well as a sociological one, indicating a weakening of the psychological defences against the use of unethical norms.

The breakdown of an individual's capacity to uphold ethical resistance when exposed to situations where unethical behaviour is consistently presented as normal or unavoidable is known as cognitive immunity failure. According to Haidt (2012), cognitive immunity is comparable to an adaptive defence mechanism against norm distortion, consisting of attentional, evaluative, and motivational components that maintain moral engagement over time.

The circumstances under which cognitive immunity failure presents itself have increased due to the quick spread of algorithmically mediated information environments. Modern digital platforms rely on predictive personalization systems, which are optimized for engagement rather than epistemic diversity (Pariser, 2011; Sunstein, 2017). When discussing corruption, these systems might unintentionally give priority to fatalistic narratives, which portray corruption as unchangeable, deeply ingrained in culture, and unreformable. The gradual decline in the attentional and affective importance of corruption as a moral issue is known as moral salience decay, and it can be accelerated over time by algorithmically reinforced exposure to such narratives.

The echo chamber structure, which minimizes the possibility of encountering counter-narratives or instances of effective anti-corruption interventions through algorithmic filtering, selective exposure, and homophily, complicates and intensifies the phenomenon even more (Garrett, 2009; Cinelli et al., 2021). The neuroeconomic implications are significant: when the perceived probability of successful collective action is low, the subjective value of ethical engagement decreases, resulting in disengagement in favour of alternative activities with higher perceived reward-to-effort ratios (Knutson, Huettel, 2015).

To investigate the relationship between predictive AI systems and the weakening of moral resistance to corruption, this essay combines psychological, neuroeconomic, and computational viewpoints (Bodislav et al., 2016). It aims to bring insight into the processes by which cognitive immunity failure develops, the sociopolitical ramifications of its entrenchment, and the tactical measures that could stop or reverse its progression by following the development from initial outrage to eventual indifference.

The relationship between predictive AI systems and the weakening of moral resistance to corruption is examined in this essay by combining psychological, neuroeconomic, and computational viewpoints. This study explores the processes by which cognitive immunity failure occurs by following the development from increased ethical salience to normative



passivity. It aims to give insight into the processes by which cognitive immunity failure develops, the sociopolitical ramifications of its entrenchment, and the tactical measures that may be able to stop or reverse its course.

## 2. Theoretical Foundations

### 2.1. Cognitive Immunity

Cognitive immunity is defined as the set of psychological and social-cognitive mechanisms that protect individuals from adopting maladaptive or unethical norms despite environmental pressure. This includes the ability to assess information critically, avoid engaging in corrupt behaviour, and uphold moral integrity when exposed to norm violations for an extended period (Haidt, 2012; Bicchieri, 2017). According to this theory, when these defence mechanisms weaken and the behaviours, they were intended to prevent become more common, cognitive immunity fails. The analogy to biological immunity is intentional: just as an immune system can be weakened by means of repeated exposure to pathogens, cognitive immunity can be weakened through repeated exposure to morally corrosive narratives.

#### *Moral Salience Decay*

According to Giner-Sorolla (2012), moral salience refers to the perceived importance, emotional weight, and attentional priority given to an ethical concern. High moral salience is linked to disapproval, a sense of injustice, and a readiness to take corrective action when corruption is present. When norm violations are repeatedly observed without accompanying proof of accountability or reform, the perceived importance gradually diminishes over time, a phenomenon known as moral salience decay (Brezina and Kaufman, 2008). Reinforcement loops that repeatedly present similar content can accelerate decay in algorithmically mediated environments, reducing novelty and emotional impact through habituation effects (Bargh, Chartrand, 1999).

#### *Inevitability Narratives*

Discourse patterns known as inevitability narratives present corruption as inescapable, deeply ingrained in culture, and unalterable (Luhmann, 2000). They can be explicit, overt claims that "corruption is part of our culture", or implicit, embedded in stories and commentaries that dismiss all anti-corruption efforts as ineffective. According to Cialdini and Trost (1998), injunctive norms, perceptions of what most people approve of, and descriptive norms, perceptions of what most people do, are shaped by such narratives, which promote acceptance rather than objections. Predictive content ecosystems may reinforce a sense of inevitability by using algorithms to preferentially surface similar content once user engagement indicates receptivity to these frames.

#### *Algorithmic Echo Chambers*

Through algorithmic filtering or self-selection, echo chambers are networked settings that systematically limit exposure to opposing viewpoints (Sunstein, 2017; Cinelli et al., 2021). Echo chambers can reinforce inevitability narratives in corruption discourse by repeating

stories of systemic dysfunction, failed reforms, and scandal persistence. This constant exposure weakens cognitive immunity by giving the impression that everyone agrees that corruption cannot be corrected (Bodislav, 2011).

#### *The Context of Neuroeconomic Decision Making*

From a neuroeconomic viewpoint, decision-making about civic engagement is determined by expected value computations (Kahneman, Tversky, 1979; Knutson, Huettel, 2015). When individuals perceive the likelihood of successful anti-corruption action is low and the effort cost is high, the subjective utility of engagement decreases. These calculations are distorted by algorithmic reinforcement of inevitability narratives, which inflate perceived risks and diminish perceived benefits, resulting in a self-reinforcing disengagement loop.

### **3. From Moral Engagement to Normative Passivity: Stages of Attention Shift**

As social norms, informational reinforcement, and cognitive adaptation change over time, patterns of change in the public's engagement with corruption-related information can be noticed. The following stages outline a prevalent risk pathway in algorithmically reinforced environments. Not everyone follows this path; many individuals continue to pay attention and be involved over time through boycotts, investigations, coordinated civic projects, or strikes. Others organize and share alternative viewpoints through online platforms. These examples show resilience pathways, where engagement is sustained over time by both personal and contextual factors.

#### *First Stage: Initial Moral Involvement*

According to Rozin et al. (1999) and Hutcherson and Gross (2011), initial exposure to a corruption-related event that goes against individual or group ethical standards usually leads to an increase in attentional focus, evaluative processing, and motivation to discover further information. The individual's priority hierarchy places the subject at a higher level, which may result in ongoing monitoring, discussion, or information sharing. Such interaction may cause the algorithm in predictive content systems to prioritize related content in the user's feed.

#### *Second Stage: Adaptation and Norm Recalibration*

Repeated exposure to the same information may make the events seem less unique and exceptional, especially if there is no discernible systemic change. Descriptive norms ("*this behaviour is common*") may influence the cognitive categorization of the conduct, while habituation can result in a decrease in emotional intensity (Bargh, Chartrand, 1999; Bicchieri, 2017). The tone of engagement at this stage frequently changes from solution-oriented discussion to commentary that reflects a lower expectation of change.

#### *Stare Three: Cognitive Fatigue and Attentional Redistribution*

Maintaining focus on recurring topics necessitates ongoing cognitive and emotional resources. Individuals may experience cognitive fatigue when these are invested without

perceivable reinforcement, such as new developments or observable reforms (Muraven, Baumeister, 2000). Topic saturation brought on by algorithmic repetition may cause individuals to shift their focus to other topics that they find more interesting, fulfilling, or relevant.

#### *Stage Four: Normative Passivity*

Although corruption-related content is still acknowledged at this point, it receives less attention and elicits fewer behavioural reactions. By presenting corruption as a constant feature of the sociopolitical environment, inevitable narratives can be integrated into a person's larger interpretive framework. This indicates a change in salience rather than the complete absence of awareness, with potential implications for participation in related public discourse and activities (Miller, 2006).

## **4. Algorithmic Amplifiers**

Digital platforms' algorithmic systems have an impact on how individuals discover, process, and rank corruption-related information. These systems work by using ranking, recommendation, and predictive personalization techniques that maximize user engagement. By doing this, they could influence the attention allocation process outlined in Section 3.

#### *Predictive Personalization*

Algorithms that modify content delivery according to past user interactions, deduced preferences, and engagement patterns are known as predictive personalization (Pariser, 2011; Sunstein, 2017). The system may make similar content more prevalent and frequent when users interact with content about corruption. This can eventually produce a steady informational landscape in which some narratives, such as those about inevitable narratives, are offered more frequently than alternative perspectives. This reinforcement is not always indicative and does not necessarily reflect the broader distribution of public opinion or events, but rather the interaction history of the user.

#### *Echo Chambers Dynamics*

Echo chambers arise when self-selection, algorithmic filtering, or both limit exposure to different points of view (Garrett, 2009; Cinelli et al., 2021). Echo chambers can cause framings, such as narratives highlighting the structural embeddedness or persistence of corruption, to be presented repeatedly in the context of corruption discourse. As discussed in Section 3, this repetition may help with norm recalibration by making some interpretations easier to remember and more cognitively accessible.

#### *Loops of Engagement*

User actions (such as viewing, sharing, and commenting) indicate the relevance of content to the algorithm, which leads to further prioritization of similar content. This feedback process is known as an engagement loop. This mechanism can maintain a large volume of thematically consistent content in a user's feed when applied to corruption-related topics,

which might accelerate changes in salience. The loop focuses on maximizing the anticipated interaction rather than the material's accuracy or representativeness.

#### *Saturation Effects*

Saturation occurs when the volume and frequency of exposure to a specific topic exceed the individual's capacity or willingness to process it. Saturation may result from recurring framing techniques or thematic emphasis in algorithmically mediated environments, in addition to repeated coverage of the same events. Regardless of whether the initial problem is still substantively relevant, this may cause attention to be redistributed toward other subjects, as outlined in Stage Three of Section 3.

### **5. A Neuroeconomic View of Salience Shift and Societal Feedback Loops**

The context of decision theory, individuals assign attention and resources toward actions with higher expected value, calculated as the anticipated benefit weighted by the perceived probability of success (Kahneman, Tversky, 1979; Knutson, Huettel, 2015). The expected value of engagement may decrease if repeated exposure to narratives about inevitability or unchanging circumstances results in a decreased perceived likelihood of impact. This change is not always indicative of a loss of awareness but can influence the prioritisation of other activities perceived as more rewarding or effective.

Given the limited nature of attention, focusing it on a single subject has opportunity costs, or the potential advantages lost by ignoring other subjects or pursuits (Kurzban et al., 2013). The constant display of similar corruption-related content in environments that are algorithmically curated may make it seem more expensive to stay focused on the subject, especially if the user anticipates greater benefits from diverting their attention elsewhere.

Habituation is the process by which repeated exposure to similar content lessens its emotional impact and novelty (Bargh, Chartrand, 1999). According to reward-processing theory, the expected psychological benefit of discussing the subject may decrease with time. This reward devaluation is not necessarily linked to changes in the underlying importance of the issue but demonstrates a shift in how the brain weighs the salience of competing inputs.

Competition for cognitive resources is heightened in high-volume information environments (Simon, 1971). When a limited number of narratives are amplified algorithmically, it can create a sense of redundancy and decrease the likelihood that individuals will devote sustained processing resources to that information. This phenomenon is consistent with Stage Three (attentional redistribution) detailed in Section 3, which involves the reallocation of focus because of the repeated presentation of similar material.

#### *Societal Feedback Loops*

Changes in individual attention patterns toward corruption-related information can, when combined, contribute to broader societal-level dynamics. These feedback loops operate and function through the interaction of collective perception, institutional response, and information flows.

Participation in civic and political activities is influenced by public perceptions of corruption (Seligson, 2002). When large segments of the population evaluate corruption as structurally persistent, participation in formal anti-corruption initiatives or related civic actions might decrease. This change in participation can, consequently, reinforce perceptions of limited societal mobilisation, contributing to the stability of the original perception.

The level of public concern about corruption can be influenced by institutional responsiveness, such as public investigations, prosecutions, or reforms. Low visibility of effective institutional action can reinforce inevitability narratives by giving the impression of inaction or ineffectiveness. This may result into a feedback loop in which reduced public engagement is met with reduced institutional initiative, further lowering the visibility of change.

As discussed in Section 4, algorithmically mediated information flows can help selectively amplify specific framings. The collective informational environment may be shaped when stories about how deeply ingrained corruption is are more widely shared than testimonies of successful reform. As time goes on, the prevalence of these narratives can influence both public discourse and the strategic communication of institutions.

Attitudes regarding corruption can be transmitted across generations through socialisation, education, and media exposure (Mishler, Rose, 2007). If inevitability narratives continue to be prevalent in public discourse, they may influence the baseline expectations of younger groups, potentially stabilising certain norms over extended periods. This doesn't rule out change but indicates that shifts in engagement may operate on long time horizons.

## 6. Design and Mitigation Considerations

Both the technological and social spheres offer viable strategies for changing the informational dynamics discussed in earlier sections. These considerations do not prescribe specific interventions but outline areas where adjustments may influence how corruption-related narratives are encountered and processed.

Recommendation systems could be designed to expose users to a broader range of perspectives and framings on corruption-related issues. Diversifying the informational inputs available to users may reduce the dominance of inevitable narratives while increasing the visibility of diverse accounts, such as those describing reform outcomes or systemic improvements (Helberger et al., 2018).

Changing the frequency or sequencing of content could help avoid saturation effects (Section 4). This could consist of introducing greater intervals between similar content types or integrating topic rotations to balance engagement with novelty.

Including contextual information, such as historical trends, comparative statistics, or case studies, alongside individual corruption-related stories can help place events in a larger analytical context. This method can help counteract an over-reliance on impressions from a single narrative and allow for more nuanced interpretations (Thorson et al., 2010).

Educational initiatives that focus on information literacy, particularly in terms of framing effects and algorithmic curation, may influence the way individuals interpret and prioritize corruption-related content. Formal education systems, community programs, or platform-integrated resources can all be used to carry out these initiatives.

Collaboration between information platforms and public institutions could aim toward making sure that verified updates on anti-corruption measures, policy changes, and legal proceedings are made visible in relevant contexts (Georgescu, Bodislav, 2025). While the efficiency of such collaborations would depend on trust in the institutions involved, their inclusion in the informational environment could expand the range of narratives encountered.

## 7. Ethical Dimensions of Perception Change

In addition to changing what individuals pay attention to, changes in the informational environment, especially in spaces that are algorithmically curated, also affect how they understand the moral implications of corruption. These effects take place at the level of behavioural intention, moral cognition, and normative framing. While changes in attentional priority can be described in cognitive or neuroeconomic terms, they also interact with processes that influence moral reasoning, responsibility allocation, and perceived agency in addressing unethical behaviour and practices.

Entman (1993) defines normative framing as the presentation of information in relation to shared moral standards. When it comes to corruption, framing can vary from overt moral denunciation to pragmatic acceptance (Bodislav, Georgescu, 2023). Inevitability narratives, in which corruption is portrayed as a permanent feature of sociopolitical life, can change its classification from a clear ethical breach to a "structural reality." This reclassification does not eliminate legal definitions, but it can reduce the perceived moral weight of individual acts, particularly when they are presented as necessary for system navigation or survival in competitive environments (Bicchieri, 2017).

The gradual acceptance of such framing can result in norm drift, which widens the gap between legal standards and socially acceptable practices. In extreme cases, actions that are formally regarded as corrupt might no longer elicit strong moral responses since they are perceived as being in line with "how things work" rather than as deviations.

According to Bandura's (2016) theory of moral disengagement, there are several cognitive processes that can decrease the influence of moral principles on behaviour. These mechanisms may be strengthened by algorithmic exposure patterns in corruption discourse:

- Moral justification is the presentation of corrupt practices as having positive social effects, like facilitating economic growth or accelerating bureaucratic procedures.
- Euphemistic labelling entails describing bribery as a "facilitation fee" or influence as "networking," thereby minimizing the perceived ethical breach.
- Through advantageous comparison we minimise the severity of local corruption by comparing it to more extreme cases elsewhere.

- Diffusion or displacement of responsibility is built when accountability is transferred to "the system" or higher authorities, personal accountability is diminished and leads to minimisation of consequences, emphasising the absence of direct harm to individuals, thus decreasing the sense of moral urgency.
- These mechanisms, when reinforced by repeated exposure to specific framings, have the potential to alter the cognitive pathways through which people evaluate corruption-related behaviours.

According to Hannah et al. (2011), ethical self-efficacy is the belief that one can behave morally when faced with ethically challenging circumstances. Algorithmic reinforcement of narratives that highlight corruption's structural resilience can reduce perceived agency by portraying anti-corruption efforts as unlikely to succeed. Over time, this may result in a shift from principled reasoning, in which decisions are primarily guided by internalized ethical values, to pragmatic reasoning, in which decisions are prioritized for self-preservation or strategic advantage.

Decreased ethical self-efficacy can also lessen the perceived social and personal pressure to act. When individuals assume that most others are unlikely to engage in ethical resistance, inaction becomes less of a deviation from the norm and more of a standard or acceptable response (Branson et al., 2010).

Inevitability narratives do not consistently dominate the informational environment. Ethical salience can be maintained or restored by exposure to a variety of narratives, such as case studies of effective anti-corruption reforms, illustrations of institutional accountability, and cross-cultural comparisons (Bodislav et al, 2023). This kind of diversity encourages ethical pluralism, in which individuals interpret governance-related issues using a variety of evaluative frameworks.

Maintaining flexible moral reasoning in intricate political contexts requires ethical pluralism. Individuals are more likely to retain an evaluative position toward corruption that withstands total normative drift if they are exposed to and consider a range of moral viewpoints. Algorithmic systems that incorporate diversity-enhancing mechanisms (Helberger et al., 2018) may therefore indirectly contribute to the preservation of ethical engagement without explicitly advocating for any stance.

The process of framing corruption ethically is not limited to the individual. Individual moral reasoning interacts reciprocally with collective norms, which are shaped by public discourse, media representation, and institutional communication. Individuals may reassess their own moral judgments to conform to the opinions of the perceived majority as public discourse grows more tolerant of corruption as a structural inevitable (Georgescu et al., 2021). On the other hand, shifts in individual ethical reasoning, when combined, can alter the collective framing of the issue.

Analysing long-term shifts in the ethical salience of corruption in society requires an understanding of this reciprocal relationship. The interplay indicates that informational interventions, even if minimal in scale, have the potential to influence both personal moral interpretation and collective normative frameworks over time.

*Normative Framing and the Reclassification of Corruption*

Normative framing pertains to the presentation of information in accordance with collective moral standards (Entman, 1993). In instances of corruption, framing may vary from overt moral condemnation to pragmatic acquiescence. Narratives of inevitability, which depict corruption as an inherent aspect of socio-political existence, can reclassify it from a distinct ethical transgression to a “structural reality.” This reclassification does not eliminate legal definitions but may diminish the perceived moral gravity of individual actions, particularly when these actions are portrayed as essential for navigating systems or surviving in competitive contexts (Bicchieri, 2017).

The incremental acceptance of this framing may result in norm drift, causing a divergence between legal standards and socially accepted practices (Georgescu, 2023). In extreme instances, actions deemed corrupt may fail to elicit significant moral responses as they are perceived as consistent with the status quo rather than deviations from it.

**8. Conclusion**

This study explored how individual attention to corruption-related information can shift over time in algorithmically mediated environments. A progression from initial moral engagement to normative passivity is outlined in the prevalent risk pathway discussed in Section 3. This progression is influenced by cognitive adaptation, informational reinforcement, and shifting social norms. While this pathway is not universal, it does provide a framework for understanding how specific environmental and psychological factors interact to influence engagement patterns.

Cognitive processes like habituation, reward devaluation, and attentional redistribution (Section 5) can interact with algorithmic mechanisms like engagement loops, echo chambers, and predictive personalization (Section 4). Collectively, these individual-level shifts can create societal feedback loops that impact intergenerational attitudes, institutional responsiveness, and corruption perceptions (Section 6).

The considerations outlined in Section 7 suggest that a variety of technological and educational strategies could influence the informational environment in ways that increase narrative diversity while decreasing saturation. These methods highlight possible areas of influence without recommending courses of action; they are descriptive rather than prescriptive.

All things considered, the analysis indicates that how corruption is viewed and prioritized over time is greatly influenced by the interplay between algorithmic content delivery and cognitive processes. Additional empirical studies could clarify the conditions under which engagement is maintained, diminished, or redirected, as well as the role of protective factors in sustaining long-term attentional commitment to governance-related issues.



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## **Beyond linearity: an ARDL threshold analysis of inflation's impact on Tanzania's economic growth from 1994 to 2024**

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**Abstract.** *This study examines the threshold effect of inflation on Tanzania's economic growth using annual data from 1990–2024 and a quadratic regression within the ARDL framework. The analysis identifies a clear inflation threshold at 5.82%, indicating that inflation's impact on growth turns negative beyond this point. Tanzania has mostly maintained inflation below this level since 2015, coinciding with stable growth, suggesting the economy has operated within a safe inflation zone. Therefore, the Bank of Tanzania should keep inflation below 5.8% through coordinated monetary–fiscal policies and strong data monitoring to maintain moderate, stable inflation that supports long-term growth.*

**Keywords:** ARDL, Economic growth, Inflation, Non-linear, Quadratic regression, Threshold.

**JEL Classification:** C32, E31, O40.

## 1. Introduction

Achieving price stability remains an important part of economic policy for every country yet its interplay with economic growth is still a subject of debate, particularly in emerging markets like Tanzania navigating global volatility (Mishra and Dubey, 2022; Ha et. al, 2022). This relationship has become more multi-faceted as economies have evolved with recent decades witnessing dramatic inflation streams stemming from supply chain disruptions, geopolitical tensions, global shocks like COVID 19 and monetary innovations including the rise of cryptocurrencies and digital payment systems. Such developments have compelled policymakers to review their approaches so as to seek an optimal balance between promoting economic expansion and maintaining price stability (Auer et al, 2025; Aiello et al., 2023). Empirical findings reveal no universal pattern in the inflation-growth nexus. Rather than exhibiting a simple linear relationship studies have consistently demonstrated that the connection between price changes and economic performance follows intricate and contradictory patterns that defy straightforward representation. Early studies established that extreme inflation clearly weakens economic growth with hyperinflationary periods providing evidence of inflation's destructive potential (Fischer, 1993; Barro, 1995). Yet as researchers expanded their investigations beyond these extreme cases, the relationship became less straightforward. The complication increases when examining moderate inflation rates where the relationship becomes far less predictable. Some studies have found evidence that modest price increases can support economic expansion while others have detected neutral or even negative effects at similar inflation levels (Bruno and Easterly, 1998; Ghosh and Phillips, 1998). This variability suggests that the inflation-growth nexus cannot be captured by universal rules or simple correlations. Instead, the relationship appears to be contingent on numerous factors including institutional quality, economic structure, development level, specific historical circumstances and others. Perhaps most significantly research has increasingly pointed toward the existence of threshold effects where the nature of the inflation-growth relationship changes dramatically at certain critical points.

Sarel (1996) identified such a structural break at around 12% inflation, while Khan and Senhadji (2001) refined these estimates for developing countries in IMF-based study. These findings suggest that inflation's impact on growth is not merely non-linear but fundamentally different across distinct regimes, with the same inflation rate potentially having vastly different effects depending on whether it falls above or below critical threshold levels. Real-world experiences further illuminate this complexity. The United States from 2015 to 2019 maintained inflation near its 2% target while sustaining solid growth, demonstrating that moderate inflation can coexist with economic growth (Armantier et al., 2023). However, other countries have experienced different outcomes with similar inflation rates, reinforcing the notion that context matters in determining how price changes affect economic performance. This recognition of non-linear, threshold-dependent relationships has prompted researchers to abandon simple linear models in favor of more sophisticated approaches. The development of threshold regression techniques, panel smooth transition models, and other advanced methodologies reflects the growing

understanding that capturing the true inflation-growth relationship requires analytical tools capable of accommodating regime switches and structural breaks (Jude and Levieuge, 2017; Kremer et al., 2013).

Current monetary policy practices reflect this evolved understanding of optimal inflation levels. It is noteworthy that countries including the most advanced economies rarely target zero inflation. Instead, most central banks prefer inflation targets in the range of 2% to 3%, a preference driven by several practical considerations. Higher targets preserve policy flexibility and help avoid the zero lower bound problem ensuring that monetary authorities retain adequate room for policy adjustments during economic downturns (Borio and Chavaz, 2025). This policy stance provides compelling evidence that some degree of inflation is generally preferred to complete price stability when considering the broader objectives of economic growth and macroeconomic stability. Studies consistently demonstrate that optimal inflation levels vary substantially between advanced and developing economies, with the advanced countries experiencing negative growth effects at much lower inflation rates than the developing countries. Advanced economies commonly show optimal inflation ranges between 1% and 3%, while developing nations often tolerate inflation rates of 7% to 11% before experiencing growth deterioration (Baharumshah et al., 2016; Ndoricimpa, 2017). These differences reflect key structural disparities in economic structure, institutional development and monetary policy effectiveness. Studies focusing on African economies reveal additional layers of detail with studies identifying threshold levels between 6.5% and 9% that reflect the unique challenges facing the continent (Akinsola and Odhiambo, 2017). However, even within this regional context, significant variation exists across individual countries influenced by factors ranging from natural resource endowments to governance quality to trade patterns. The evolving global economic environment adds another dimension to this intricacy. Globalization has increased economic interdependencies making individual economies more vulnerable to external price shocks and monetary spillovers from major economies. Financial technology developments, digital currencies, and changing payment systems are creating new channels for monetary transmission that may alter traditional inflation-growth relationships (Aiello et al., 2023). These developments suggest that threshold relationships identified in historical data may not remain stable as economic structures continue to evolve.

What has been emphasized as more knowledge and understanding of the inflation-growth relationship has been understood is that both excessively high and persistently low inflation can be detrimental to economic growth challenging the idea that lower inflation is always preferable. When inflation remains significantly below identified thresholds for extended periods it can create deflationary pressures that worsen debt dynamics, limit monetary policy effectiveness and increase economic vulnerability (IMF, 2015). Central banks have recognized this complication with major institutions confirming that both extreme high and low inflation rates can disrupt economic stability (ECB, 2017). This understanding explains why most advanced economies target positive inflation rates around 2% rather than attempting to achieve zero inflation. Tanzania presents a compelling case for examining these intricate inflation-growth dynamics. Since 2000 the country has demonstrated remarkable economic resilience, sustaining robust growth rates of 6% to 7% annually. This

growth has been driven by a diversified economic base made up of mining operations, agricultural production and a growing tourism sector. This has contributed to considerable improvements in living standards as evidenced by the elevation of GDP per capita from approximately \$500 to \$1,200 by 2025 (World Bank, n.d). The country achieved a significant milestone in 2020 when it was upgraded from low-income to lower-middle-income status by the World Bank reflecting decades of sustained economic progress. Tanzania's inflation experience has been equally noteworthy, with rates spiking to 16% during the early 2010s due to food and fuel price pressures before stabilizing below 5% by 2025. Despite Tanzania's economic achievements and clear policy objectives significant empirical gaps persist in understanding the country's optimal inflation threshold. A review of existing studies reveals striking discrepancies in findings that show the need for additional research. Epaphra (2016) identified what appeared to be a U-shaped relationship between inflation and growth. This research suggested that economic growth suffers at both very low and very high inflation rates, with an optimal narrow range estimated at 3.25% to 3.75%. Later study by Mbowe and Mpango (2024) reached noticeably different conclusions estimating a much higher threshold level of 7%. This substantial discrepancy between studies with optimal inflation ranges emphasized the sensitivity of threshold estimates to methodological choices, data periods and analytical approaches. This study uses a quadratic regression approach to determine the inflation threshold for Tanzania's economy. The analysis begins from the 1990, marking the period when the country underwent significant privatization, financial sector reforms, and other structural adjustments that continue to shape its economic framework today (Joseph, 2024; Lwesya and Ismail, 2021). This starting point ensures the analysis captures the modern economic structure that remains relevant for current policy formulation.

## **2. Literature review**

### **2.1. Theoretical Framework**

A wide range of theories have attempted to explain the relationship between inflation and economic growth, spanning classical, monetarist, structuralist, and endogenous growth paradigms. Classical economists view inflation as neutral in the long run, while monetarists argue that inflation is primarily a monetary phenomenon that erodes macroeconomic stability and discourages investment (Friedman, 1968). Structuralist models applied to developing economies, acknowledge inflation as an outcome of supply blockages and institutional constraints with more complicated implications for growth (Sunkel, 1960). Endogenous growth models tend to treat inflation as a distortionary factor that hampers innovation and reduces productivity (Barro, 1995). What unites many of these frameworks is their assumption of a monotonic relationship between inflation and growth either consistently negative or neutral over time. This assumption has increasingly come under scrutiny, both theoretically and empirically. None of these models explain in a convincing way the observed non-linear dynamics whereby low to moderate inflation sometimes coincides with improved economic performance, especially in economies with underutilized resources or rigid price systems. This is better explained by Tobin's portfolio-balance theory and Keynesian demand-side theory.

### 2.1.1. Tobin's Portfolio-Balance Theory

James Tobin (1965) advanced a framework in which inflation can influence long-run economic growth by altering the composition of asset holdings. Unlike classical models where money is neutral, Tobin treated money and physical capital as imperfect substitutes in wealth portfolios. When inflation rises, the real return on holding money declines which prompts economic agents to shift their portfolios toward real assets, specifically capital. This reallocation leads to greater investment, higher capital accumulation and as a result, faster economic growth. The demonstration is as follows. Let total wealth be allocated between money balances  $M$  and physical capital  $K$ , with returns  $r_m = -\pi$  for money and  $r_k > 0$  for capital. As expected inflation  $\pi$  increases, the relative attractiveness of capital improves. Assuming a standard production function  $Y=F(K)$ , and savings rate that increases with inflation,  $s(\pi)$ , the capital accumulation dynamic becomes;

$$K' = s(\pi) \times F(K) - \delta K$$

Where  $\delta$  is the depreciation rate. The important insight is that  $\frac{ds}{d\pi} > 0$  holds only for low to moderate inflation levels. Thus, inflation induces a shift away from idle balances toward productive investment, supporting growth (Tobin, 1965). However, the mechanism has limits. At higher levels of inflation, uncertainty, volatility, and financial repression can outweigh portfolio reallocation benefits. Levhari and Patinkin (1968) argued that if inflation also reduces real income or raises consumption incentives, the savings function  $s(\pi)$  may flatten or even decline. Dornbusch and Frenkel (1973) showed that once inflation induces expectations of further macroeconomic instability, the reallocation toward capital breaks down. Ghatak and Sánchez-Fung (2007) suggested in developing economies, the idea that the Tobin effect functions and may operate within a narrow band of inflation usually below 10% beyond which the benefits vanish. Tobin's theory supports a non-linear relationship between inflation and growth, governed by a threshold beyond which inflation becomes counterproductive.

### 2.1.2. Keynesian Demand-Side Theory

Another foundation for non-linearity stems from Keynesian macroeconomics, mainly the analysis of economies operating below full employment due to insufficient aggregate demand. In such settings, inflation can play a positive role in stimulating output through two principal channels. These are real wage adjustment and real interest rate effects. Keynes (1936) emphasized that nominal wages are mostly downwardly rigid due to contracts and resistance to nominal wage cuts. This rigidity prevents labor markets from clearing during recessions. Inflation, by raising the general price level  $P$  effectively reduces the real wage  $w_r = \frac{W}{P}$  where  $W$  is the nominal wage. When real wages fall in this way, firms are more willing to hire labor, increasing employment and output. Simultaneously, inflation lowers the real interest rate when nominal rates are sticky in the short term, improving investment. The real interest rate is defined as;

$$r = i - \pi^e$$

Where  $i$  is the nominal interest rate and  $\pi^e$  is expected inflation. A rise in  $\pi^e$  reduces  $r$ , which ends up stimulating investment and aggregate demand. These mechanisms are captured within the IS-LM model, where investment  $I(r)$  rises as real interest rates fall, pushing output  $Y$  higher. Empirical studies have reinforced this view. Akerlof et al (1996) argue that moderate inflation smoothes the labor market by enabling real wage adjustments that support employment. IMF (1999) also finds that countries with very low inflation below 3% may suffer from output volatility suggesting that moderate inflation can improve macroeconomic stability. Card and Hyslop (1996) provide microeconomic evidence that nominal wage rigidity is widespread, further validating the Keynesian explanation of how inflation supports employment when prices rise modestly but wages are slow to adjust. Like Tobin's theory, Keynesian theory also suggests a non-linear relationship. At low inflation levels, price increases facilitate adjustment and stimulate demand but beyond a threshold, inflation generates distortions that harm economic performance.

## 2.2. Empirical review

Global analyses of inflation thresholds reveal stark contrasts between developed and developing economies emphasizing structural differences in economic resilience. Azam and Khan (2022) examined data from 1975 to 2018, identifying thresholds of 5.36% for developed economies and 12.23% for developing ones. Beyond these levels, inflation significantly limits economic growth likely through reduced investment efficiency and distorted prices. This pattern resonates in analyses of D-8 Islamic developing countries including Bangladesh, Indonesia, Iran, Malaysia, Pakistan, and Turkey where thresholds around 11.88 to 12.88% were estimated from 1971 to 2014. Below these levels, inflation facilitates resource allocation and supports growth; above them, economic output declines due to inefficiencies (Aydin et al., 2019; Hoomani Farahani et al., 2021). These findings suggest that developing economies can tolerate moderate inflation, but exceeding threshold points disrupts economic stability, necessitating tailored monetary frameworks. Asia's dynamic economies exhibit a range of inflation thresholds, influenced by trade integration and monetary policy. In China, stringent controls yield a low 2% threshold, above which inflation hampers growth, reflecting a growth model reliant on export stability (Chen & Kim, 2024). India's situation is a bit complicated, presenting thresholds ranging from 4.77% to 7.84%. A vector autoregression analysis estimated 4.77%, while others reported 6% and 7.84%, noting an asymmetric trade-off where reducing inflation below 6% could cut long-term growth by 0.8 percentage points compared to a 0.3 point loss from slight overshoots suggesting that overly restrictive policies carry significant costs (Mallick and Sethi, 2019; Dholakia et al., 2023). Southeast Asian nations show similar non-linear patterns. A study of ASEAN-5 countries from 2000 to 2016 reported thresholds from 1.16% in Singapore to 5.26% in Indonesia, with inflation stimulating growth below these levels and impeding it above through reduced competitiveness (Galih and Safuan, 2018). Indonesia's provincial data from 1994 to 2019 revealed regional thresholds of 5.75% in western provinces and 9.64% in eastern ones which converges to a national 9.59% or 5.22% excluding crisis periods (Kusumatrisna et al., 2022). Vietnam's analysis from 1986 to 2013 identified a 7% threshold with inflation slightly boosting growth below but reducing it by 0.143–0.21% per percentage point above (Thanh, 2015). Looking at South Asian evidence, Bangladesh has 7.84% and 8% thresholds, alongside Pakistan's 6% threshold which



indicates negligible effects below and reduced growth above reflecting reliance on stable monetary environments (Asaduzzaman, 2021; Younus, 2015; Arby & Ali, 2017). European economies demonstrate resilience to inflation's effects, shifting policy focus to monetary instruments. A study of European Union economies from 2000 to 2023 found no robust evidence that inflation directly harms growth. Instead, aggressive monetary tightening to curb inflation poses greater risks, as its adverse effects outweigh the ambiguous benefits of rapid inflation reduction suggesting that robust institutions and integrated markets allow tolerance for moderate inflation (Pappas & Boukas, 2025). Looking at evidence from Oceanic regions, Papua New Guinea is said to have a 12% threshold above which inflation negatively affects growth, while below, the relationship remains unclear, reflecting challenges in resource-dependent economies with volatile price dynamics (Tumsok, 2023). African economies, marked by structural constraints and volatility tolerate higher inflation thresholds. A panel threshold regression across African nations estimated a 6.7% threshold, rising to 9% for low-income and 6.5% for middle-income countries with low inflation supporting growth in middle-income settings but adverse effects above these levels (Ndoricimpa, 2017). Sub-Saharan Africa regional communities including SADC, COMESA, ECCAS, and the West African Monetary Zone show thresholds of 9% to 10.6% from 2001 to 2021, suggesting that strict monetary convergence criteria may limit growth potential (Pambu, 2023; Olowofeso, 2022). In South Africa studies identify thresholds around 5.4% to 6%, with inflation below stimulating growth and employment, while exceeding 6% exacerbates income inequality and hampers gross domestic product (Khoza et al., 2016; Ndou, 2024). Ethiopia's high 16.46% threshold reflects distinct regimes where low inflation aligns with robust gross domestic product but high inflation signals decline though still positive (Mulu et al., 2025). In North Africa, Morocco's 1990–2019 data suggest a 3% threshold, with inflation insignificant below but negative above, prompting recommendations to relax monetary policies at 2% (Sadok et al., 2022). In Kenya, threshold regression analyses estimate thresholds around 5.83% to 6.13% with inflation below 6.13% stimulating significant growth. A unit increase at 5.83% improves economic growth by 2.89% and positive but potentially weaker effects between 6.13% and 9.63%, with adverse impacts above 9.63% (Mugi, 2017; Kiptum, 2022). In Tanzania, studies are fewer but reflect similar variability. An early study of three EAC countries found an average threshold of 8.46%, with Tanzania's at 8.8%, suggesting moderate inflation could support growth (Yabu and Kessy, 2015). Recent analyses indicate lower tolerance. Manamba (2016) estimated thresholds between 3.25% and 3.75%. Maiga (2024) found high inflation generally slows GDP growth in Tanzania without specifying a threshold. A 2023 study confirmed a negative causal link from inflation to growth without quantifying a threshold (Nkwabi, 2023). Tanzanian thresholds range from 3.25% to 8.8%, reflecting global variability. The limited number of studies and inconsistent threshold estimates emphasize the need for more precise analysis to guide Tanzania's monetary policy. Across multiple studies, what is evident is the non-linear inflation-growth relationship, with thresholds lower in advanced economies of around 4% to 6% and higher in developing ones of around 7% to 12%. Africa and East Africa align with the latter, but methodological differences limit applicability. The variability in threshold estimates, especially ranges rather than precise values represent critical gaps. Tanzania's achievement of lower-middle-income status from low-income in 2020 may change inflation thresholds (World Bank, 2020).

Using the standards and targets set when the country didn't achieve this upgrade may leave Tanzania chasing targets which are a level below what they should actually aspire for. Yet no studies examine this transition.

### 3. Methodology

#### 3.1. Data source and variables

The study uses annual time series data for Tanzania from 1990 to 2024. The data are collected from two main sources: the World Bank's World Development Indicators (WDI) and the International Monetary Fund (IMF) databases. The key variables are:

**Table 2.1.** *Variables used*

| Variable              | Proxy                                                       |
|-----------------------|-------------------------------------------------------------|
| Economic Growth (GDP) | GDP Growth (annual %)                                       |
| Inflation (INF)       | Inflation, Consumer Prices (annual %)                       |
| Investment (GCF)      | Gross Fixed Capital Formation (% of GDP)                    |
| Population Growth     | Population Growth (% annual)                                |
| Government Spending   | General Government Final Consumption Expenditure (% of GDP) |
| Trade Openness        | Trade (% of GDP)                                            |
| Money Supply (M2)     | Broad Money Supply M2 (% of GDP)                            |

Before estimating the model, the study performs several diagnostic checks. Descriptive statistics are generated to understand the general behavior of the variables, including mean, standard deviation, minimum and maximum values. This helps detect outliers or abnormal trends in the data. Then the Augmented Dickey-Fuller (ADF) test is conducted to check the stationarity of all variables. This is important because time series data usually have unit roots, and using non-stationary variables can lead to spurious regression results. The ADF test is applied both at level and first difference. If the results show a combination of  $I(0)$  and  $I(1)$  variables, the study proceeds to test for cointegration using the Bounds testing approach proposed by Pesaran et al. (2001). This approach is suitable when the data is a mix of stationary and non-stationary variables. Once the cointegration relationship is confirmed, the Autoregressive Distributed Lag (ARDL) model is estimated. The ARDL model is chosen because of its flexibility in dealing with small sample sizes and its ability to handle variables that are integrated at different levels ( $I(0)$  and  $I(1)$ ), as long as none are  $I(2)$ . It also allows simultaneous estimation of short-run and long-run relationships. The ARDL model includes lagged values of both the dependent and independent variables to capture dynamic behavior in the data. The optimal lag length is selected using Akaike Information Criterion (AIC) or Schwarz Bayesian Criterion (SBC). The long-run coefficients from the ARDL model are then used to compute the inflation threshold using the quadratic equation described in the quadratic model earlier.

#### 3.2. Model Specification

To investigate how inflation affects economic growth and whether there is a threshold beyond which its effect turns negative, this study follows the approach used by several earlier researchers who applied non-linear models. In particular, a quadratic form is used to allow for non-linearity between inflation and growth, which makes it possible to capture the potential threshold. The idea is that at low levels, inflation may not harm growth or may even support it but beyond a certain point, its impact becomes negative.

$$\log GDP_t = \alpha_0 + \beta_1 \log INF_t + \beta_2 (\log INF_t)^2 + \beta_3 \log GCF_t + \beta_4 \log POPG_t + \beta_5 \log GOVS_t + \beta_6 \log TRADE_t + \beta_7 \log M2_t + \varepsilon_t$$

Here, the dependent variable is the logarithm of real GDP growth, while the independent variables include the logarithm of inflation and its square to capture the non-linearity, along with other control variables like investment, population growth, government spending, trade openness, and money supply. All variables are converted into natural logarithms except for those already in percentage growth form. Converting variables into logarithms reduces the scale of variables, making interpretation easier, especially when variables are in different units. Taking logs can help stabilize variance and reduce heteroskedasticity. Coefficients in log models can be interpreted as elasticities, which is useful for policy analysis. Logarithmic transformation is suitable when dealing with exponential growth trends often found in macroeconomic data (Gujarati, 2009). The threshold inflation level is derived from the quadratic regression by taking the first derivative of GDP with respect to inflation and setting it to zero:

$$\frac{d(\log GDP)}{d(\log INF)} = \beta_1 + 2\beta_2 \log INF = 0$$

Solving this equation for log INF;

$$\log INF = -\frac{\beta_1}{2\beta_2}$$

Exponentiating both sides, the actual threshold inflation level is:

$$INF = \exp\left(-\frac{\beta_1}{2\beta_2}\right)$$

This gives the turning point at which the effect of inflation on growth changes from positive or neutral to negative.

## 4. Results

### 4.2. Descriptive Statistics

To get a general picture of how the variables have behaved over the period from 1990 to 2024, basic summary statistics were calculated. These include the mean, median, maximum and minimum values, standard deviation, and normality checks.

**Table 4.1.** *Descriptive Statistics*

| Variable     | LGDP    | LINF   | LGCF    | LPOPG   | LGOVS   | LTRADE | LM2     |
|--------------|---------|--------|---------|---------|---------|--------|---------|
| Mean         | 1.5212  | 2.1487 | 3.2452  | 1.0319  | 2.2679  | 3.5967 | 2.9275  |
| Median       | 1.7185  | 1.8870 | 3.4391  | 1.0296  | 2.2805  | 3.5707 | 3.0028  |
| Std. Dev.    | 0.5845  | 0.7322 | 0.4012  | 0.1374  | 0.2089  | 0.2313 | 0.2110  |
| Skewness     | -1.9070 | 0.5787 | -0.5594 | -0.7809 | -0.1296 | 0.0512 | -0.5024 |
| Kurtosis     | 6.3564  | 2.0422 | 2.1421  | 5.0982  | 2.4195  | 1.9813 | 1.8825  |
| Jarque-Bera  | 36.569  | 3.1977 | 2.8160  | 9.6934  | 0.5724  | 1.4847 | 3.1995  |
| Probability  | 0.0000  | 0.2021 | 0.2446  | 0.0078  | 0.7510  | 0.4759 | 0.2019  |
| Sum          | 51.721  | 73.058 | 110.33  | 35.085  | 77.111  | 122.28 | 99.536  |
| Observations | 34      | 34     | 34      | 34      | 34      | 34     | 34      |

The mean of LGDP is around 1.52, but with a wide range from about -0.54 to 2.04. This indicates there were years with low or even negative growth, and the high negative skewness confirms that the distribution is pulled more to the left. LINF averages 2.15, showing moderate inflation levels during the period. It varies from 1.19 to 3.58, which reflects Tanzania's experience with both low and high inflation years. LGCF and LPOPG have means of 3.25 and 1.03 respectively, with small standard deviations, suggesting they didn't fluctuate too much over the years. LGOVS, LTRADE, and LM2 also show somewhat a stable behavior, with values clustered around their means and low dispersion. There are no extreme outliers for these variables, and the distributions seem symmetric in most cases. From the Jarque-Bera test results, only LGDP and LPOPG show clear signs of non-normality. But since the ARDL model is robust to normality violations, this isn't a major issue.

#### 4.1. Unit root test

Before estimating the model, it's important to check whether the variables are stationary to avoid spurious results. The ADF test was used to test for unit roots, and the results are summarized in table 4.2 below.

**Table 4.2.** Unit root test from ADF

| Variable | At Level  |           |        | At First difference |           |        |
|----------|-----------|-----------|--------|---------------------|-----------|--------|
|          | t-stat    | 5%        | Prob   | t-stat              | 5%        | Prob.  |
| LNGDP    | -2.481884 | -2.954021 | 0.1288 | -6.159559           | -2.957110 | 0.0000 |
| LNINF    | -1.792110 | -2.954021 | 0.3777 | -5.852451           | -2.960411 | 0.0000 |
| LNGCF    | -0.978429 | -2.954021 | 0.7493 | -6.010785           | -2.957110 | 0.0000 |
| LNPOPG   | -2.438172 | -2.960411 | 0.1401 | -7.160039           | -2.960411 | 0.0000 |
| LNGOVS   | -3.151286 | -2.960411 | 0.0330 | -5.744097           | -2.889314 | 0.0000 |
| LNTRADE  | -2.472033 | -2.957110 | 0.1315 | -3.723579           | -2.957110 | 0.0084 |
| LM2      | -1.695823 | -2.957110 | 0.4237 | -3.770813           | -2.957110 | 0.0075 |

Most of the variables including LNGDP, LNINF, LNGCF, LNPOPG, LNTRADE, and LNM2 were found to be non-stationary at level but became stationary after taking the first difference, meaning they are integrated of order one, or I(1). This is shown by the fact that their t-statistics at level are not more negative than the 5% critical values, but become significant at first difference. Also, all their prob values become less than 0.05 which proves their significance. Since the variables are a mix of I(0) and I(1), but none are I(2), it is appropriate to proceed with the ARDL model which allows for such a combination. This also justifies using the Bounds test to check for cointegration among the variables.

#### 4.3. Bounds Test for Cointegration

Since the ADF results showed that the variables are a mix of I(0) and I(1), the ARDL bounds testing approach was used to check whether a long-run relationship exists among them.

**Table 4.3.** Bounds test

| F-Stat    | Critical Value | Lower bound I(0) | Upper bound I(1) |
|-----------|----------------|------------------|------------------|
| 25.062407 | 5%             | 2.17             | 3.21             |

The computed F-statistic from the bounds test is 25.06, which is well above the upper bound critical value of 3.21 at the 5% significance level. This means the null hypothesis of no cointegration was rejected. In simpler terms, this suggests that the variables move together in the long run a stable long-term relationship exists between GDP growth and its determinants, including inflation.

#### 4.4. ARDL Estimation and Threshold Calculation

With the confirmation of cointegration from the bounds test, the next step was to estimate the ARDL model. The model includes the lagged levels and first differences of the main variables, with a special focus on inflation (LINF) and its squared term (LINF<sup>2</sup>) to capture the possibility of a non-linear threshold effect on economic growth.

**Table 4.4.** *ARDL Long run Coefficients*

| Variable               | Coefficient | Std. Error | t-Statistic | Prob.  |
|------------------------|-------------|------------|-------------|--------|
| C                      | -4.3900     | 0.8865     | -4.9522     | 0.0003 |
| LGDP(-1)               | -1.5005     | 0.1262     | -11.8876    | 0.0000 |
| LINF(-1)               | 3.8118      | 0.5760     | 6.6181      | 0.0000 |
| LINF <sup>2</sup> (-1) | -1.0844     | 0.1241     | -8.7402     | 0.0000 |
| LGCF(-1)               | -1.7762     | 0.2699     | -6.5801     | 0.0000 |
| LPOPG(-1)              | 0.2282      | 0.3965     | 0.5757      | 0.5755 |
| LGOVS(-1)              | -0.4164     | 0.3038     | -1.3704     | 0.1957 |
| LTRADE                 | 1.1891      | 0.5475     | 2.1721      | 0.0506 |
| LM2(-1)                | 2.1029      | 0.8216     | 2.5595      | 0.0250 |

From the long-run results:

- The coefficient for lagged LINF(-1) is 3.81 and is statistically significant ( $p < 0.01$ ).
- The coefficient for LINF<sup>2</sup>(-1) is -1.08, also significant ( $p < 0.01$ ).

This shows an inverted U-shaped relationship between inflation and GDP growth meaning inflation at first boosts growth but beyond a certain point it begins to hurt growth. This justifies the use of a quadratic equation in the model to capture that turning point. To determine the inflation threshold, we follow the standard procedure of taking the first derivative of the regression equation with respect to inflation and setting it equal to zero:

$$\frac{d(\log GDP)}{d(\log INF)} = \beta_1 + 2\beta_2 \log INF = 0$$

Substituting the coefficients

$$3.81 + 2(-1.08) \times \log(INF) = 0$$

Solving for log(INF):

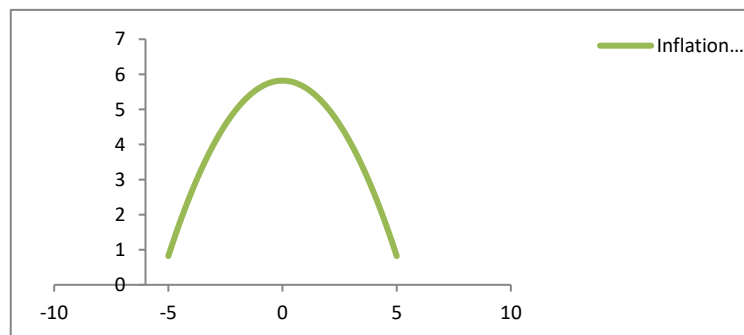
$$-1.08 \times 2 \log(INF) = 3.81$$

$$\log(INF) = \frac{3.81}{2 \times 1.08} \approx 1.76$$

Exponentiating both sides to get the threshold in regular terms:

$$INF = e^{1.76} \approx 5.82\%$$

The threshold inflation for Tanzania's inflation in relation to economic growth is 5.82%.

**Figure 4.1.** *Turning point/threshold inflation*

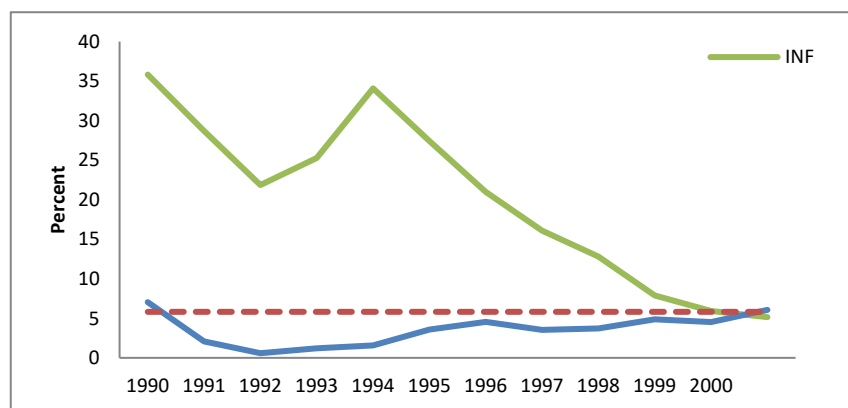
**Source:** Researcher (2025).

So, the estimated inflation threshold for Tanzania is about 5.8%. Below this level, inflation seems to not hinder economic growth, while above it, the impact becomes negative. This kind of non-linear behavior is important for policymakers because it suggests that inflation targeting should aim to keep inflation below this threshold to avoid harming long-run growth.

#### 4.5. Perspective from different decades

##### 4.5.1. High Inflation, Low and Unstable Growth (1990 to 2000)

The decade from 1990 to 2000 was marked by extremely high inflation with most years far above the 5.82% threshold. In fact, in 1990 inflation stood at 35.83%, and although growth was decent that year at 7.05%, the following years saw major drops in GDP. In 1991 and 1992, inflation was still above 20%, but growth fell to as low as 0.58%. This pattern continued throughout the decade, with inflation averaging around 20–30%, while growth stayed modest and inconsistent.

**Figure 4.2.** *Inflation and economic growth 1990-2000*

**Source:** Researcher (2025).

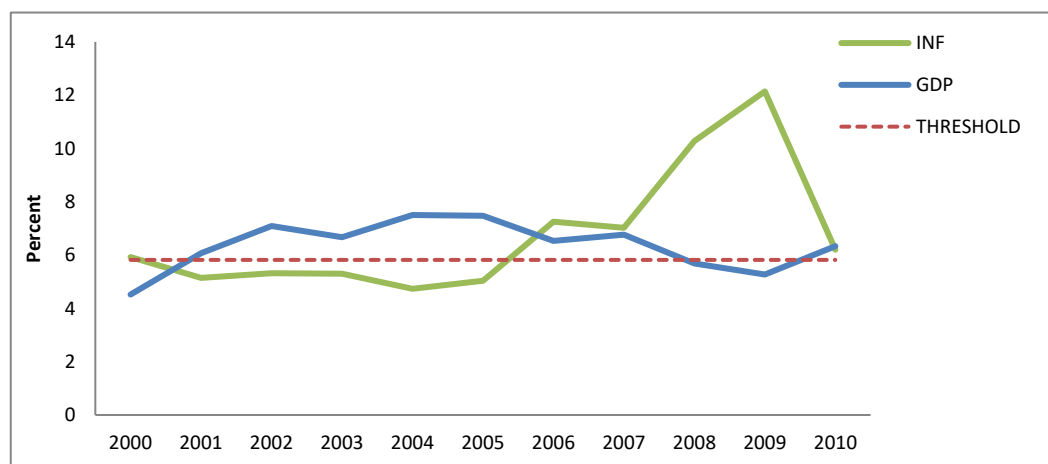
The year 1994, for instance, had 34.08% inflation but only 1.57% growth. Even as inflation began to decline slightly by the late '90s, it was still high at 16.09% in 1997 and 12.80% in 1998. Only in 1999 did inflation begin to approach single digits at 7.89%, and GDP growth

improved to 4.86%. Overall, this period was far from the threshold, and the frequent inflation shocks likely affected the country's ability to maintain stable growth. It's clear that this was the most inflationary and unstable decade in the dataset.

#### 4.5.2. Approaching the Threshold with Stronger Growth (2000–2010)

The 2000s showed a major improvement in both inflation control and GDP growth. Right at the start of the decade, in 2000, inflation stood at 5.92%, just slightly above the estimated threshold. This was followed by a few years from 2001 to 2005 where inflation mostly stayed below or right around the 5.82% mark. In 2001, inflation was 5.15%, and GDP grew by 6.07%. In 2004 and 2005, inflation was 4.74% and 5.03% respectively, while growth remained strong at around 7.5%. This suggests that inflation closer to or under the threshold may have supported a more favorable environment for growth. However, after 2006, inflation started to rise again, hitting 7.25% in 2006 and remaining above the threshold through to 2009. The highest was in 2009, when inflation reached 12.14%, though growth remained positive at 5.27%. While inflation wasn't as wild as the previous decades, this decade had a lot of volatility. Early years performed well when inflation was close to or below the threshold, but the later years again showed the downside of going beyond it. This coincided with the economic crisis from 2008

**Figure 4.3.** *Inflation and economic growth 2000-2010*



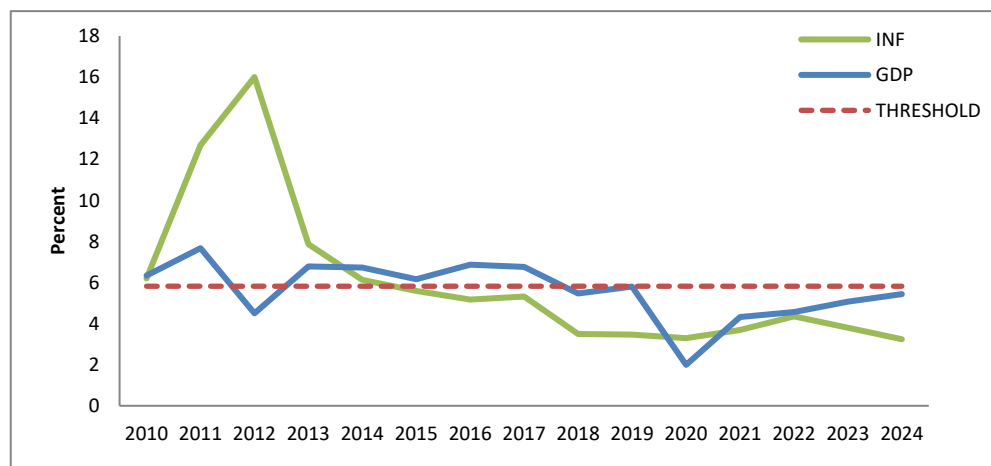
Source: Researcher (2025).

#### 4.5.3. Stable inflation below the threshold and steady growth (2010–2024)

From 2010 onward, inflation in Tanzania showed much more stability and remained mostly below the 5.82% threshold. Although there was a brief spike in 2011 and 2012 with inflation at 12.69% and 16% respectively, most of the following years saw inflation drop significantly. By 2015, it had gone back down to 5.59%, and since then it has mostly remained in the 3–5% range. At the same time, GDP growth was relatively stable and healthy, averaging around 6% in many years. For example, in 2017, inflation was just 5.32%, and growth was 6.76%. Even during the global pandemic in 2020, inflation remained low at 3.29%, and although growth dipped to 1.99%, it recovered quickly in the

following years. The most recent years, like 2022 to 2024, show inflation well below the threshold while growth remains moderate. Compared to the previous decades, this is the closest Tanzania has come to consistently staying below the 5.82% mark.

**Figure 4.3.** *Inflation and economic growth 2010-2024*



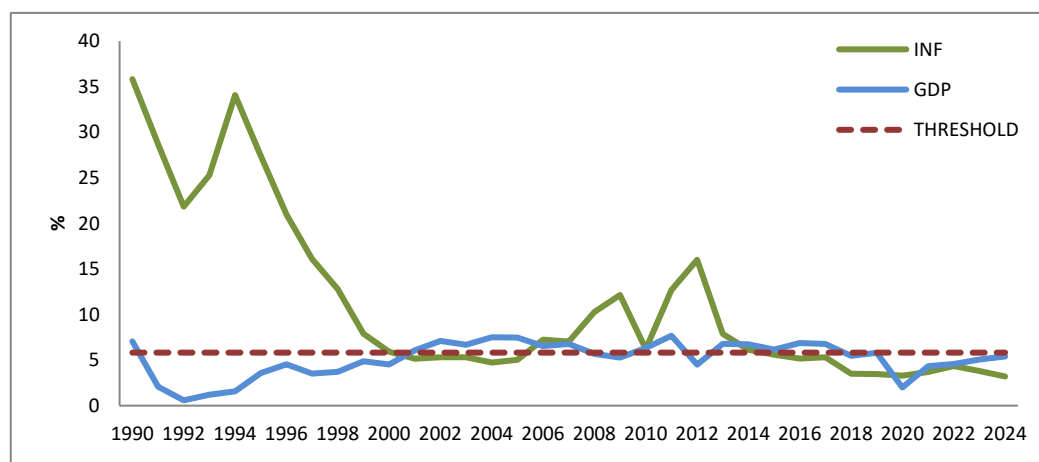
Source: Researcher (2025).

## 5. Discussions

The results of this study confirm the existence of a non-linear relationship between inflation and economic growth in Tanzania, with a clear turning point. The threshold level of inflation was estimated at 5.82%, meaning that inflation below this level has no detriment on economic growth, while inflation above it becomes harmful. This finding aligns with the general belief that a moderate amount of inflation can support growth, but too much of it becomes a drag on the economy. When comparing this threshold to past literature, we see that it falls within the middle of what other studies have found for Tanzania. Yabu and Kessy (2015) found a threshold of 8.8%, while Manamba (2016) suggested a much lower range of 3.25% to 3.75%. So, the estimated 5.82% seems to sit somewhere in the middle of these earlier results. One possible explanation for this middle ground could be that Tanzania's economic structure has slightly changed in recent years, but not enough to drastically shift inflation dynamics. This result is also somewhat in line with regional studies. Ndoricimpa (2017) found a threshold of 6.7% for Africa. However, other studies like Inam and Ebong (2023) for Nigeria and Mulu et al. (2025) for Ethiopia found much higher thresholds of 13% and 16.46% respectively.

This suggests, countries with different macroeconomic environments may tolerate higher inflation levels before growth is affected. Since Tanzania is still considered a low-middle income country, and relatively more stable in terms of inflation targeting, it makes sense that its threshold is not as high as in countries with more volatile inflation histories. The movement between inflation and economic growth also confirmed a negative relationship above the threshold level.



**Figure 5.1.** *Inflation and economic growth 1990-2024*

**Source:** Researcher (2025).

Whenever inflation is above the threshold level of 5.82%, economic growth seems to decline. The 1990s is the period where inflation was the furthest from the threshold peaking above 35% in 1990 and averaging above 20% in the first half of the decade. This period coincided with major structural reforms, including trade liberalization, financial sector restructuring, and privatization under the structural adjustment programs (Balele et. al, 2018). While these reforms aimed to improve efficiency and attract investment, they initially destabilized prices due to exchange rate devaluations, removal of subsidies, and fiscal imbalances. From 2000 to 2007 inflation mostly hovered near or below the 5.82% threshold alongside stable growth of around 6% to 7.5%. The global financial crisis and global food and fuel price shocks from 2008 onwards disrupted prices which shot inflation to around 12%. An important observation is that the decade between 2015 and 2025 was the most stable period for inflation. Throughout this entire time, inflation never once crossed the estimated 5.82% threshold, staying consistently below it. This is quite significant because according to the findings of Maiga (2024), Tanzania's economic growth tends to perform better under low and stable inflation conditions, even though his study didn't specify a threshold. The fact that GDP growth also remained relatively steady during this low inflation decade averaging around 5% to 6% supports the view that moderate inflation is good for growth but too much of it is damaging. This reinforces the idea that the Bank of Tanzania's recent monetary policies which managed to keep inflation low around 5%, might have contributed to more stable growth during this time. It also shows that Tanzania has already experienced what seems to be an optimal inflation environment, and maintaining this could be key to future economic success.

## 6. Conclusion

This study set out to examine the threshold effect of inflation on economic growth in Tanzania using the ARDL approach and a quadratic inflation term to capture non-linearity. The main objective was to determine whether there is a specific inflation level beyond which economic growth is negatively affected. The secondary objective was to review the

overall relationship between inflation and economic growth across the years, considering the existence of such a threshold. The results showed a clear inflation threshold at 5.82%, meaning that inflation below this level generally supports growth, while inflation above it has a harmful effect. This confirms the idea that inflation impacts economic growth in a non-linear way moderate inflation may reflect a growing economy, but excessive inflation reduces purchasing power, increases uncertainty, and slows investment. Examining the historical data, Tanzania has managed to keep inflation consistently below this threshold during the period from 2015 to 2025, which corresponds to a relatively stable economic growth phase. This suggests the country has been operating within a safe zone for inflation and maintaining this stability should remain a priority.

## **7. Policy recommendation**

From the results of this study, it can be seen clear that keeping inflation under control is important for Tanzania's economic growth. The Bank of Tanzania should continue focusing on policies that keep inflation below the threshold of about 5.8%, since going above that tends to hurt growth. This means managing the money supply carefully and avoiding actions that could push inflation too high. At the same time, it is important that the government manages its spending wisely. If fiscal policy leads to big deficits or too much borrowing, it can cause inflation to rise beyond the safe level. So, coordinating monetary policy with fiscal discipline will help keep inflation stable and predictable. Improving how inflation data is collected and monitored can make a big difference. If the authorities have better and quicker info on inflation trends, they can react faster and avoid surprises that might harm growth. It is worth noting that very low inflation or deflation isn't good either. The goal should not just be to keep inflation low, but to keep it moderate and steady, where it supports growth instead of holding it back.

## **Contributions**

The main author's name is Christopher Sylvester Machibula (CSM) and author's email is christopher.machibula@mu.ac.tz and the corresponding author is Neema Aspedito Mfugale (NAM). The authors confirm his contribution to his work as follows: Research concepts and design were provided by CSM and NAM. Data collection was provided by CSM, and NAM. And interpretations of the results were provided by CSM and NAM. Manuscript design production was provided by CSM and NAM. All authors reviewed the results and approved the final version of the manuscript.

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## **Conflict of interest**

No potential conflict of interest was reported by the author(s).

## **Data availability statement**

Upon reasonable request, the appropriate author (CSM) will provide the data.

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## **Sustainable consumption and experimental economics – a bibliometric analysis**

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**Abstract.** *Sustainable consumption represents a crucial research area for modern debates and in addressing globally salient environmental challenges, while experimental economics provides rigorous methods for creating empirically grounded solutions. This study aims to empirically analyze the intersection of the two fields of study, especially in the context of the current climate crisis. The analysis focuses on mapping the dominant research themes, the main actors involved and the collaboration and the influence networks that shape this interdisciplinary area. The article proposes a bibliometric analysis, using VOSviewer software, based on a dataset of 2,596 articles extracted from the Web of Science database. The study includes co-occurrence, co-authorship and co-citation analyses, with the aim of highlighting the intellectual and social structure of the field and the results indicated an exponential growth in publications, especially after 2017. Furthermore, the analysis underscored a geographical shift in scientific productivity, concentrated in Asia, particularly China and India, while the theoretical foundations remain predominantly Western. In addition, collaboration networks highlight the central role of China and the United States as global research hubs. The study provides a comprehensive quantitative mapping of this complex interdisciplinary domain, delineating its intellectual structure, key actors and emerging trends.*

**Keywords:** sustainable consumption, experimental economics, bibliometric analysis, VOSviewer.

**JEL Classification:** A1, O1, O3.

## 1. Introduction

Sustainable consumption is about minimizing negative impacts on the environment in terms of finding ways to optimize the usage of resources so that both current and future generations could still benefit from them (Sargin & Dursun, 2023). Although economic growth can be considered a threat to the environment, it is essential for all business agents to adopt a “to do more and better with less” attitude when it comes to reducing the environmental impact, allocating resources efficiently, using renewable resources, managing waste, and, overall, implementing circular economy processes (UN, 2021). The same attitude should be adopted by individuals, households and governments altogether (Vargas-Merino, et al., 2023).

Experimental economics refers to studying economic questions by applying scientific experimental methods. In order to do that, despite using only historical data and theoretical models, economists observe the ways in which people make economic decisions by creating controlled environments in laboratories or in the field (Eckel, 2014). These controlled experiments in which human behavior is observed when tested against incentives are linked to behavioral economics. This branch of economics investigates consumption patterns based on people’s misconceptions, prejudices and social characteristics. Research in this domain gains importance in terms of sustainability due to finding solutions for allocating scarce resources more efficiently, so as to encourage sustainable consumption strategies (Zengi, 2023).

As this topic is well-known nowadays, due to the climate change issues, it is extremely important for researchers to add value to it and to innovate constantly. Thus, this bibliometric analysis has the scope of identifying the current state of knowledge in the field of sustainable consumption and experimental economics, so that researchers interested in this area can assess potential future topics of discussions for finding solutions to the problem of unsustainable overconsumption. Our study consists of the following research questions: (1) What are the main existent academic research topics and subjects on sustainable consumption and experimental economics? (2) What are the subject areas that shape the study around sustainable consumption and experimental economics? (3) Which countries, institutions and authors contribute the most to the research field of sustainable consumption and experimental economics at the moment? (4) Which authors are the most cited in this field of study and what are the current links between organizations and countries? They are explored using the analytics from the chosen database and network landscapes from VOSviewer software in the Results and Discussions section, followed by Conclusions and References.

## 2. Literature Review

### 2.1. Sustainable Consumption: Theoretical Foundations

The concept of sustainable consumption is essential in the debates on sustainable development and the ecological crises that have arisen as a result of modern production and



consumption processes. This concept was initiated as a corrective mechanism aimed at diminishing the negative environmental externalities resulting from consumerism (Jackson, 2005). Early strategies focused on this concept were oriented towards efficiency, by supporting recycling or using diminished volume of resources and adopting less harmful products. These initial approaches were structured around environmental impact, making it necessary to expand the ecological perspectives to also include the impact on economic and social dimensions (Lorek and Fuchs, 2013).

The responsible approach to resource consumption was highlighted in the seminal Brundtland Report (WCED, 1987), which defined sustainable development as meeting the needs of the present without compromising the ability of future generations to meet their own needs. Subsequently, the imperative of adopting sustainable production and consumption models was consolidated at the 1992 Earth Summit in Rio de Janeiro (United Nations, 1992). Modern perspectives have become multidimensional, encompassing the impact of social equity, the economic context and the ecological footprint, highlighting the need to optimize resources use for long-term societal benefits (Agyeman, Bullard and Evans, 2003).

The theoretical framework for sustainable consumption is based on social and environmental psychology and behavioral economics. An influential model developed by Ajzen (1991), the Theory of Planned Behavior, posits that an individual's intention to perform a certain behavior is determined by three factors: the individual's attitude toward the behavior, the perceived social pressure from referent individuals and perceived behavioral control. However, criticism of this model has highlighted its disregard for past habits and the impact of broader contextual factors that can influence behavior independently of intention (Bamberg and Möser, 2007). The Value-Belief-Norm theory, developed by Stern et al. (1999), extended Schwartz (1977) Norm-Activation Model by establishing a causal link: enduring personal values influence environmental worldviews and beliefs, which lead to problem awareness and subsequently trigger personal moral norms for pro-environmental actions. This model links individual values to specific actions, highlighting the deep motivational underpinnings of sustainable consumption behaviors (Stern, 2000).

Furthermore, sustainable consumption is influenced by economic, social, cultural and public policy factors. Cultural norms dictate consumption patterns and the absence of infrastructure facilities, such as public transport or recycling facilities affects individual intention regarding sustainable choices (Evans, 2011). Moreover, socio-economic factors affect access to sustainable options and the content of public policies shapes consumers' final choices (Thøgersen, 2005).

A pervasive challenge is “greenwashing”, a practice often encountered in the promotion of false image of ecological responsibility by companies in order to attract consumers (Delmas and Burbano, 2011). In addition, another challenge is represented by issues of equity in the discourse on sustainable consumption, as responsibility can be disproportionately shifted onto individuals, ignoring the crucial role that corporations and

governments have in the environmental burdens that unequally affect marginalized communities (Agyeman, Bullard and Evans, 2003; Shove, 2010).

Recent perspectives challenge the growth-oriented paradigm. The “degrowth” movement argues in favor of planned reduction of production and consumption in wealthy countries, in favor of equity and sustainability (Kallis, Demaria and D’Alisa, 2015). Moreover, the circular economy proposes a model opposite to the linear one, aiming to eliminate waste and keep material in use for an extended time (Ellen MacArthur Foundation, 2016). Likewise, the idea of “consumption corridors” calls for establishing minimum and maximum consumption limits, with the aim of guaranteeing general well-being without affecting ecological stability (Fuchs et al., 2021).

## **2.2. Experimental Economics: A Methodological Framework**

Experimental economics represents an innovative methodological approach for the study of decision-making processes, making a paradigm shift that captures the transition from exclusively theoretical models and observational data to one that uses controlled empirical methods to test hypotheses (Kagel and Roth, 1995). The pioneer of using laboratory experiments in economics was Vernon Smith, who demonstrated how market dynamics can be replicated and studied under laboratory conditions through incentive-compatible mechanisms aligned with participants’ preferences (Smith, 1962). Furthermore, Daniel Kahneman and Amos Tversky highlighted deviations from classical economic rationality through the use of experiments and their Prospect Theory (Kahneman and Tversky, 1979) underscored the role of experimental methods in identifying the “anomalies” of human behavior.

To achieve scientific legitimacy and analytical rigor, experimental economics is based on a set of fundamental principles (Smith, 2003). The ability to control variables of interest while holding other conditions constant (*ceteris paribus*) defines the essence of this methodology, which allows for the establishment of clear causal inferences. Additionally, the randomization procedure ensures that observed discrepancies between groups cannot be attributed to pre-existing factors but rather to the experimental intervention, thus ensuring that experimental decisions are both relevant and reflective of real preferences (Hertwig and Ortmann, 2001). Robustness and validity are achieved through replicability, by reproducing the experimental protocol to obtain similar results.

Behavioral economics has capitalized on this methodological diversification, using experiments to validate numerous cognitive biases, such as loss aversion or the anchoring effect, to demonstrate systematic deviations from perfect rationality (Camerer and Loewenstein, 2004). Moreover, the significant impact of framing effects, where the presentation of information influences the decision, has been demonstrated (Tversky and Kahneman, 1981). Additionally, the concept of the “nudge”, developed by Thaler and Sunstein (2008), utilizes choice architecture to guide people towards better decisions without limiting their available options. Field experiments have highlighted the relationship between economics and public policy, particularly through “plumber” approaches

(plumber economics), where institutional details are adjusted by the experimenter to improve the function of policies (Duflo, 2017).

However, the most evident limitation attributed to this methodology relates to its reduced external validity, as results obtained in controlled environments with small groups of participants cannot be readily generalized to the diverse social behaviors of the real world (Levitt and List, 2007). Furthermore, complex experimental studies are difficult to replicate and the robustness of their conclusions is diminished (Camerer et al., 2016). Recent critiques emphasize the need to integrate the institutional and systematic dimensions that condition economic decisions in order to deepen the analysis of individual behaviors (Guala, 2005).

Despite these limitations, experimental economics remains an extremely valuable methodological framework. Through its ability to capture how individuals react to incentives, norms and institutional arrangements, it offers useful tools for analyzing behaviors related to common resources (Ostrom, 1990), cooperation and public policies. Moreover, recent research explores the application of experimental economics to ecological transitions and sustainable consumption (Allcott and Rogers, 2014; Nyborg et al., 2016). The criticisms aimed at experimental economics do not diminish its relevance; they merely highlight the need for methodological transparency to allow for the evolution from laboratory simulations to an interdisciplinary framework with direct applications to current global challenges.

### **2.3. The Intersection of Sustainable Consumption and Experimental Economics**

The intersection of experimental economics and sustainable consumption captures a fundamental methodological evolution, making the transition from purely theoretical model to those oriented towards the identification of rigorous causal inferences. The theoretical framework in section 2.1. outlines the possible factors that can determine sustainable behaviors, while section 2.2. establishes the analytical toolkit. At this confluence, the specialized literature has highlighted several major directions of research, which collectively illustrate how experimental methods contribute to a more sophisticated knowledge of the dynamics of sustainable consumption.

#### *2.3.1. Choice Architecture and Behavioral Interventions (Nudges)*

A prolific area of research focused on applying choice architecture to design “nudges” (Thaler and Sunstein, 2008), more specifically, subtle adjustments to the decision-making context to encourage individuals towards sustainable options, but without limiting their choices. Experiments represent the primary methods for the causal validation of the effectiveness of these interventions. One canonic example is the manipulation of social norms, using large-scale field experiments, it has been demonstrated that providing households with comparative information about their energy consumption relative to their neighbors leads to significant and durable reductions (Schultz et al., 2007; Allcott, 2011). Likewise, changing classical electricity contracts to a “green” tariff leads to substantial increases in the adoption rate of renewable energy (Pichert and Katsikopoulos, 2008).

Furthermore, the framing of information is crucial, as in the case of carbon footprint labels, confirming that the mode of presentation is as important as the information conveyed (Lohmann et al., 2022; Edenbrandt and Nordström, 2023). Thus, large-scale behavioral changes can be achieved with low-cost interventions, if they are well-anchored psychologically.

### *2.3.2. Pro-Social Behavior and Public Goods Games in Environmental Contexts*

Sustainability challenges, such as climate crises or the overexploitation of natural resources, can be defined as collective action dilemmas, having the classical structure of a public goods game. Understanding the mechanisms that promote or inhibit cooperation in such dilemmas is achieved through laboratory experiments. Extending the research of Ostrom (1990), experimental studies have demonstrated that introducing pre-decisional communication channels increases the level of cooperation. Furthermore, the “altruistic punishment” mechanism reveals that individuals are willing to bear a personal cost in order to sanction selfish behavior, thereby strengthening cooperation norms (Fehr and Gächter, 2000). A recent large-scale online experiment with over 18,000 participants from ten countries revealed that differences between cultural contexts varied minimally and cooperation levels remained stable over long periods, emphasizing that individual differences are superior to cultural particularities (Frey, 2019). Furthermore, introducing an option to exploit the common resource in a collective risk experiment substantially diminished the probability of meeting the cooperation threshold, crystallizing the need for climate policies that discourage exploitation (Cloos, Greiff and Kempa, 2025). Thus, these findings represent important benchmarks for institutional design for establishing empirically validated principles in shaping policies for common resource management.

### *2.3.3. Consumer Preferences and the “Attitude-Behavior Gap”*

The “attitude-behavior gap” is a persistent theme in debates on sustainable consumption, owing to the discrepancy between consumers’ declared pro-environmental intentions and their actual purchasing behaviors. Experimental methods allow for the rigorous quantification of the real willingness-to-pay (WTP) for sustainable attributes, transcending the limitations of hypothetical survey responses. Studies have shown that while there are consumers willing to pay a price premium for products with eco-labels or a reduced carbon footprint (Teisl, Roe and Hicks, 2002), they often confront barriers such as high prices or a lack of trust in labels, which is eroded by the “greenwashing” phenomenon (Carrington, Neville and Whitwell, 2010; Delmas and Burbano, 2011). To explain why this gap occurs, recent theoretical models, such as SHIFT framework (Social, Influence, Habits, Individual self, Feelings and cognition, Tangibility), explain how psychological and contextual factors determine consumer behavior (White, Habib and Hardisty, 2019). In this context, eco-labels are considered effective marketing tools, yet their effectiveness is contingent upon credibility and regulation (Testa et al., 2015). Therefore, experimental studies play a dual role: they not only measure WTP but also test specific interventions and identify the contextual and psychological factors capable of reducing the “attitude-behavior gap” in sustainable consumption.

To sum up, the literature on sustainable consumption and experimental economics has captured the transition from abstract theoretical models towards the empirical testing of mechanism that determine individual and collective behaviors, “Nudge”-type interventions have highlighted how changes in consumption behavior can generate through subtle adjustments in the decision-making architecture, while studies on public goods and pro-social behaviors have underscored the importance of communication and of creating an institutional design capable of fostering cooperation in the face of environmental dilemmas. Simultaneously, research on the “attitude-behavior gap” has outlined the impact of the psychological context and the importance of consumer behaviors. These directions have created a complex framework, which demonstrates the essential role of experimental methods in supporting the development of public policies aimed at sustainable consumption.

### 3. Methodology

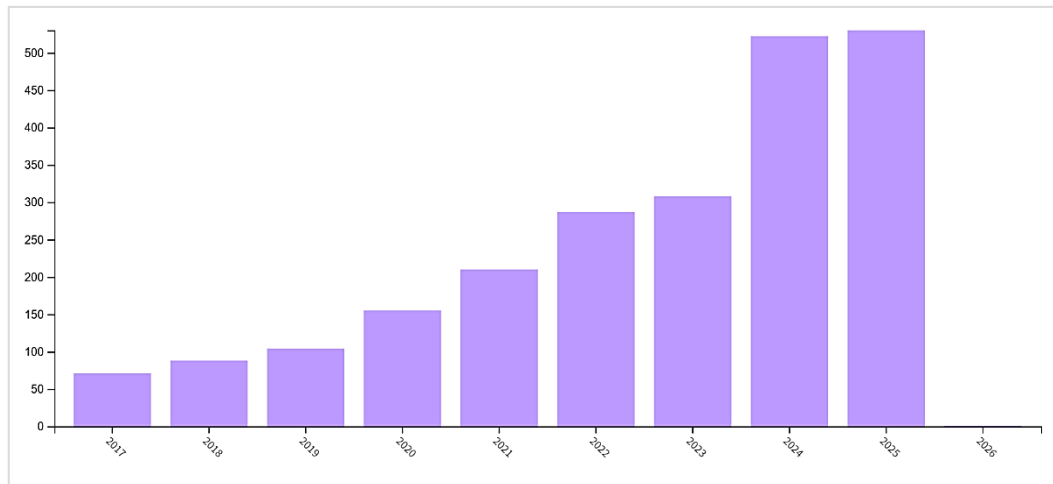
The research questions mentioned in the beginning of the paper are supported by a bibliometric analysis performed in the VOSviewer software. This type of quantitative research looks into bibliographic data in order to assess the current level of research in the area of sustainable consumption and experimental economics by analyzing keywords and organizations, countries and authors connections.

Our data was extracted from the well-known database Web of Science and resulted in 2596 findings ( $n = 2596$ ) of papers written on the topic of sustainable consumption and experimental economics. Findings from another illustrious database, i.e. Scopus by Elsevier, were checked, but they resulted in only 1127 results, so Web of Science was our final choice for a better understanding of the topic.

The search was performed in August 2025 and contained the keyword mix and Boolean operator “AND” such as: “sustainable consumption” AND “experimental” AND “study”, while keeping the “Article title, Abstract, Keywords” option regardless of the time range. The findings were exported in a Plain Text File so as to be further exported to VOSviewer for the bibliometric analysis. The processing of data with this software led to graphical networks using bibliographic and text data and revealed the current state of research on this topic.

### 4. Results and Discussions

As we mentioned in the Methodology section, we wanted to discover what the actual level of research on this topic is as a starting point for fellow academics who will engage in a related subject in their future research. As the extracted data shows in *Figure 1*, the topic of sustainable consumption and experimental economics started to gain importance in 2017 with a number of 71 papers dedicated to it and the number of papers has been growing ever since, with a high peak this year in 2025 (530 papers).

**Figure 1.** *No. of publications per year*

**Source:** Authors' own research.

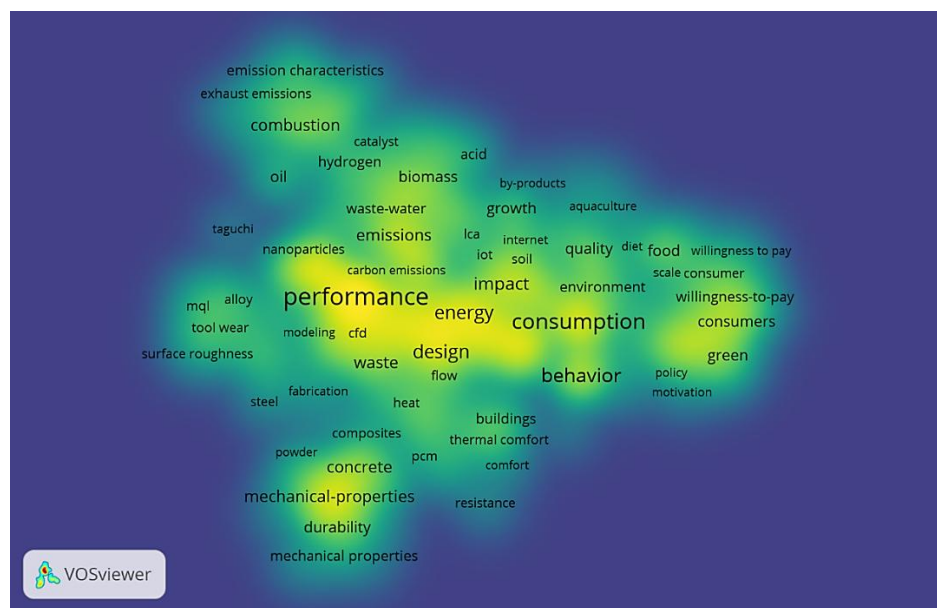
**Figure 2.** *Type of documents*

**Source:** Authors' own research.

The majority of papers (87.67%) is represented by scientific articles, followed by proceeding papers (7.78%), review articles (4.31%), early access papers (2.5%) and book chapters (0.84%), as per *Figure 2*. For the first and second research questions, i.e. “*RQ1: What are the main existent academic research topics and subjects on sustainable consumption and experimental economics?*” and “*RQ2: What are the subject areas that shape the study around sustainable consumption and experimental economics?*”, we have looked into data both in VOSviewer and WoS database. Until now, several themes were touched in the existent academic research, and, by introducing the data to VOSviewer, we

looked into the keywords occurrence to discover some of those main themes. The keyword occurrence can also predict future potential topics to write about for other researchers. Thus, for our topic, the following keywords stand out: “energy consumption”, “performance”, “optimization”, “circular economy”, “sustainable consumption”, “willingness to pay”, “performance evaluation”, “performance evaluation”, “quality”, “management”, “planned behavior”, “motivation”, “climate change”, “growth”, “recovery”, “emission characteristics”. *Figure 3* discloses the words with the strongest total links.

**Figure 3.** Keyword co-occurrence in density visualization



**Source:** Authors' own research.

Besides the keywords analysis, it is also of great importance to look into the prevalent research areas on this topic. As demonstrated by *Figure 4*, 1003 papers are engineering-related, followed by environmental sciences ecology (564 papers), science technology (554 papers), energy fuels (436), materials science (243), construction building technology (199), chemistry (193), thermodynamics (157), business economics (155), agriculture (132) and computer science (123).

We have also looked into the publishers and Elsevier turned out to be the first in the ranking with 1026 papers, followed by MDPI with 396 papers, Springer Nature with 244 papers, Wiley with 124 papers, IEE with 68 papers, and Taylor & Francis with 67 papers.

For the last two research questions, i.e. “*RQ3: Which countries, institutions and authors contribute the most to the research field of sustainable consumption and experimental economics at the moment?*” and “*RQ4: Which authors are the most cited in this field of study and what are the current links between organizations and countries?*”, the below results reflect upon them.

Y. Wang is the most productive author (*Figure 5*) with a number of 18 papers written on this topic, followed by Y. Zhang with 16 papers, H. Wang with 13 papers, L. Wang with 13 papers, and R. Kumar with 10 papers. With regards to the countries which contributed the most, results show that China is on top with 623 papers, then comes India with 314 papers, United States with 234 papers, Italy with 176 papers, United Kingdom with 133 papers, Spain with 121 papers, Germany with 98 papers, Australia with 97, and France with 94 papers.

**Figure 4.** *Research Areas*

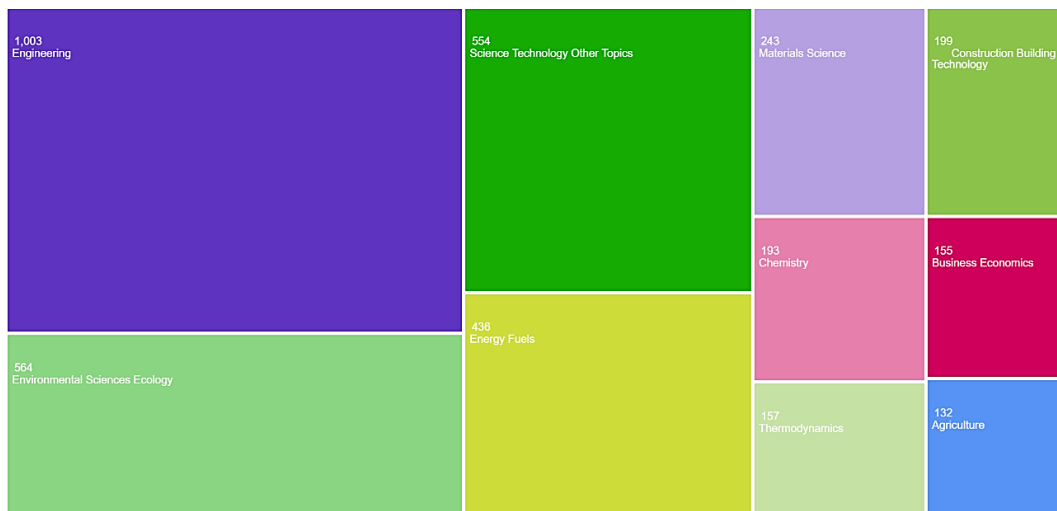
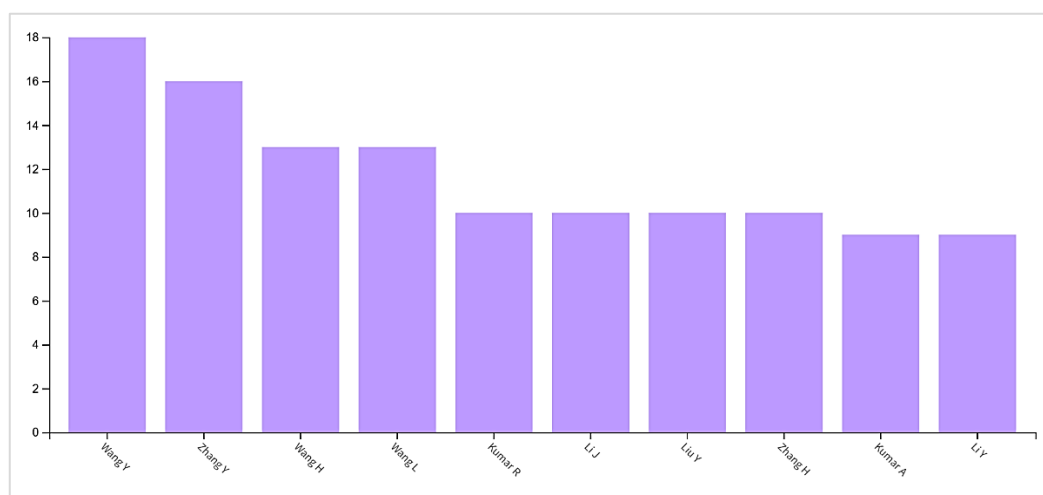


**Figure 5.** *Most productive authors*



**Source:** Authors' own research.

In order to look into the citation frequency of authors, there as a minimum of 5 papers per author set in VOSviewer and a minimum of 10 citations per authors, and the results showed



that the most cited ones are M. Jamil with 8 papers and 328 citations, N. He with 6 papers and 295 citations, A.M. Khan with 5 papers and 287 citations, S. Jia with 6 papers and 173 citations, F. Septianto with 5 papers and 149 papers. *Figure 6* shows the most cited authors and *Figure 7* depicts a cluster of the 3 authors that cited each other the most.

**Figure 6.** *Citation of authors*

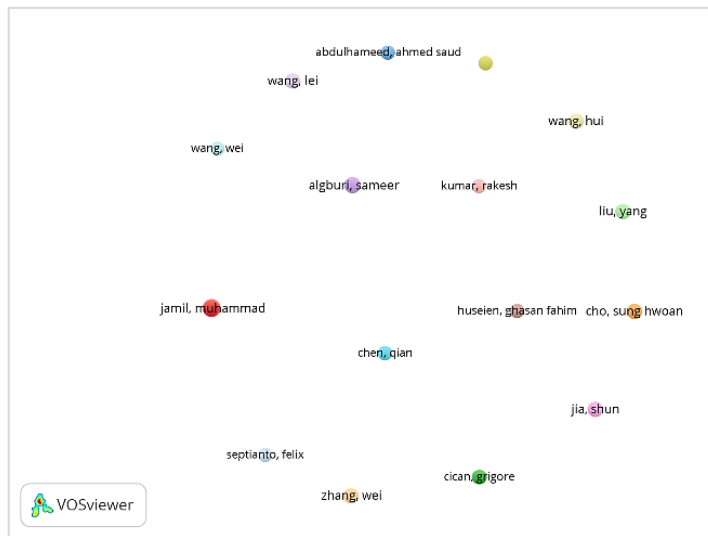
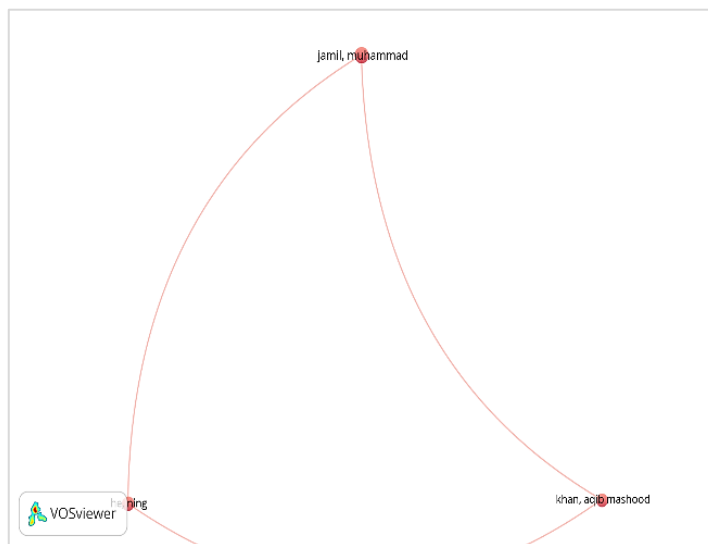


**Figure 7.** *Citation Links*



**Source:** Authors' own research.

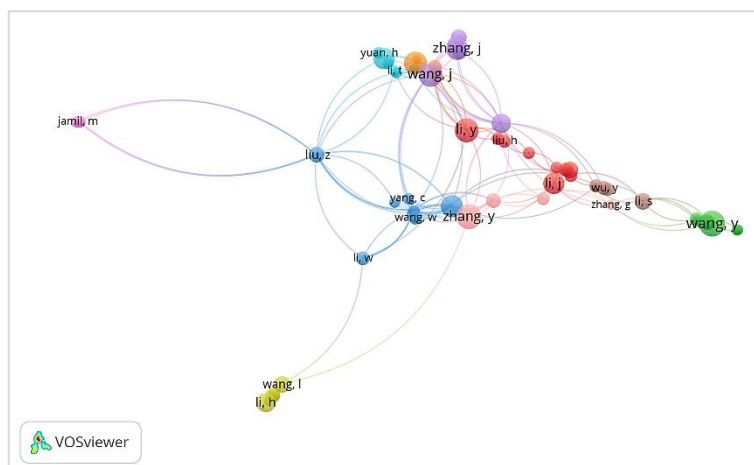
There are several co-authorship clusters of authors that worked together on a minimum of 5 papers, while there are also isolated clusters of only one author (*Figure 8*). *Figure 9* delves deeper into the relationships of authors based on how they cite one another's work.

While the co-authorship of authors shows a more fragmented network than the citation one, we can draw a comparison between the two: in the citation map, author M. Jamil is connected to author Z. Liu, which means they are cited by influential authors in a bigger network, and, in the co-authorship map it is seen that M. Jamil only collaborates with author A.M.Khan, which indicates an influence through citations rather than a broader collaboration. Some authors like Z.Liu, Y. Wang, for example, are major citation hubs and collaborate outside smaller groups in the co-authorship network, while pairs of authors like H. Wang and S. Jia publish together quite often but do not have a strong citation impact. Author M. Jamil is part of a small co-author group and linked to high-impact authors via citations.

**Figure 8.** Co-authorship of authors



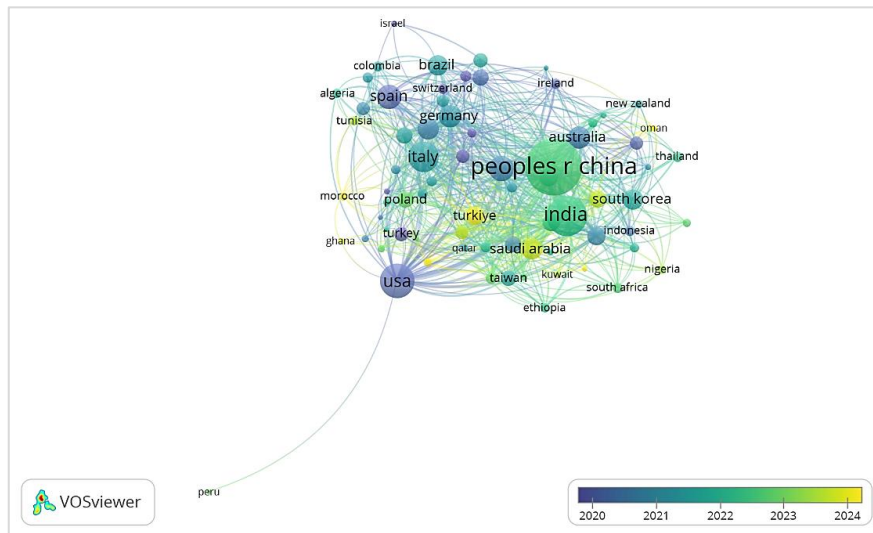
**Figure 9.** Citation authors



**Source:** Authors' own research.

The co-authorship network among countries illustrates the frequency of authors from different countries collaborating on publishing papers. As *Figure 10* shows, the largest nodes are represented by countries such as China, US and India, which means that they have collaborated on more papers with other countries, and China and US are strongly interconnected with other countries, as well, during 2020–2021 and around 2022, based on the colors blue and green from the scale. This means that authors from countries like Saudi Arabia, Oman and Qatar have worked together more recently. While clusters highlight strong interlinked groups of countries like China, India, Saudi Arabia, South Korea and Spain, Italy, Germany, Brazil, there is also one country, Peru, positioned in a far away point on the network map because it has fewer collaborations, mainly with US.

**Figure 10.** Co-authorship of countries

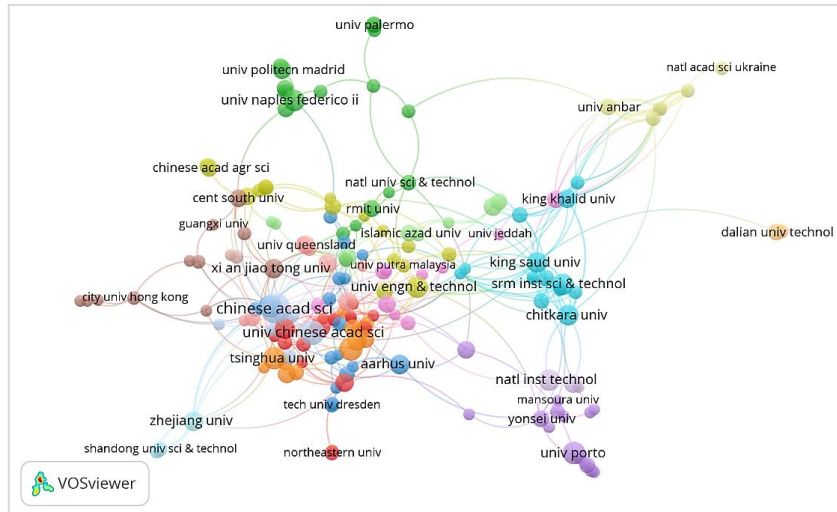


**Source:** Authors' own research.

When it comes to co-authorship relationships between organizations, based on the very large nodes in the network visualization, Chinese Academy of Sciences, University of Chinese Academy of Sciences, and Tsinghua University display high publication volume. The first two mentioned organizations have strong connections with institutions like Tsinghua University and Zhejiang University. The colored clusters show collaborations between groups of institutions, thus the red cluster in *Figure 11* is dominated by research institutions from China, the green cluster highlights University Politecnica de Madrid, University Naples Federico II, and University Palermo, the blue cluster shows universities from the Middle East and South Asia such as King Saud University, King Khalid University, and SRM Institute of Science and Technology, and, lastly, the purple cluster illustrates University of Porto, Yonsei University, and Mansoura University. The organizations that are closer to each other collaborate more often. Central hubs, like the Chinese Academy of Sciences) are connected to several different clusters and act like bridges between regions, while peripheral nodes indicate isolated collaborations, such the one shown by Dalian University of Technology. This network visualization outlines

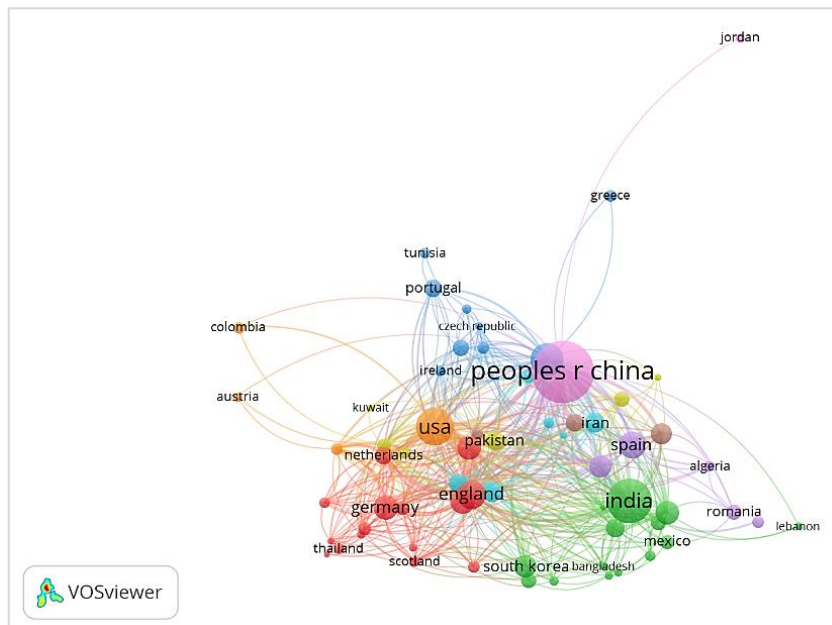
institutions from China as central hubs in global collaborations, universities from Europe have tight sub-networks and links between each other and with Asian partners, while Middle Eastern institutions have collaborations with China and other regional partners on the rise.

**Figure 11.** *Co-authorship of organizations*



Source: Authors' own research.

**Figure 12.** *Citation countries*

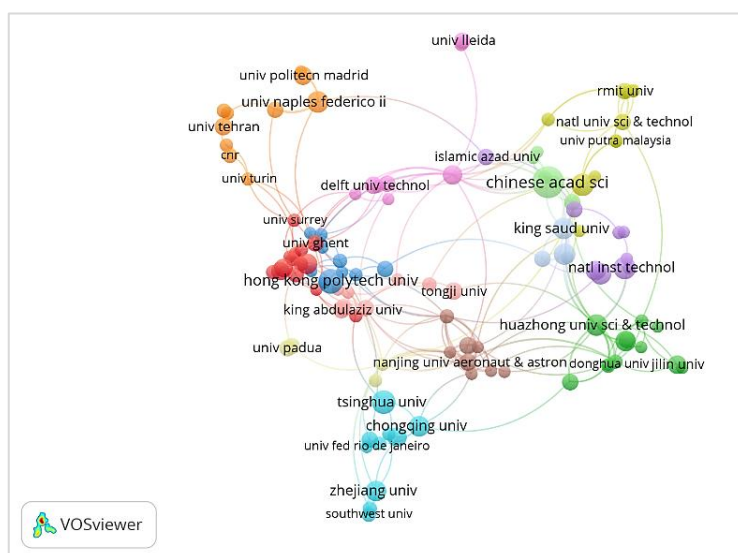


Source: Authors' own research.

By looking at the network of countries based on citation patterns (*Figure 12*), the map reveals that dominant research hubs are composed of China, US, United Kingdom and India. These countries are central to the global research landscape, because of the high volume of publications and citations. There are strong citation relationships among countries like US, United Kingdom, Germany, Netherlands, Thailand, Scotland and Austria. The green cluster indicates another important group of countries like India and South Korea, which have connections to Mexico and Bangladesh. There are also strong ties between countries from Europe, such as Ireland, Czech Republic, and Portugal, as seen in the blue cluster. Due to the high number of lines connecting different colored clusters, it can be seen that international collaboration and knowledge sharing play a significant role. The thick lines between China, US and UK indicate a strong flow of citations among them.

On the other hand, by looking at the network citation of organizations (*Figure 13*), the prominent institutions are Chinese Academy of Sciences, Hong Kong Polytechnic University, King Saud University, Islamic Azad University, along with a cluster of universities from the UK such as University of Surrey and University of Ghent. The purple cluster being centered around “Islamic Azad University” and “King Saud University” suggests an important research network in the Middle East, while the green cluster represents a strong domestic research network inside China. The blue cluster showcases collaborations between European and Chinese universities, and the yellow cluster looks into the relationships among organizations from Australia and the Southeastern Asia. These maps give a visual representation of the collaborative structures and highlight the fact that there is a multi-polar world of research, with hubs in North America, Europe, and Asia, and US and China being the “central players”. Even though the clusters of organizations tend to reflect geographical proximity, there exists significant evidence of international from different clusters.

**Figure 13.** *Citation organizations*



**Source:** Authors' own research.

## 5. Conclusion

The bibliometric analysis in this article provided a quantitative perspective on the intersection of sustainable consumption and experimental economics, highlighting several relevant structural characteristics. The results confirmed a recent and exponential growth in the volume of publications after 2017, outlining the relevance and importance of knowledge in this field. One of the central findings is the thematic duality, with the field being structured along two directions: on one hand, a foundational literature, with a theoretical orientation focused on a socio-behavioral mechanisms, and on the other hand, a quantitatively dominant corpus with a technical orientation. The study also crystallized significant geographical particularities, revealing a dichotomy between the predominantly Western theoretical foundations and the centers of scientific productivity located mainly in China and India. Collaboration networks are robust, with China and the United States acting as central global hubs.

The article's contribution lies in expanding the understanding of this interdisciplinary field. The bibliometric analysis empirically validated the exponential growth of the scientific literature, most importantly, revealed a possible disconnect between technical and socio-behavioral research. The results highlighted that scientific productivity is predominantly focused on creating a techno-economic agenda, while the most foundational studies are deeply influenced by behavioral science.

Future research directions should focus on bridging this gap. A first direction could consist of a more detailed analysis of how insights from behavioral economics can be integrated to enhance the effectiveness of technical solutions. Furthermore, extending the bibliometric analysis by including other databases, such as Scopus, would allow for more robust comparisons. Finally, a qualitative meta-analysis of the research originating from the highly productive Asian hubs would provide a deeper understanding of their research agendas, facilitating more targeted international collaborations.

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## **Heterogeneous and dynamic impacts of growth, urbanization, deforestation, and energy intensity on environmental degradation in Africa using the MM-Quantile regression method**

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**Abstract.** *This study investigates how economic growth, urbanization, energy use, trade openness, and forest area affect pollution in Africa from 1990 to 2022. Using the moment-quantile approach for panel data, we capture heterogeneous effects across the conditional distribution of CO<sub>2</sub> emissions. Economic growth raises emissions at all quantiles, with stronger effects at higher pollution levels. Trade openness is beneficial at lower quantiles, while energy intensity worsens environmental quality everywhere. Forest resources mitigate emissions, especially in high-pollution countries, whereas urbanization mainly affects intermediate pollution levels. The findings support smart urban planning, energy transition, and forest management to curb emissions without hindering development.*

**Keywords:** dioxide emissions, growth, heterogeneous effects, Africa, MM quantile.

**JEL Classification:** Q53, O55, C23, Q56.

## 1. Introduction

In recent decades, Africa has experienced continued economic growth, rapid urbanisation and expanded trade along with an increasing consumption of energy (Kazemzadeh et al., 2023). The favorable aspect of this phenomenon is an impetus for economic change and development opportunities, which however comes with many environmental fallout including climate change due to greenhouse gas emission, deforestation, water and food security issues, as well as urban sprawl management (Pawar, 2023).

Despite contributions from Africa to global CO<sub>2</sub> emissions being less than the contribution of developed countries (Pata et al., 2021), the continent remains one of the most vulnerable regions due to its geographical location, high dependence on climate-sensitive sectors and limited capacity for adaptation (Abidoye & Odusola 2015; Ntarmah et al., 2021). These vulnerabilities are then compounded by a growing frequency and severity in climate-related hazards that directly obstruct national development (Dodman, 2009).

The linkage of Africa to the world economy depends upon and/or reifies its accelerated industrialization, rapid urbanization and enhanced trade but it is challenged by series of structural problems like unemployment, poverty, inflation (Muftau et al., 2014). These processes are not only shaping the continent's economy and society, but they are also causing increasing pressure on biodiversity and the environment. This pressure can be seen in increasing depletion of energy and timber resources, increased release of carbon dioxide to the atmosphere and, overall reduced environmental quality. This seems to be a paradox of development vs. based environmental sustainability (Azam et al., 2022; Congregado et al., 2016; Muftau et al., 2014).

As the environment becomes polluted, scientists and governments should prioritize sustainability. The UN's Sustainable Development targets, specifically SDG 13 on climate action and sustainable ecosystem management, and the Paris Agreement's climate targets make Africa more resilient to climate change and push African countries to consider their development. Countries must balance economic, social, and environmental growth to guarantee a sustainable long-term trajectory (Kazemzadeh et al., 2022; Muftau, 2014). Several studies have linked environmental degradation to energy consumption, global trade, natural resource dependence, deforestation, and demographic needs. These assessments stress the need for dynamic models to better explain complex economic growth-pollution linkages in Africa.

The literature on distributional heterogeneity is limited. Most studies assume homogeneous impacts, although pollution affects growth, urbanization, trade, energy consumption, and forest resources. This work fills this gap by using quantile regression via moments to capture the distinct effect of these factors on African carbon dioxide emissions. This study improves understanding of the varied dynamic effects of economic growth, trade openness, urbanization, energy consumption, and forest resources on CO<sub>2</sub> emissions across quantiles. Policymakers can use the empirical results to construct environmental and development policies that balance economic growth with environmental sustainability.

In fact, this research aims to address the following question: To what degree do economic growth, trade openness, urbanization, energy use, and forest resource influence CO<sub>2</sub> emissions in Africa, with differences depending on pollution levels?

**Research hypotheses:** This research assumes that Africa's economic and demographic development is putting increasing pressure on the environment, the intensity of which varies according to national contexts and pollution levels.

**Limitations of the research:** This study is confined to 25 African countries (N=25) over the period 1990–2022 (T=33 years), with a specific focus on the theoretical framework of the STIRPAT model.

**Research methodology:** The study combines a descriptive analysis of the theoretical framework with an econometric approach applied to a panel of 25 African countries over the period 1990–2022. Advanced dynamic panel techniques were used to take into account the specific heterogeneity of each country. The moment-based quantile regression (MM-QR) was used to understand the conditional distribution of the effects of dioxide emissions in both low-emission and high-emission nations. Finally, this approach is resilient to non-normality models and cross-sectional dependence, which reinforces the relevance of the results for public policy.

**Study content:** The article is structured in four sections. The next section provides a concise overview of previous research. The section 3 describes the model and the data. The section 4 presents and analyzes the empirical outcomes. The final section closes by addressing the primary implications of the study.

## 2. Literature review

Recent researches have extensively examined the impacts of economic growth, trade liberalization, urbanization, and natural resource management on the quality of the environment. These factors are key determinants in the analysis of pollutant emissions, particularly in developing countries. However, empirical results remain mixed, due to differences in socio-economic contexts, methodologies used and regional specificities. A critical review of existing work thus highlights the main contributions and limitations concerning the interactions between development, trade integration, urban dynamics and ecosystem preservation, while emphasising the specific challenges facing the African continent.

The amount of work regarding the connection between economic growth and environmental degradation is largely organized around the environmental Kuznets curve hypothesis, which suggests an inverted U-shaped correlation between income and pollution (Kuznets, 1995; Grossman & Krueger, 1991). In the early stages of development, Economic growth initially increases emissions (size effect), then a composition effect and, at higher income levels, a technical effect associated to cleaner inventions reduce pollution. As GDP grows, countries gain financial, institutional, and technological capacity to invest in sustainable infrastructure, promote energy efficiency, and enforce stronger environmental regulations, reducing emissions and ecological degradation.

However, the empirical evidence remains mixed and varies across countries and periods. Several studies confirm the environmental Kuznets curve (EKC) hypothesis in Africa and elsewhere (Abidoye & Odusola, 2015; Ali et al., 2017; Baidoo, 2023; Ertugrul et al., 2016; Haciimamoğlu & Cengiz, 2024; Neagu & Neagu, 2022; Özkan et al., 2023; Satrio et al., 2025; Shahbaz et al., 2013; Tachea et al., 2021; Wani et al., 2025; York et al., 2003), highlighting disparities according to income levels, regional specificities and economic structures. Indeed, economic activity tends to be correlated with significant energy consumption, infrastructure expansion and intensified industrial production, thereby placing greater pressure on natural resources (York et al., 2003; Satrio et al., 2025; Abdi et al., 2025; Ahmad et al., 2019). Some research shows that while high-income countries can achieve a decoupling of GDP and environmental degradation through technological advances and green policies, middle- and low-income countries generally see their environmental pollution increase with economic progress due to limited access to sustainable technologies (Satrio et al., 2025).

Furthermore, the literature has mixed findings in relation to trade liberalisation and pollution. Al-Mulali & Ozturk (2015); Ertugrul et al. (2016); Sultana et al. (2023) report that international trade brings about additional ecological pressure by promoting the exploitation of fossil resources and economic growth. Conversely, Ali et al. (2017) and Shahbaz et al. (2013) have an article on the reduction of the CO<sub>2</sub> emissions because of liberalization of trade. Other reports suggest a two-way association (Abdi et al., 2025; Wani et al., 2025), with Sharma et al. (2022) argue that the effects are determined by the composition of imports. A distributed organization structure can contribute to promote such eco-footprint, whereas an integrated one may help assimilate it. Lastly, Ghazali & Ali (2019) as well as Salahuddin et al. (2019) draw a very limited role of trade liberalisation in polluting the environment. Overall, these results draw attention to the ambivalence of trade for environmental sustainability which is conditioned by economic and structural contexts.

Urbanization is an issue in literature with inconsistent consequences. On the contrary, urban growth (aggr scratch) is perceived as a home to due to its purpose of concentration/aggregation human activities taking place within it., contributing in no small part in wear and tear on fossil fuel use that adds more nuisance to climate stress (Grimm et al., 2008; Al-Mulali & Ozturk, 2015, Mignamissi & Djeufack, 2022). In other words urban population growth leads to demand for energy, water and land which goes beyond the available local or regional biocapacity (York et al., 2003). It leads to enormous amounts of waste and pollution produced primarily by heightened consumption in cities that are being driven by rising incomes, infrastructure needs, transportation (Satrio et al., 2025; Zhang et al., 2022). Alternatively, studies indicate that in certain contexts, dense urban areas can enhance energy efficiency and reduce carbon footprints when equipped with sustainable infrastructure, which promotes economies of scale and resource-efficient designs. Furthermore, the research conducted by Martínez-Zarzoso & Maruotti (2011) found an inverted U-shaped link between urbanization and pollution. At low levels of urbanization, urbanization leads to an increase in emissions, reflecting a greater environmental impact in less developed regions.

A review of the literature highlights a close link between energy consumption and pollution, particularly in emerging nations where fossil fuel use increases ecological vulnerability. Several studies confirm that energy consumption directly stimulates pollution. Ertugrul et al. (2016) show that increased energy consumption leads to environmental degradation without generating sustainable economic growth, suggesting that reducing energy intensity could be an effective way to limit emissions. Similarly, Shahbaz et al. (2013), Acaravci and Ozturk (2010), Azam et al. (2022), Apergis & Payne (2010) and Ozcan (2013) identified high energy intensity as a core carbon emission determinant. Other research emphasizes the incredible generator effect of a fossil fuel dominated power structure. Al-Mulali & Ozturk (2015) and Apergis & Payne (2010) prove that in emerging countries, the reliance on fossil fuels causes a high increase of CO<sub>2</sub> emissions, so they defend diversification towards clean renewable energies. Kazemzadeh et al. (2023) indicated that energy intensity policies have opposite impacts on pollution according to the context (the countries and intensity levels). This leads the authors to argue that replacing fossil fuels with clean energy increases ecological quality.

Furthermore, results suggest that technological innovation can play a role in reducing environmental degradation by stretching energy. Energy efficiency increases, spread of new energy vehicles, and the introduction of more energy efficient industrial processes would also decompose decrease in CO<sub>2</sub> intensity and emission from correspondent source but less than that (Mushtaq et al., 2024; Wang et al., 2025).

Finally, the literature shows how forest cover is related to environmental deterioration. In the following paragraphs, we will see many pieces of research and study that argue that deforestation has great influence on the air pollution and ecosystem degradation. Arshad et al. (2020) and Andrée et al. (2019) demonstrate that forest loss, and land use in terms of production contribute to pollution and the loss of biodiversity. In addition, the rapid urbanization contributes to deforestation and pressure on natural ecosystems as it supersedes forest in favour of infrastructures and housing (Ahmad et al., 2019).

### 3. Materials and methods

**Research Population and Sample:** This quantitative study uses panel data to measure variable changes over time and across countries. The analysis covers 1990–2022, including 25 African nations. It analyzes how economic growth, urbanization, energy use, and forests resources affect dioxide emissions. The countries included in the sample are: Benin, Botswana, Burkina Faso, Cameroon, Democratic Republic of Congo, Egypt, Eswatini, Ethiopia, Gabon, Kenya, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, South Africa, Tanzania, Togo, Uganda, Zambia and Zimbabwe. These nations were determined by the availability and quality of data during the review period. Econometric estimates were performed using STATA 17 software.

**Variables and sources:** The various variables used in this study are compiled in Table 1, and with the corresponding sources. The dependent variable is the total volume of carbon dioxide emissions, measured in megatonnes of CO<sub>2</sub> equivalent.

The independent variables are:

- GDP per capita (in current dollars), used as a proxy for the level of economic development;
- Trade openness (TRADE), measured as a percentage of GDP, is used as an indicator of the degree of globalization;
- Urban population growth (in annual %), representing the dynamics of urbanization;
- Energy consumption (in kilograms of oil equivalent per capita), used as a proxy for energy intensity;
- Forest cover (as a percentage of total land area), to take into account the availability of natural resources and their role in environmental regulation.

**Table 1.** Description of all variables

| Variable                                     | Designation                                       | Source                                                       |
|----------------------------------------------|---------------------------------------------------|--------------------------------------------------------------|
| CO <sub>2</sub> emissions (CO <sub>2</sub> ) | Total carbon dioxide emissions                    | World Development Indicators<br>(www.databank.worldbank.org) |
| GDP per capita (GDPpc)                       | Gross Domestic Product per capita (constant US\$) |                                                              |
| Trade Openness (TRADE)                       | (Exports + Imports) as a percentage of GDP        |                                                              |
| Urban population growth (URB)                | Urban population growth (annual %)                |                                                              |
| Energy intensity (ENERGY use)                | Energy use per unit of GDP                        |                                                              |
| Forest area (FOREST)                         | Forest area (% of land area)                      |                                                              |

**Study model:** The panel model utilized in this research is articulated in equation (1). This specification indicates that the impact of the explanatory variables ( $Z$ ) varies across the conditional quantiles of the dependent variable ( $Y$ ).

$$Y_{it} = \alpha_i + X'_{it}\beta + (\delta + Z'_{it}\gamma)U_{it} \dots \quad (1)$$

Where:

$Y_{it}$  is the dependent variable CO<sub>2</sub>,

$\alpha_i$  : the fixed effects specific to each country  $i$ ,

$X_{it}$  : vector of explanatory variables ( $GDPpp$ ,  $TRADE$ ,  $URB$ ,  $ENERGYuse$ ,  $FOREST$ )

$\beta_i$  : average coefficients associated with  $X_{it}$ ,

$Z_{it}$  : vector of explanatory variables that allows heterogeneity to be introduced into the quantiles,

$\delta, \gamma$  : parameters that modulate how the quantiles are influenced,

$U_{it}$  : random term (i.i.d)

Equation (1) will be estimated using the moment-based quantile regression (MM-QR) developed by Machado & Santos Silva (2019), which allows for the heterogeneity of the conditional distribution of CO<sub>2</sub> emissions. Unlike traditional least squares approaches, this method offers a more robust analysis by capturing the differentiated effects of environmental determinants across the entire distribution, not just on the mean, while correcting for bias issues related to heteroscedasticity and unobserved individual effects (Machado & Santos Silva, 2019). Equation (1) can be written as follows, given that the effect of the explanatory variable is not constant but depends on the position of the conditional distribution of  $Y$ .

$$Q_{\tau}(Y_{it}|X_{it}) = \alpha_i(\tau) + X'_{it}\beta + Z'_{it}\gamma q(\tau) \dots \quad (2)$$



Where:

$Q_{\tau}(Y_{it}|X_{it})$  : is the  $\tau^{th}$  quantile of the dioxide emissions for country  $i$  and  $t$  conditional on the covariates,

$\alpha_i(\tau) = \alpha_i + \delta q(\tau)$  : fixed effects vary according to the quantile,

$q(\tau)$  : function that depends on the quantile (in our case 0.10, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90).

### Data description and Correlation matrix:

This study draws on a balanced panel of annual data covering 25 African countries over the period 1990–2022. All variables were transformed into logarithmic values to simplify coefficient interpretation in terms of CO<sub>2</sub> elasticity and reduce heteroscedasticity.

The descriptive statistics of the variables for 25 African nations over 33 years are shown in Table 2 (N = 25; T = 33). CO<sub>2</sub> emissions have a mean of 2.51 with a standard deviation of 1.56, ranging from 0.32 to 6.88. The dispersion is mainly inter-country (1.53), much more pronounced than the intra-country temporal variation (0.45). GDP per capita (GDPpc) averages 7.67 with an overall standard deviation of 1.08, ranging from 5.26 to 10.05; the differences are due more to variation between countries (0.98) than over time (0.49). Trade openness (TRADE) averages 4.47, with a variability of 0.52, mainly explained by differences between countries (0.45). The urban population (URB) has an average of 1.90 and a standard deviation of 0.58, ranging from -1.89 to 4.13; inter-country disparities (0.47) dominate over intra-country disparities (0.34). Finally, energy intensity (ENERGYuse) has an average of 6.88 with a standard deviation of 0.68, with greater variability between countries (0.62) than over time (0.30). The share of forests (FOREST) shows relatively moderate variability: overall values range from 0.0439 to 5.217, with an average of 3.73 and a standard deviation of 1.18. The variation between countries (standard deviation = 1.20) remains more pronounced than that observed within countries over time (standard deviation = 0.07), indicating that the differences are explained more by national specificities than by temporal fluctuations.

**Table 2.** Descriptive Statistics

| Variable        |         | Mean  | Std. Dev. | Min    | Max    | Observations |
|-----------------|---------|-------|-----------|--------|--------|--------------|
| CO <sub>2</sub> | overall | 2.516 | 1.569     | 0.321  | 6.883  | N = 825      |
|                 | between |       | 1.531     | 0.739  | 6.683  | n = 25       |
|                 | within  |       | 0.457     | 1.121  | 3.747  | T = 33       |
| GDP pc          | overall | 7.677 | 1.080     | 5.261  | 10.056 | N = 825      |
|                 | between |       | 0.980     | 6.289  | 9.410  | n = 25       |
|                 | within  |       | 0.493     | 6.375  | 9.074  | T = 33       |
| TRADE           | overall | 4.475 | 0.524     | 2.270  | 5.860  | N = 825      |
|                 | between |       | 0.451     | 3.839  | 5.317  | n = 25       |
|                 | within  |       | 0.280     | 2.906  | 5.440  | T = 33       |
| URB             | overall | 1.901 | 0.580     | -1.898 | 4.136  | N = 825      |
|                 | between |       | 0.474     | 0.319  | 2.460  | n = 25       |
|                 | within  |       | 0.347     | -1.938 | 4.096  | T = 33       |
| ENERGY~use      | overall | 6.886 | 0.687     | 0      | 8.685  | N = 825      |
|                 | between |       | 0.628     | 5.696  | 8.431  | n = 25       |
|                 | within  |       | 0.306     | -0.059 | 7.732  | T = 33       |
| FOREST          | overall | 3.736 | 1.177     | .0439  | 5.217  | N = 825      |
|                 | between |       | 1.197     | .0543  | 5.212  | n = 25       |
|                 | within  |       | .0650     | 3.488  | 4.038  | T = 33       |

Source: Author.

### Correlation matrix and multicollinearity test:

Table 3 presents the results of the correlation matrix and the estimates of the variance inflation factor (VIF). CO<sub>2</sub> emissions are positively and significantly correlated with GDP per capita (0.416) and energy consumption (0.360). Conversely, they are negatively correlated with trade openness (-0.093), urbanization (-0.141) and forest cover (-0.265). Furthermore, the correlations observed between the independent variables remain well below the critical threshold of 0.8, ruling out any risk of severe multicollinearity. The VIF values corroborate this finding: they vary between 1.143 and 2.19, with an average of 1.60, well below the threshold of 10. These results thus confirm the statistical validity and relevance of the econometric model used.

**Table 3.** Pairwise correlations and VIF estimation

| Variables           | (1)                | (2)                | (3)                | (4)                | (5)               | (6)   |
|---------------------|--------------------|--------------------|--------------------|--------------------|-------------------|-------|
| (1) CO <sub>2</sub> | 1.000              |                    |                    |                    |                   |       |
| (2) GDPpc           | 0.416*<br>(0.000)  | 1.000              |                    |                    |                   |       |
| (3) TRADE           | -0.093*<br>(0.008) | 0.537*<br>(0.000)  | 1.000              |                    |                   |       |
| (4) URB             | -0.141*<br>(0.000) | -0.413*<br>(0.000) | -0.323*<br>(0.000) | 1.000              |                   |       |
| (5) Energyuse       | 0.360*<br>(0.000)  | 0.653*<br>(0.000)  | 0.393*<br>(0.000)  | -0.363*<br>(0.000) | 1.000             |       |
| (6) Forest          | -0.265*<br>(0.000) | 0.014<br>(0.695)   | 0.261*<br>(0.000)  | 0.097*<br>(0.005)  | 0.093*<br>(0.007) | 1.000 |
| VIF                 | -                  | 2.19               | 1.584              | 1.281              | 1.81              | 1.143 |
| 1/VIF               | -                  | .457               | .631               | .781               | .553              | .875  |

\* p<0.1

Source: Author.

## 4. Empirical results

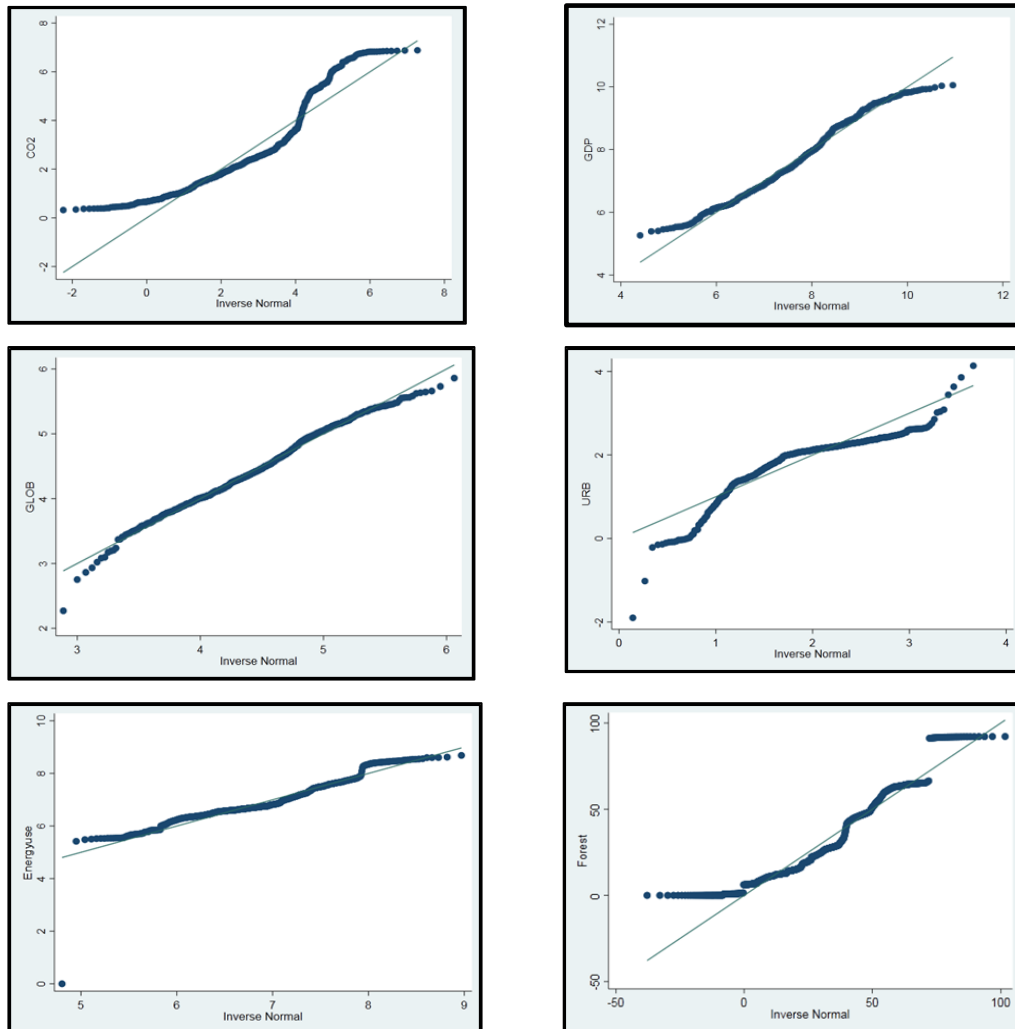
Prior to estimating the MM-QR model, it is crucial to verify several prerequisites, namely: the normality test of the distribution, the presence of slope heterogeneity, the presence of Pesaran's cross-sectional dependence, and the presence of the unit root.

**Normality test:** Table 4 shows the Shapiro–Wilk and Kolmogorov–Smirnov normality tests for distribution normality. The results of both tests indicate that all variables in the model reject the null hypothesis of normality at the 1% threshold. These results support the quantile approach, which better captures heterogeneous impacts along the conditional distribution of variables.

**Table 4.** Normal distribution test

| Variables       | Shapiro–Wilk Test |        | Kolmogorov–Smirnov Test |         | Observations |
|-----------------|-------------------|--------|-------------------------|---------|--------------|
|                 | z                 | Prob>z | D                       | P-value |              |
| CO <sub>2</sub> | 14.125            | 0.000  | 0.3992                  | 0.000   | 825          |
| GDPpc           | 12.013            | 0.000  | 0.8090                  | 0.000   | 825          |
| TRADE           | 9.413             | 0.000  | 0.1256                  | 0.000   | 825          |
| URB             | 12.170            | 0.000  | 0.9415                  | 0.000   | 825          |
| ENERGY use      | 12.373            | 0.000  | 0.2131                  | 0.000   | 825          |
| FOREST          | 8.874             | 0.000  | 0.1312                  | 0.000   | 825          |

Source: Author.

**Figure 1.** *The normal Q-Q plot of all variables*

**Source:** Author, generated using STATA.

Furthermore, Figure 1 illustrates the distribution of data using Q-Q plots to test the normality of variables. When the points coincide with the reference line, the distribution can be considered normal. Conversely, any marked deviation from this line reveals a deviation from normality. As shown in Figure 1, all variables show significant deviations, confirming their non-normal distribution. This finding justifies the use of robust econometric methods, such as quantile regression.

**Breusch Pagan and Hausman tests:** In order to test for the existence of specific, fixed or random effects, Table 5 presents the Breusch-Pagan and Hausman LM optimal model selection tests. The results show that the Breusch-Pagan LM test is highly significant ( $p < 0.01$ ), confirming the presence of individual effects, which makes the pooled OLS

regression model inappropriate (Pooled OLS). Furthermore, the Hausman test rejects the null hypothesis of the validity of random effects in favour of fixed effects ( $p < 0.01$ ). The findings suggest the fixed effects model is best for our dataset.

**Table 5.** *Model selection tests*

| Breusch-Pagan (LM test) |        | Hausman Test |        |
|-------------------------|--------|--------------|--------|
| chibar2(01)             | Prob   | chibar2(05)  | Prob   |
| 8876.15                 | 0.0000 | 113.8        | 0.0000 |

Source: Author.

**Homogeneity test:** Table 6 presents the results of the Pesaran and Yamagata (2008) homogeneity test for slopes. The results indicate that the p-value of the Delta test is less than 0.05, which means that the hypothesis of homogeneous slopes is rejected, indicating significant heterogeneity.

**Table 6.** *Pesaran & Yamagata test for slope homogeneity*

| Pesaran & Yamagata test | Statistique value | P-value |
|-------------------------|-------------------|---------|
| Delta                   | 32.485            | 0.000   |
| adj                     | 36.616            | 0.000   |

Source: Author.

**Pesaran CD test:** Cross-sectional dependence of errors was tested using the Pesaran CD test. As the p-values shown in Table 7 are all below 5%, the hypothesis of cross-sectional independence is rejected, revealing a significant dependence between units.

**Table 7.** *Pesaran CD test analysis*

| Variable        | CD-test | p-value | corr  | abs(corr) |
|-----------------|---------|---------|-------|-----------|
| CO <sub>2</sub> | 60.660  | 0.000   | 0.613 | 0.729     |
| GDPpc           | 84.850  | 0.000   | 0.856 | 0.856     |
| TRADE           | 16.610  | 0.000   | 0.168 | 0.370     |
| URB             | 8.780   | 0.000   | 0.089 | 0.336     |
| Energy~e        | 18.730  | 0.000   | 0.190 | 0.535     |
| Forest          | 58.330  | 0.000   | 0.589 | 0.877     |

Source: Author.

**Panel Unitroot test:** In light of the presence of cross-sectional error dependence, second-generation unit root tests, such as CADF and CIPS Pesaran (2007), are applied. The findings in Table 8 indicate that all series display integration of order 1 (I(1)).

**Table 8.** *CADF and CIPS Unitroot test*

| Variables       | PESCADF           |                      | CIPS     |          | Observations |
|-----------------|-------------------|----------------------|----------|----------|--------------|
|                 | At level          | $\Delta$             | At level | $\Delta$ |              |
| CO <sub>2</sub> | 1.887<br>(0.970)  | -4.016***<br>(0.000) | -2.132   | -5.254   | I(1)         |
| GDPpc           | -0.306<br>(0.380) | -2.612**<br>(0.005)  | -2.743   | -5.042   | I(1)         |
| TRADE           | -1.224<br>(0.110) | -5.809***<br>(0.000) | -2.272   | -5.520   | I(1)         |
| URB             | -0.442<br>(0.329) | -6.256***<br>(0.000) | -2.515   | -4.509   | I(1)         |
| ENERGY use      | -1.069<br>(0.142) | -4.727***<br>(0.000) | -2.206   | -5.168   | I(1)         |
| FOREST          | 1.184<br>(0.882)  | -4.514***<br>(0.000) | -1.807   | -4.971   | I(1)         |

\*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$

Source: Author.

**Cointegration Test:** The long-term cointegration relationship between the model variables is examined in Pedroni and Westerlund's cointegration tests in Table 9. The findings of the Pedroni test reveal that the Modified Phillips–Perron  $t$  statistic is significant ( $p < 0.01$ ), suggesting the existence of a cointegration relationship, although the other statistics are less conclusive. Similarly, the Westerlund test shows that two statistics are significant (, supporting the hypothesis of possible cointegration between  $\text{CO}_2$  and its determinants. These findings may indicate a long-term relationship. We then proceed to evaluate the dynamics between  $\text{CO}_2$  emissions and the independent variables (GDPpc, TRADE, URB, ENERGYuse, FOREST) using the moment quantile approach (MM-QR).

**Table 9.** Cointegration test results

|                 | Cointegration Test           | Value      | Robust P-value |
|-----------------|------------------------------|------------|----------------|
| Pedroni Test    | Modified Phillips–Perron $t$ | 3.1030**   | 0.0010         |
|                 | Phillips–Perron $t$          | -0.9148    | 0.1802         |
|                 | Augmented Dickey–Fuller $t$  | -3592      | 0.3597         |
| Westerlund test | $G_T$                        | -1.788**   | 0.050          |
|                 | $G_a$                        | -3.500     | 0.160          |
|                 | $P_T$                        | -10.523*** | 0.000          |
|                 | $P_a$                        | -4.051*    | 0.010          |

\*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$

Source: Author.

Given the presence of heterogeneity in slopes, cross-sectional dependence of errors, unit roots and non-normality of the model variables, as well as the potential existence of long-term cointegration, estimation of the model using the quantile moment method is the most appropriate way to estimate the dynamic relationship between the dependent variable ‘carbon dioxide emissions’ and the independent variables ‘GDPpc, TRADE, URB, ENERGYuse, FOREST’. This approach takes into account the heterogeneity of the impact of the determinants on the entire conditional distribution of  $\text{CO}_2$  and provides robust estimates in the face of endogeneity and cross-sectional dependence issues.

#### Estimation by the Method of Moments quantile regression (MM-QR):

Table 10 displays the results of the model estimates derived from the MM-QR approach, considering the 10th, 20th, 30th, 40th, 50th, 60th, 70th, 80th, and 90th quantiles. Figure 2 provides a visual representation of the effects of the independent variables on the dependent variable, complementing the results shown in Table 10.

This table indicates a positive and significant relationship between GDP per capita and  $\text{CO}_2$  emissions across all quantiles. The coefficients increase gradually from 0.380 at the 30<sup>th</sup> quantile to 0.402 at the 90<sup>th</sup> quantile, reflecting an intensification of the effects of economic growth associated with elevated emission levels. These results indicate that economic growth contributes to increased  $\text{CO}_2$  emissions in all contexts, but that its effect is more pronounced in countries or situations characterised by high emissions. In other words, the more a country is on a highly polluting trajectory, the more growth amplifies environmental degradation.

These findings demonstrate that economic expansion drives  $\text{CO}_2$  emissions in Africa. The rise in coefficients along the quantiles aligns with the findings of York et al. (2003) and Satrio et al. (2025), demonstrating that economic activity intensifies environmental pressures through increased energy consumption and industrial expansion, especially in contexts where access to clean technologies remains limited.

Furthermore trade openness, the findings indicate that trade openness has a positive and considerable impact on carbon dioxide emissions, so affirming that international commerce exacerbates ecological pressure (Al-Mulali & Ozturk, 2015; Ertugrul et al., 2016; Sultana et al., 2023). However, the intensity of this effect gradually decreases along the conditional distribution, from 0.209 at the 30th quantile to 0.113 at the 90th quantile. This finding indicates that trade openness induces more pollution in low-polluted countries; however, the effect of trade openness becomes less significant in high polluting economies. These results indicate that in low-emitting countries, trade openness has a relatively higher effect on emission growth while in high-emitting environments its impact gradually stagnates. This is due to the heterogeneities of moving forward in order to strengthen polluting activities and in order to adopt pollution abatement technologies that can be obtained through an increasing trade (Abdi et al., 2025; Bakri et al., 2025; Sharma, et al., 2022; Wani, et al., 2025). The outcome agrees with that of Bakri et al. (2025); Frankel & Rose (2005) and Özkan et al. (2023) which found that trade liberalization is an avenue for the spread of cleaner technologies and environmentally friendly techniques. Furthermore, economies that are highly integrated into international trade tend to reorient their productive structure towards less carbon-intensive sectors, taking advantage of their comparative advantages in more environmentally efficient activities.

Urbanization has a significant adverse effect only in the intermediate quantiles (30<sup>th</sup> q and 60<sup>th</sup> q), with coefficients ranging from -0.091 to -0.047. These findings suggest that in situations of average pollution, urbanization can promote more efficient organization (better energy management, modern infrastructure). These findings correspondent with the research of Dodman (2009) and Glaeser & Kahn (2010), which highlights the potential of cities to reduce their carbon footprint when technological innovations and investments in sustainable infrastructure accompany urbanization.

However, the effect becomes insignificant at the extremes of the distribution. At low emission levels, this can be explained by the fact that urbanization remains insufficient to induce real energy efficiency gains, as highlighted by Martínez-Zarzoso & Maruotti (2011), who associate initial urban growth with increased resource consumption and environmental pressures (Ahmad et al., 2019). At high emission levels, the absence of a protective effect could be interpreted as a sign that urban capacity to offset pollution has reached the saturation point: above a certain threshold, urban density and expansion contribute more to increasing pressures (waste production, energy demand, motorised transport), thereby limiting the effect of pollution mitigation. This dynamic is consistent with the idea that urbanization alone is not enough to reverse the pollution trend in high-emission countries, supporting the hypothesis of a non-linear relationship put forward by Martínez-Zarzoso & Maruotti (2011).

Table 10 indicates that energy intensity displays a positive, stable, and significant effect across all quantiles, with coefficients between 0.254 and 0.257. This consistency reflects the central role of energy consumption in emissions dynamics, confirming that regardless of the intensity of emissions, energy use remains a major driver of pollution. In other words, the countries studied remain heavily dependent on fossil fuels, which limits the possibility of decoupling economic growth and environmental sustainability.

**Table 10.** Estimation results from the MM-QR/XTOREG approach

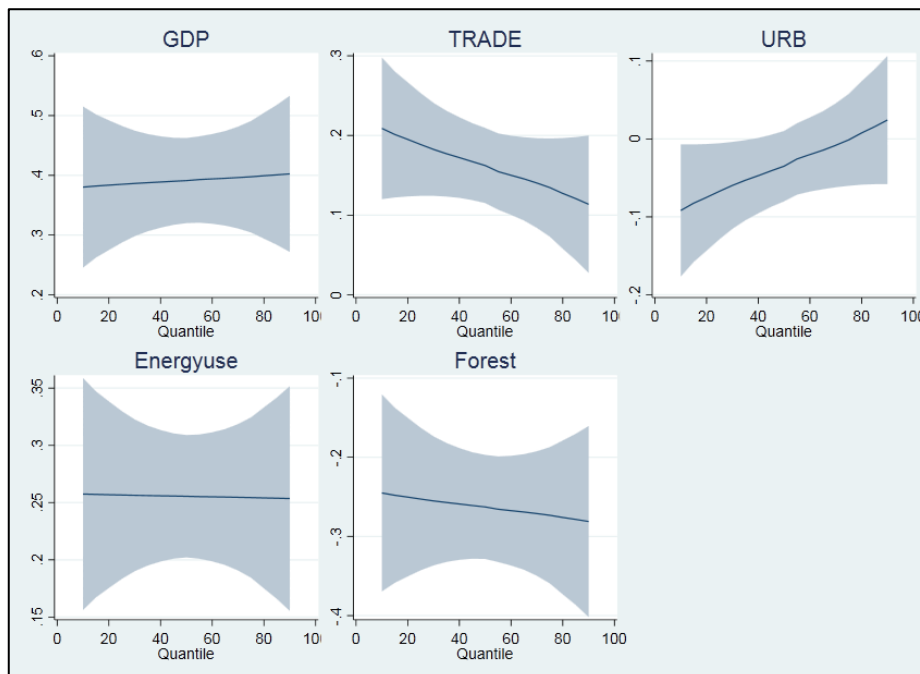
| Variables | (1)                  | (2)                  | (3)                 | (4)                 | (5)                 | (6)                 | (7)                 | (8)                 | (9)                 | (10)                | (11)                |
|-----------|----------------------|----------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
|           | Location             | Scale                | 0.10                | 0.20                | 0.30                | 0.40                | 0.50                | 0.60                | 0.70                | 0.80                | 0.90                |
| GDPpc     | 0.391***<br>(0.077)  | 0.007<br>(0.025)     | 0.380***<br>(0.068) | 0.383***<br>(0.055) | 0.386***<br>(0.045) | 0.388***<br>(0.039) | 0.391***<br>(0.036) | 0.394***<br>(0.038) | 0.396***<br>(0.043) | 0.399***<br>(0.053) | 0.402***<br>(0.066) |
| GLOB      | 0.161***<br>(0.044)  | -0.030<br>(0.021)    | 0.209***<br>(0.045) | 0.195***<br>(0.036) | 0.182***<br>(0.029) | 0.172***<br>(0.025) | 0.162***<br>(0.024) | 0.150***<br>(0.025) | 0.140***<br>(0.28)  | 0.127***<br>(0.035) | 0.113**<br>(0.044)  |
| URB       | -0.033<br>(0.046)    | 0.036<br>(0.022)     | -0.091**<br>(0.043) | -0.074**<br>(0.034) | -0.059**<br>(0.028) | -0.047*<br>(0.024)  | -0.034<br>(0.023)   | -0.019<br>(0.024)   | -0.008<br>(0.027)   | 0.007<br>(0.033)    | 0.024<br>(0.041)    |
| Eng-use   | 0.255**<br>(0.087)   | -0.001<br>(0.015)    | 0.257***<br>(0.051) | 0.256***<br>(0.041) | 0.256***<br>(0.033) | 0.255***<br>(0.029) | 0.255***<br>(0.027) | 0.255***<br>(0.028) | 0.254***<br>(0.032) | 0.254***<br>(0.040) | 0.253**<br>(0.050)  |
| Forest    | -0.263***<br>(0.092) | -0.011<br>(0.024)    | 0.245***<br>(0.063) | 0.250***<br>(0.051) | 0.255***<br>(0.041) | 0.258***<br>(0.035) | 0.262***<br>(0.033) | 0.267***<br>(0.035) | 0.271***<br>(0.040) | 0.275***<br>(0.049) | 0.281***<br>(0.061) |
| Constant  | 0.003***<br>(0.0005) | 0.425***<br>(0.0002) | /                   | /                   | /                   | /                   | /                   | /                   | /                   | /                   | /                   |

Std. err statistics in parentheses

\* p &lt; 0.05, \*\* p &lt; 0.01, \*\*\* p &lt; 0.001

Source: Author.

These results are consistent with the literature that identifies energy consumption as one of the main determinants of ecological degradation (Ertugrul et al., 2016; Apergis & Payne, 2010; Acaravci & Ozturk, 2010; Ozcan, 2013; Shahbaz et al., 2013; Azam et al., 2022). As pointed out by Al-Mulali & Ozturk (2015) and Kazemzadeh et al. (2023), the predominance of fossil fuels in the energy mix of developing countries explains the strong correlation between energy intensity and emissions. In this context, the absence of significant variation in coefficients between quantiles suggests that structural dependency on fossil fuels affects the environment despite changing emission levels.

**Figure 2.** Heterogeneous effects of independent variables across quantiles

Source: Author, generated using stata.

### Causality analysis

Given the heterogeneity of slopes and the cross-sectional dependence of errors, the Dumitrescu-Hurlin (2012) causality test is the most appropriate for detecting short-term Granger causality between CO<sub>2</sub> and the various independent variables.

**Table 11.** *Dumitrescu-Hurlin causality test results*

| Direction                   | W-bar  | Z-bar stat | p-value | Observations                                                                        |
|-----------------------------|--------|------------|---------|-------------------------------------------------------------------------------------|
| GDPpc → CO <sub>2</sub>     | 1.9983 | 3.5295     | 0.0004  | GDPpc does Granger-cause CO <sub>2</sub> for at least one panel var (Country).      |
| TRADE → CO <sub>2</sub>     | 1.6497 | 2.2972     | 0.0216  | TRADE does Granger-cause CO <sub>2</sub> for at least one panel var (Country).      |
| URB → CO <sub>2</sub>       | 2.3243 | 4.6821     | 0.0000  | URB does Granger-cause CO <sub>2</sub> for at least one panel var (Country).        |
| Energyuse → CO <sub>2</sub> | 2.0204 | 3.6077     | 0.0003  | Energy use does Granger-cause CO <sub>2</sub> for at least one panel var (Country). |
| Forest → CO <sub>2</sub>    | 4.2087 | 11.3445    | 0.0000  | Forest does Granger-cause CO <sub>2</sub> for at least one panel var (Country).     |

Source: Author.

Table 11 presents the results of the Dumitrescu-Hurlin causality test, demonstrating that all causal relationships between the independent variables and carbon dioxide emissions are significant at the 5% threshold, particularly economic growth, trade, urbanization, energy use, and forest resources, thus confirming the role of economic and structural dynamics in increasing environmental pressure. The results obtained are consistent with several conclusions in the literature, noting that economic growth, trade openness, and urban concentration fuel energy demand and consumption, with subsequent increases in emissions.

### Robustness check

To validate the robustness of the estimates generated by the MM-QR model, two complementary techniques were applied: fixed effects estimation (FE model) and Jackknife bias correction (JK correction).

**Table 12.** *MM-QR results with JK correction and clustered standard errors (for the median)*

| VARIABLES | (1)<br>FE model       | (2)<br>JK correction model |
|-----------|-----------------------|----------------------------|
| GDPpc     | 0.391***<br>(0.0297)  | 0.371***<br>(0.052)        |
| TRADE     | 0.162***<br>(0.0225)  | 0.170***<br>(0.033)        |
| URB       | -0.0339<br>(0.0219)   | -0.031<br>(0.031)          |
| Energyuse | 0.256***<br>(0.0239)  | 0.264***<br>(0.039)        |
| Forest    | -0.263***<br>(0.0287) | -0.287***<br>(0.048)       |
| Constant  | 0.00307<br>(0.0210)   | /                          |
| R-squared | 0.638                 | /                          |

*t* statistics in parentheses

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

Source: Author.



The findings in Table 12 indicate that the coefficients maintain consistent signs and levels of significance across both alternative definitions. Specifically, GDP per capita, international trade, and energy consumption exhibit a positive and significant effect on CO<sub>2</sub> emissions, while forest cover continues to play a negative and protective role. Urbanization remains insignificant, confirming its limited impact.

The similarity of the coefficients between the reference model and the corrected versions (e.g. the effect of GDP varies from 0.391 to 0.371 and that of forests from  $-0.263$  to  $-0.287$ ) attests to the stability and reliability of the estimates. The JK correction also reduces biases associated with small sample sizes and dynamic specifications, while the fixed-effects model incorporates for unobservable country-specific heterogeneity. These consistent results reinforce the empirical validity of the main conclusions and suggest that the relationships identified are not sensitive to estimation biases or model choice.

## 5. Conclusion

This study examines the heterogeneous dynamic impact of economic growth, trade openness, urbanization, energy intensification and forests resource on various levels of environmental degradation in 25 African countries over the period from 1990 to 2022. This relationship was estimated with the moment based quantile regressions (MM-QR), that takes into account the distribution non-normalities of variables, country heterogeneity and cross-sectional error dependence (Machado & Santos Silva, 2019). Fixed effects modeling and Jackknife bias correction (JK correction) were used to reduce the likelihood of spurious results. The findings supported the efficiency of MM-QR estimator and thus empirical relevance of our conclusions.

The empirical results suggest that economic growth has detrimental effects on the environment, at all levels of emissions. It is especially impactful in high-emission situations. By contrast, the overall effects of trade openness on pollution are positive, however such effect is mitigated in polluted economies, now individuating a possible evidence about the cleaner technologies' diffusion.

Urbanization is a two-sided issue. While it reduces emissions at the middle quantiles, its effect is limited to low and high emission levels. Energy consumption is another climate-vulnerable variable, but its effect on environmental quality is consistent across all quantiles, implying that African countries do not use renewable energy to the same extent as their counterparts elsewhere. The contribution of forest resources is even more important in reducing environmental pressure in polluted regions and higher quantiles, highlighting its strategic role in addressing climate change.

The adoption of targeted programs is essential for African countries to avoid environmental decline. First, governments must imperatively increase the energy efficiency of their economies by reducing their dependence on fossil fuels and encouraging innovation in industrial pollution reduction. Green trade openness could increase through international cooperation, trade treaties, and technology transfer for cleaner processes. These measures could promote pro-environmental behaviors and reduce energy conservation and

sustainability. Third, urban form and population growth must be controlled. To prevent premature urban pollution in low-emission countries, we must ensure planned urbanization and early action on the energy transition. In high-emission countries, environmental fees and property taxes will be necessary to compensate for the saturation of urbanization benefits by energy. Finally, environmental policy must be country-specific and not an indissoluble link between growth, environmental sustainability, poverty reduction, regional conservation, and unemployment.

This research has some limitations, mainly related to data availability. Future research could rely on longer observation periods and include a larger number of countries and variables, particularly institutional ones, to refine the results. Such research could also examine environmental convergence between countries with similar trajectories, thus allowing for a better understanding of these processes.

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## **Institutional governance in developing countries, political factors as drivers of institutional change: evidence from sub-Saharan Africa**

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**Abstract.** *This article provides a theoretical and empirical analysis of institutional dynamism in 38 sub-Saharan African countries, considering institutions as a form of capital. Empirical results show, using the generalized least squares method, the maximum likelihood method, the Akaike information criterion, the Bayes information criterion, and the Davidson and Mackinnon (1981) non-nested hypothesis test, that institutional change is fundamentally linked to political factors. Democracy, regime characteristics, autocracy, income inequality, and natural resource rents are fundamental to the institutional capital stock. However, the cultural environment is a determinant of institutional equilibrium, which is the central element in institutional determination in SSA countries.*

**Keywords:** governance, institutional change, political factors, Generalized Least Squares, Sub-Saharan African.

**JEL Classification:** B51, B52, C23, N37.

## 1 Introduction

The organisation of a productive sector through the rules that govern it is a fundamental element in the decision to invest and the success of development projects and programmes (Coudel and Tonneau, 2007). Thus, in recent decades, we have seen a triumphant return of institutional theories, which explain that an institution is constrained by its economic, political, cultural, historical and geographical environment, to which it conforms to guarantee its legitimacy and durability. Institutions, in turn, are defined as rules of the game set up by humans to shape human interactions (North, 1990). This definition suggests a dynamic evolution of institutions, giving rise to the notion of institutional capital, which is defined globally as a stock of rules and organisational techniques that coordinate human behaviour in interactions with resources (Wells, 1998). This definition suggests a dynamic evolution of institutions, giving rise to the notion of institutional capital, which is defined globally as a stock of rules and organisational techniques that coordinate human behaviour in interactions with resources (Wells, 1998).

Specifically, the notion of institutional capital is subject to various definitions depending on the underlying approach. Indeed, according to the economic approach (institutional efficiency theory), institutional differences are based on a cost–benefit analysis (Caose, 1960; Demsetz, 1967; North and Thomas, 1973; Williamson, 1994). In this context, institutional accumulation is explained by scarcity. For the cultural approach, the establishment of institutions is the result of beliefs, customs and behaviour in society (Weber, 1980; Putnam, 1993; Hayek, 1973; Banfield, 1958; Landes, 1998). With respect to conflict-of-interest theory (political approach), institutional capital is the choice of the group holding political power at a given time and not a collective choice of the members of society (Acemoglu *et al.*, 2005; Bourguignon and Verdier, 2000; Glaeser, 2003; Gradstein, 2004; Beck and Laeven, 2006; North, 1998). In this case, an institution can be created or maintained because it ensures the interest of the group holding power; otherwise, it is destroyed. For the geographical approach, the physical characteristics of a country are at the origin of the institutions implemented (Diamond, 1997; Sachs, 2000). Proponents of the historical approach argue that colonial origin is fundamental to the institutional accumulation of a nation (Acemoglu, *et al.*, 2001; Sokoloff and Engermann, 2000; La Porta, *et al.*, 1998).

The definition used for institutional capital varies from one context to another and from one region to another. For example, in developed countries, there is a tendency to see a definition of institutional capital of the economic type (private property rights, banking and financial regulation, the management system of senior officials, cooperative, social and solidarity organisations).

This homogeneity in the definition of institutional capital in these countries is related to the similarity of their economic and political environments. However, while SSA countries have similar institutional and political environments, their economic trajectories differ from one country to another. In this context, it becomes imperative to know which approach is best suited to understanding the nature of institutions in SSA countries. The objective of

this paper is to identify the most relevant approach to institutional adoption and reform in SSA countries by policymakers and development practitioners so that they are accepted by the people. This paper contributes generally to the foundation of the institutional capital theory under construction. In particular, this study is one of the first to focus on the analysis of institutions as a form of capital in SSA.

To achieve the objective set by this study, we defined a synthetic index of institutional capital via principal component analysis (PCA). This index is defined by combining six (06) World Bank indicators. We then estimate an empirical model on panel data of thirty-eight (38) countries covering the period 1996–2018 via the generalised least squares method and the maximum likelihood method. Each approach is captured through appropriate indicators. The results showed that the policy approach is the most relevant for analysing institutional change in SSA countries. On the other hand, the cultural environment of SSA countries is necessary for a better institutional balance that favours the implementation of the best development policies.

The remainder of this article is organised as follows. Section 2 presents a brief review of the literature, while Section 3 describes the data and the methodological approach used. Section 4 discusses the results, and Section 5 concludes.

## 2. Literature review

The concept of embedded capital, which has long been sidelined in economics, as reflected by the legal economist Trebilcock in 1996, is used from various angles. For Micallef (1969), it is the stock of goods necessary for real production or a set of services. For Bresser and Millonig (2003), institutional capital is defined as the specific conditions of the internal and external institutional contexts of the organisation allowing it to form competitive advantages. Institutional capital refers to the set of governance structures that are effective in reducing uncertainty while stimulating the adaptive efficiency of a system to different changing conditions and the functional efficiency of the allocation system of both sustainable

production and consumption patterns (Platje, 2008). For Garrabé (2008), institutional capital is a dynamic network of formal and informal rules that are complementary and articulated, which constitutes the incentive structure organising relations between individuals or between organisations within economic and social production processes. All these definitions indicate that the concept of institutional capital is linked to the notion of institutions.

The incorporation of institutional change into the equilibrium assumption has given rise to an integrated strand of economic thought on the basis of criticisms of the work of the American institutionalists of the early 20th century. This is neo-institutionalism or new institutional economics (NIE). By distinguishing between informal and formal institutions

in the sense of North, five theories allow for the analysis of institutional dynamics. These are economic, political, historical, geographical and cultural theories.

According to the theory of institutional efficiency, the level of development and degree of openness and investment influence institutional accumulation (Williamson, 1994; Kauffman and Kraay, 2002; Alonso and Garcimartin, 2013). The latter base their analyses on the theory of transaction costs and scarcity.

With respect to the dynamics of the cultural approach, authors such as Opsahl and Lacoste (2018) and Stulz and Williamson (2003) prove that the cultural environment is a very determinant in the implementation of business strategies, as cultural differences are thus supposed to lead to more decision-makers in international mergers and acquisitions of companies as people with divergent values cultures are induced to create (Ahern *et al.*, 2015). Zallé and Ouédraogo (2020) suggested that in West Africa, cultural factors determine the quality of existing institutions. La Porta *et al.* (1998) used data from the Fraser Institute over a decade in 149 developed and developing countries to show that countries with Protestant faiths are better at protecting private property rights than those with Catholic and Muslim faiths.

According to the theory of historical determinism, legal origin is fundamental to the accumulation of institutions in colonised countries, as common law countries are more favourable to the protection of private property rights than civil law countries are (Ayyagari *et al.* 2006; Beck *et al.* 2003; Djankov *et al.* 2003; Mohamey, 2001; La Porta *et al.* 1997, 1998).

In line with conflict of interest theory, Dollar and Kraay (2002) use two measures of governance proposed by Kaufmann *et al.* (1999), namely, political governance (voice and accountability) and economic governance (rule of law), to analyse the link between political and economic institutions. They find a strong and positive relationship of approximately 0.75 between the two indices in a sample of 100 developing countries. However, the relationship becomes weak (approximately 0.29) for the 60 poorest countries in the sample.

Empirical work on the geographical approach to the determination of institutional accumulation has focused on elements such as country position (latitude) and climatic conditions. In this respect, authors such as Sachs and Warner (1997; 2001), Diamond (1997), Sachs (2000) and Easterly and Levine (2003) have shown that there is a strong link between the geographical characteristics of a country and the quality of its satisfactory institutions.

In previous works, it should be noted that there is no empirical analysis that considers institutions as a form of capital that can be abused and accepted or rejected as they apply to culturally diverse populations. Furthermore, the authors who have dealt with this issue have assigned only one indicator of institutions among many others and without identifying the appropriate approach that has sat for the analysis of the foundations of these institutional changes. This does not allow the concept to be grasped in its entirety.



### 3. Methodologies and data

#### 3.1. Specification of the institutional capital analysis model

We rely on the work of Acemoglu *et al.*, 2005; Beck *et al.*, 2003; Zallé and Ouédraogo, 2020; and Mijiyawa, 2010, for the characteristics of our econometric model. Thus, equations (1) and allows us to estimate the simple and relative relevance of the different theories: the political, economic, historical, geographical and cultural approaches. In the estimation strategy, the relevance of the theories is captured by the coefficient matrix  $\alpha$ . The different approaches are introduced in turn in the vector  $X$  for estimation. In these models,  $cap\_inst_{it}$  denotes our proxy for the index of institutional capital in all its dimensions.  $P$ : a vector of political variables,  $C$ : a vector of cultural variables,  $G$ : a vector of geographical variables,  $E$ : a vector of economic variables,  $H$ : the vector of historical variables and  $\varepsilon$ , the error term.

$$Cap_{it} = \varphi + \alpha X_{it} + \theta Z_{it} + \varepsilon_{it} \quad (1)$$

In this equation, all the approaches are introduced simultaneously, and the relative relevance of each approach is captured by the coefficient of each approach.

$$Cap_{it} = \beta_0 + \beta_1 E_{it} + \beta_2 P_{it} + \beta_3 C_{it} + \beta_4 H_{it} + \beta_5 G_{it} \varepsilon_{it} \quad (2)$$

To measure the relative relevance of the different approaches, the proxy variables of the different approaches are also included.

#### 3.2. Choice of proxies for the different variables to capture the different approaches

Institutional capital is captured through a synthetic index constructed on the basis of six World Bank institutional indicators through principal component analysis (PCA). The results of the PCA are valid because the KMO index is approximately 80.04%.

The identification of proxies for the different approaches is analytical and follows our focus. Indeed, the political debate on the determinants of institutional accumulation is often focused on the form of the state (Borner *et al.* 2004). Theoretically, the nature of a country's regime is linked to the level of its institutional framework. Thus, a democratic regime (the expression of the will of the people) positively influences the institutional accumulation of a country. In contrast, an autocratic regime characterised by the absence of plurality is a source of institutional inefficiency. Mijiyawa (2010) agreed that institutions are often created to serve the interests of those who hold the state apparatus; this leads to the formation of dominant interest groups. Furthermore, Keefer and Knack (2002) have shown that countries with high levels of inequality (high social polarisation) have institutions that allow fewer private property rights.

Religious affiliation and cultural, linguistic and ethnic diversities are sometimes used to capture the cultural approach. Landes (1998) believes that Protestantism teaches openness and tolerance and therefore breeds good institutions. For cultural and even linguistic diversity, most authors agree that strong ethnic polarisation increases the occurrence of conflict and violence (Landes, 1998; Alesina *et al.* 2003; Easterly and Levine, 2003).

For the proxies of the economic approach, the economic quantities that can test the relevance of institutional efficiency theory are the level of development, the degree of

openness and the growth of GDP/head. For Borner *et al.* (2004), the scarcity of resources and the various reasons for market failure require that institutions be created to coordinate the interactions of individuals and organisations. Indeed, individual rationality, when left unchecked by institutions and compliant regulations, leads to rent-seeking, corruption and crime (Tirole, 2016). For Rosenberg and Birdzell (1987), the demand for the creation of institutions for the protection of private property rights increases with the number and volume of economic transactions to be carried out and thus with the level of economic development.

Empirically, the geographical approach is often captured by the position relative to the equator (Zallé and Ouédraogo, 2020; Acemoglu *et al.*, 2014). This links the physical and climatic characteristics of the country with the level of appropriate institutions. One might think that countries that are favoured by nature, especially in terms of climate, have favoured good institutions. This is because, in these countries, settlers have established institutions for settlement to live there. In contrast, in countries where the climate was not very favourable for survival, they set up extractive institutions.

The historical approach is tested by the proxy of the legal origin of the legal system. The proxy variable for the test of the historical approach is a dummy variable taking a value of one for countries with a *common law* legal tradition and zero for those with a Romano–Germanic legal tradition or countries with a socialist legal system. La Porta *et al.* (1997, 1998), Mohoney (2001), Beck *et al.* (2003) and Djankov *et al.* (2003) agree that *common law* countries accumulate institutions that better ensure the protection of property rights than civil law countries do. Hayek (1973) suggested that the advantage of *common law* countries over civil law countries is due to the different roles of the state and the individual in the economy. He argues that, in general, in *common law countries*, there is less state interventionism in the economy and more individual freedom and therefore better protection of private property rights.

**Table 1.** Summary of variables and expected signs

| Approaches               | variables          | Definition                                  | Expected signs |
|--------------------------|--------------------|---------------------------------------------|----------------|
| policy                   | Unequal_rep_income | Income inequality                           | -              |
|                          | Democ              | The democracy index                         | +              |
|                          | Autoc              | The autocracy index                         | -              |
|                          | Resource_nat       | Natural resource rents                      | +              |
|                          | Political system   | The characteristics of the political regime | +              |
| Cultural                 | Protes             | Proportion of Protestants                   | +              |
|                          | Catho              | Proportion of Catholics                     | -              |
|                          | Muslim             | Proportion of Muslims                       | -              |
|                          | Other              | Other religions                             | -              |
|                          | Fragment_ethn      | Ethnolinguistic fragmentation               | -              |
| Economic                 | GFCF               | Gross fixed capital formation               | +              |
|                          | GDP                | GDP/head growth rate                        | -              |
|                          | Opening            | Economic openness                           | +              |
| History                  | Legal origin       | The identity of the coloniser               | +/-            |
| Geographic               | Latitude           | Distance from the equator                   | +              |
|                          | Urba               | Proportion of urban population              | +              |
| Z (controlled variables) | Human_Capital      | The level of human capital                  | +              |
|                          | EDI                | Foreign direct investment                   | +              |

Source: Authors.

### 3.3. Descriptive statistics of the variables

Table 2 shows that in Sub-Saharan Africa, there is generally very little decline across countries for any factor. The different variables are homogeneous because the variables are weakly dispersed with respect to the average. Table 2 summarises the descriptive statistics of the different variables used.

**Table 2.** *Descriptive statistics of the variables*

| Variable    | Obs | Signify    | Std. Dev. | Min       | Max      |
|-------------|-----|------------|-----------|-----------|----------|
| Cap_inst    | 874 | -1,685316  | 0,8508304 | -3,194713 | 1,354632 |
| Annuity_res | 874 | 11,78707   | 10,93635  | 0,0658137 | 59,61957 |
| Gini        | 874 | 43,3714    | 7,377589  | 29,8      | 64,8     |
| GDP         | 874 | 1,898,072  | 5,696839  | -36,8299  | 91,64805 |
| Latitude    | 874 | 11,34763   | 7,628271  | 0         | 29,7     |
| Opening     | 874 | 72,2405    | 34,61862  | 17,85861  | 311,3553 |
| GFCF        | 874 | 19,78197   | 8,404591  | -2,424358 | 59,72307 |
| Human       | 874 | 39,08775   | 21,10017  | 5,21012   | 102,7539 |
| Urba        | 874 | 38,58313   | 16,22183  | 7,412     | 89,37    |
| EDI         | 874 | 4,403567   | 8,836325  | -82,8921  | 89,47596 |
| Political   |     |            |           |           |          |
| system      | 874 | -2,443936  | 19,35902  | -88       | 10       |
| Autoc       | 874 | -2,281465  | 18,83882  | -88       | 9        |
| Demo        | 874 | -0,4839817 | 19,39404  | -88       | 10       |
| Fragment    | 874 | 0,1647597  | 0,5961643 | 0         | 3        |
| Prot80      | 874 | 13,60789   | 12,99797  | 0         | 50       |
| Nocpm       | 874 | 31,9       | 19,16177  | 0,1       | 63,8     |
| Musi80      | 874 | 29,03158   | 32,5629   | 0         | 99,7     |
| Cat80       | 874 | 25,46053   | 23,98943  | 0,1       | 95,9     |

Source: Author, based on data.

### 3.4. Estimation strategy

The generalised least squares (GLS) estimator is used to analyse the determinants of institutional change in our research. Preliminary tests (Fisher and Hausman tests) allowed us to identify the random effect model for the estimation of the different equations. Ouellet *et al.* (2005) reported that GCMs are able to consider the problems of autocorrelation and heteroscedasticity of errors. In addition, Wald statistics, the likelihood ratio, Akaike's information criterion, Bayes' information criterion, and the Davidson and Mackinnon (1981) nonnested hypothesis test are used in this work for an in-depth analysis of the estimation results. First, we proceed with specification tests of our model.

## 4. Results and discussion

The Wald statistic tests have shown that the approaches are more or less relevant for analysing institutional change in SSA countries.

**Table 3.** *Results of the validity of the relevance of the approaches*

| Approach         | Policy (1) | Cultural (2) | Economic (3) | History (4) | Geographic (5) |
|------------------|------------|--------------|--------------|-------------|----------------|
| Wald statistics  | 49,65      | 73,59        | 17,97        | 6,96        | 12,30          |
| Prob>chi2        | 0,0000     | 0,0000       | 0,0030       | 0,0732      | 0,0153         |
| Relevance or not | Relevant   | Relevant     | Relevant     | Relevant    | Relevant       |

Source: Authors.

The results of the different estimates are presented in Table 3.

Considering the estimation of equation (1), the political variables all have significant effects on institutional capital in SSA countries. Overall, the simple relevance of the policy approach could be accepted. Indeed, income inequality and democracy translate positively and significantly to institutional accumulation in SSA at the 10% and 5% thresholds, respectively. A1 percentage point improvement in democracy leads to a 10.9 percentage point improvement in institutional capital accumulation in SSA. Democracy favoured the development of institutions that could be accepted by all, given the participation of the population in the decision-making process and in the management of public affairs. An increase in income inequality of 1% benefits the accumulation of institutional capital by 0.3%. Our result is similar to those of Mijayawa (2010) and Engermann and Sokoloff (2002).

For them, there would be a positive relationship between income inequality and the percentage of land devoted to sugarcane cultivation. On the one hand, it can be assumed that the richest in developing countries adopt laws and norms in their favour at the expense of the poor or by corrupting them. Land tenure laws mean that, in most cases, the poor give their land to the rich at a low price. New acquirers, in most cases, tend to reinforce land tenure laws through corrupt acts with legal institutions to maintain their social position. On the other hand, this effect could also be explained by the reinforcement of anticorruption measures and the promotion of good governance by international organisations (World Bank, IMF, etc.) at the national level and by certain NGOs.

Moreover, inequality undermines the control of elites over institutions that they use to serve their own interests (Philippot, 2009). Moreover, the deepening of poverty in SSA despite the many aids and investments in it may justify the maintenance of certain institutions that benefit only those in power. This can also be explained by the corruption of the poor for the establishment of certain norms or laws by the richest, who give them all their authority. Autocracy, political regime characteristics and natural resource rents all have significant negative effects on institutional adoption in SSA. This result was reported by Siba (2008) and Acemoglu *et al.* (2005). Note that autocracy is significant at the 1% level and that regime characteristics are significant at the 5% level. A strengthening of autocracy and the character of the political regime deteriorate institutional capital by 0.608% and 0.0456%, respectively, in sub-Saharan African countries. This result is explained by the unilateral adoption of societal norms and rules of conduct that are generally not approved by the population. In addition, natural resource rents negatively influence institutional accumulation in SSA and are therefore a real impediment to institutional achievement. This is because natural resource rents are used to buy the consciences of those who can demand better institutions and uphold laws or regulations on natural resource exploitation. This finding corroborates that of Ross (2001). This may confirm the thesis that natural resources are a curse for developing countries, especially those in SSA. This result also corroborates that of Philippot (2009).

In terms of simple relevance, the cultural approach is valid because the coefficients associated with its variables are significantly different from zero. Moreover, the effects of its variables on the constitution of institutional capital confirm the expected signs of these

variables. However, not all variables are significant. The nonsignificance of the coefficients associated with the religious variables can be explained by the secularity of the SSA states. Indeed, the groups holding power or at the origin of the legislature are not constituted according to religious denominations but rather according to technical skills and political convictions, although some religious leaders may be consulted in the case of certain crises (political, social).

Note that ethnolinguistic fragmentation is significant at the 1% level, with a negative effect on the level of institutional capital in sub-Saharan Africa. A deterioration of the social climate by 1% leads to the destruction of institutional capital by 17.2%. This means that ethnic diversity is a source of social polarisation and thus leads to the constitution of an interest group that will adopt unilateral rules and norms that are always contested. Bozio and Grenet (2010) noted that the fragmentation of power between different entities (clans, warlords, mafias, etc.) hinders wealth creation because the fragmentation of coercive power does not allow for the effective protection of property rights. Authors (Siba, 2008; Zallé, 2018; Alesina *et al.*, 2003; Landes, 1998; Easterly and Levine, 1997; Easterly and Levine, 2003) have also shown that a peaceful social climate is a source of social cohesion. Notably, this state of affairs leads to a good adoption of rules and norms that the populations themselves respect without and contribute to maintaining them. Chalençon (2020) argues that cultural institutions have an important effect on the institutional strategy of corporate acquisition. It is clear that in sub-Saharan Africa, people value ethnicity over religious affiliation.

The results in column (3) shows that the economic approach has simple relevance. Indeed, the coefficients associated with its variables have the expected signs and are also different from zero. Notably, public investment is a determining factor in the economic approach because the associated coefficient is significant at the 1% level. An increase in public investment leads to an improvement in institutional capital in Sub-Saharan African countries. An increase in public investment will allow the costs associated with institutional accumulation and maintenance to be met in the reality of reality, which is consistent with the theory of institutional efficiency. This would not be the case in regard to foreign investment, as foreign investors already have return sectors in which they wish to invest.

Thus, foreign funding is not conducive to building institutional capital in SSA countries because investors want to have laws in their favour, which can negatively influence the building of consensual institutions. It could be argued that financial autonomy is a source of political independence. Notably, the level of development is not significant for a high level of institutional accumulation. This result is explained by the fact that SSA countries correspond little of the fruits of growth to institutional accumulation and are almost concerned with external financing.

For the historical approach, the sign of the coefficient of the variable 'legal origin' is negative. This shows that the identity of the coloniser negatively influences the accumulation of institutional capital in SSA countries. In SSA, this result is easily explained because the countries colonised by France may have the same laws and norms. Several authors have supported this view empirically (Hayek, 1960; Borner *et al.*, 2004; Mijiwaya, 2010; Chong and Zanforlin 2000). Furthermore, Treisman (2000) argues that

the origin of the legal system can have a negative influence on institutional capital but in the case of corruption. This is the case for sub-Saharan African countries, although its effect is not significant.

The institutional capital of sub-Saharan Africa (SSA) can be explained to a lesser extent by its geographical characteristics. Indeed, the coefficients associated with the different proxies used to measure geography are nonzero and show the expected effects. Urbanisation and the level of access are favourable to the development of institutional capital in SSA. Urbanisation is significant at the 1% level. This can be explained by modernisation. Citizens from diverse backgrounds who interact with each other in various ways want a formalised framework that can constrain the economic, social and other organisational games they play. Thus, it is imperative that the state acts as the referee of the game, setting the rules and enforcing them. Any violators do so at their own expense. Furthermore, Alaya *et al.* (2004) reported that the level of urbanisation and institutional development is a source of accessibility to different institutions (social, cultural, health, sports, etc.), thus stimulating the accumulation of knowledge and the development of human skills. Notably, however, the level of accessibility is not significant. This result contradicts the finding of other authors that reducing transaction costs related to trade and investment is important (Hall and Jones, (1999)). In the case of SSA, the result can be explained by adaptations to compensate for these costs. This result is also proven by (Nunn and Puga, 2012).

Ultimately, the results of the estimations show that the selected approaches all seem applicable for the analysis of institutional dynamics in SSA. However, it would be of paramount importance to discriminate the approaches by confrontation to identify the approach(es) that can best explain institutional capital (relative relevance) in SSA countries.

For all the equations, the coefficients of the human capital proxy and that of foreign direct investment (FDI) always remain significant and negatively related to the institutional capital index. The level of education is supposed to improve the setting up of institutions through cognitive learning because a more educated population requires more transparent and dynamic institutions and allows their construction. It could therefore be argued that the level of human capital in sub-Saharan African countries is insufficient for institutional accumulation. Rauch and Evans (2000) have limited this educational effect on the control of corruption. The unintended effect of FDI can be explained by the level of institutional maturity of SSA countries, as investors want a favourable situation for their investments and direct them in the areas of their choice. This orientation is usually not imposed on citizens by those in power, and these decision-makers often sign agreements without the knowledge of the population. This can lead to a lack of interest in the people and a boycott of institutions. Similarly, the works of Hernández and Nieto (2015) and Kogut and Singh (1988) show that companies are tempted to move toward investments that minimise the resources involved and, consequently, the risks incurred when there are enormous cultural differences between the host and the host country. Thus, the results in column (6) makes sense.

Column (6) of Tables 4 provides an account of the relative relevance of the approaches used to compare the theories. Thus, the criteria for relative relevance show that all the theories seem to meet these criteria. We note that the expected effects of the proxy variables did not deviate from the rule and that the coefficients associated with these proxy variables are statistically nonzero. However, these approaches are discriminating in terms of the significance of the proxy variables. Indeed, the results show that beyond the criteria of relative relevance, the political and cultural approaches have more significant variables. The same is true of the geographical approach. For the economic and historical approaches, the proxy variables are not significant. These findings show that these approaches do not explain institutional change in SSA countries to a great extent. However, these approaches cannot be discarded from the analysis, as their simple and relative relevance is validated.

**Table 4.** *Results of the estimates of the relevance of the approaches*

| variables        | cap_inst               | cap_inst                 | cap_inst                | cap_inst               | cap_inst                 | cap_inst                 |
|------------------|------------------------|--------------------------|-------------------------|------------------------|--------------------------|--------------------------|
| prot80           |                        | 0,000267<br>(0,0132)     |                         |                        |                          | -0,0223<br>(0,0157)      |
| musl80           |                        | -0,00189<br>(0,00578)    |                         |                        |                          | -0,0112*<br>(0,00675)    |
| Nocpm            |                        | 0,00438<br>(0,00760)     |                         |                        |                          | -0,0104<br>(0,00995)     |
| Fragment         |                        | -0,172***<br>(0,0232)    |                         |                        |                          | -0,203***<br>(0,0392)    |
| Human            |                        | -0,00265**<br>(0,00113)  | -0,00309**<br>(0,00122) | -0,00214*<br>(0,00117) | -0,00638***<br>(0,00239) | -0,00661***<br>(0,00229) |
| EDI              |                        | -0,00622***<br>(0,00159) | -0,00240*<br>(0,00143)  | -0,00151<br>(0,00139)  | -0,00188<br>(0,00204)    | -0,00194<br>(0,00207)    |
| Gini             | 0,00777*<br>(0,00465)  |                          |                         |                        |                          | 0,00942**<br>(0,00459)   |
| annuity_res      | -0,00308*<br>(0,00300) |                          |                         |                        |                          | -0,00388<br>(0,00298)    |
| Demo             | 0,109**<br>(0,0456)    |                          |                         |                        |                          | 0,106**<br>(0,0452)      |
| Autoc            | -0,0459***<br>(0,0150) |                          |                         |                        |                          | -0,0516***<br>(0,0151)   |
| Political system | -0,0608*<br>(0,0328)   |                          |                         |                        |                          | -0,0557*<br>(0,0325)     |
| Opening          |                        |                          | 0,0296<br>(0,0526)      |                        |                          | 0,00145<br>(0,000900)    |
| GFCF             |                        |                          | 0,0873***<br>(0,0320)   |                        |                          | -0,00468<br>(0,00307)    |
| GDP              |                        |                          | 0,00287<br>(0,00191)    |                        |                          | 0,00289<br>(0,00273)     |
| Egal_orig        |                        |                          |                         | -0,397<br>(0,270)      |                          | -0,538<br>(0,329)        |
| Urba             |                        |                          |                         |                        | 0,0190***<br>(0,00608)   | 0,0127**<br>(0,00550)    |
| Latitude         |                        |                          |                         |                        | 0,223<br>(0,192)         | 0,0350*<br>(0,0211)      |
| Constant         | -2 014***<br>(0,278)   | -1 024**<br>(0,474)      | -1 345***<br>(0,235)    | -0,766***<br>(0,216)   | -2 411***<br>(0,491)     | -1 398*<br>(0,731)       |
| Comments         | 874                    | 836                      | 835                     | 836                    | 814                      | 836                      |
| ID number        | 38                     | 38                       | 38                      | 38                     | 37                       | 38                       |

Z statistics in brackets \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

**Source:** Author, based on estimation results.

The joint estimation of all the theories allows us to confirm once again the simple relevance and capture the relative relevance of the different theories but does not allow us to discriminate the most relevant theory to best capture institutional capital in sub-Saharan Africa. To achieve this, it is imperative to carry out additional tests to capture the approach that best provides the information. Thus, the likelihood ratio is mobilised for this purpose. In addition to the likelihood ratio, the Akaike information criterion (AIC) and the Bayesian information criterion (BIC) are also tested. Indeed, the information conveyed by these different models constitutes one of the main axes of comparison. Moreover, these criteria make it possible to evaluate the degree of fit of the model while taking into account the addition of new explanatory variables. An approach is said to be relevant if it minimises the AIC and BIC criteria and offers a small likelihood ratio in absolute value. The results of the different theory tests in Table 5 show that the political approach is the most relevant of all the effective approaches in the study.

**Table 5.** *Results of discrimination tests for the most relevant approach*

| Models | Political approach | Cultural approach | Economic approach | Historical approach | Geographical approach |
|--------|--------------------|-------------------|-------------------|---------------------|-----------------------|
| L/R    | -973.927           | -1000.121         | -1002.093         | -1066.246           | -1004.351             |
| AIC    | 1959.854           | 2014.242          | 2016.186          | 2142.492            | 2086.422              |
| BIC    | 1974.94            | 2040.61           | 2037.8231         | 2152.401            | 2034.82               |

**Source:** Author's calculation on the basis of the statistical regression results.

The analysis of the results in Table 5 indicates that the policy approach is the most important determinant of institutional capital in sub-Saharan Africa. Indeed, it has the lowest likelihood ratio value (-973.9) in absolute terms. It differs very significantly from the other theories. It can therefore be assumed that in sub-Saharan Africa, the theory that institutional capital is the result of a power relationship (conflict of interest) is validated. This is because those in power choose and implement laws and principles that serve their interests and not those of society as a whole. After the political approach, the cultural approach can be followed by the economic approach. They have likelihood ratios of -1000.12 and -1002.09, respectively. The historical approach comes last after the geographical approach. They have likelihood ratios of -1066.24 and -1004.351, respectively.

The Akaike and Bayesian information criteria once again confirm the predominant relevance of the political approach. The political approach has a value of 1959.852 for the AIC. In view of the complexity of the 'institutional capital concept' and the interaction of the theories with each other, it is important to determine which combination of approaches can offer a better fit while simultaneously determining which political approach is the most relevant. This involves a policy analysis of the effects of the different proxies on institutional capital. This will provide a snapshot of the optimal combination of approaches to capture the dynamics of institutional change in SSA countries.

A pairwise combination of approaches reveals that the combination of the political approach with the economic approach is the best. This combination gives us the lowest likelihood ratio (247.04). Thus, to better understand institutional capital in sub-Saharan Africa, political aspects should be taken into account in economic analysis of institutions.



Thus, any economic policy has a political basis. Moreover, the combination of the political approach and the geographical approach results in an LR test value of 272.25. One might therefore think that beyond the economic aspect, the geographical configuration is necessary for understanding institutional accumulation in sub-Saharan Africa. Indeed, urbanisation has led to the formalisation of rules to govern human relations from various backgrounds. Notably, ethnic diversity and religious denominations are crucial for the implementation of institutional elements from a political point of view. Barro and McCleary (2003) provide evidence of a positive correlation between the prevalence of religious beliefs about hell and heaven and economic growth.

The combination of political and historical approaches has a positive and significant effect on institutional capital in SSA. Indeed, at the political level, the legal origin of the legal system has a positive influence on the development of the institutional framework of a country. For example, most legal and judicial systems in ex-colonies have restrictions with those of their colonisers.

An attempt to combine the political approach with two other approaches shows that the political-economic-geographical approach is the most relevant, with an LR statistic of (-849.0005), followed by the (political-cultural-geographical) approach, with a statistical value of (-851.05), and then the (political-cultural-economic) approach, with an LR statistic value of (-859.51). Note that the signs and the different significances did not change regardless of the number and type of combinations made. Thus, institutional accumulation in SSA countries requires the consideration of geo-cultural and geo-economic factors in a policy analysis. Indeed, most SSA countries still have cultural and religious considerations that are often brought to the forefront in certain policy decisions. This can be observed during political crises where religious and traditional leaders are often called upon to calm the social climate. The latter propose principles and laws to reconcile antagonistic parties if necessary. The results of the estimations are presented in Table 6.

The results in Table 6 show that policy analysis is relevant for any understanding of institutional accumulation in SSA countries. Indeed, the proxies of the policy approach retain their effects and significance.

At the political level, religious denominations, people's norms and traditions, and cultural diversity could influence institutional capital in SSA. On the one hand, a decision maker's traditional or religious stance may bias his or her position in adopting rules to meet his or her demands.

This could naturally challenge the secular nature of states. On the other hand, some religious or customary leaders are sometimes called upon to make state decisions. Furthermore, Easterly and Levine (1997) and Alesina *et al.* (2003) reported that in an ethnically polarised environment, policy makers set up institutions that only allow property rights for members of their ethnic groups; this has resulted in inefficient institutions. Furthermore, Alesina and Giuliano (2015) demonstrated that culture affects formal and informal legal laws.

The political-economic analysis of institutional capital suggests that all economic policy has a political underpinning. Rodrick (2004) argues that all economic policy is dependent

on the institutional environment in which it is implemented. Thus, economic objectives may push political actors to a certain level of institutional change or creation. In the logic of Acemoglu *et al.* (2005), economic institutions are the products of political institutions.

The geopolitical analysis of the institutional capital of sub-Saharan African countries shows that it could be strongly linked to their urbanisation and other strategic factors. The establishment of multinationals, the management of urban land, and the establishment of texts to regulate the business climate between citizens from different areas are all elements that could justify institutional needs.

**Table 6.** Estimation results by combination of approaches

| VARIABLES        | cap_inst                 | cap_inst                 | cap_inst                | cap_inst                | cap_inst                | cap_inst                 | cap_inst                | cap_in               |
|------------------|--------------------------|--------------------------|-------------------------|-------------------------|-------------------------|--------------------------|-------------------------|----------------------|
| Gini             | 0,0129***<br>(0,00331)   | 0,0167***<br>(0,00327)   | 0,0179***<br>(0,00317)  | 0,0183***<br>(0,00324)  | 0,00972***<br>(0,00350) | 0,0207***<br>(0,00320)   | 0,0101***<br>(0,00348)  | 0,0223*<br>(0,0032)  |
| annuity_res      | -0,0122***<br>(0,00215)  | -0,00991***<br>(0,00225) | -0,0115***<br>(0,00213) | -0,0125***<br>(0,00221) | -0,0163***<br>(0,00237) | -0,00910***<br>(0,00228) | -0,0158***<br>(0,00241) | -0,0108<br>(0,0022)  |
| Demo             | 0,250***<br>(0,0439)     | 0,266***<br>(0,0436)     | 0,320***<br>(0,0428)    | 0,303***<br>(0,0439)    | 0,291***<br>(0,0434)    | 0,334***<br>(0,0432)     | 0,275***<br>(0,0431)    | 0,313*<br>(0,043)    |
| Autoc            | -0,118***<br>(0,0141)    | -0,124***<br>(0,0140)    | -0,139***<br>(0,0136)   | -0,137***<br>(0,0140)   | -0,132***<br>(0,0138)   | -0,143***<br>(0,0138)    | -0,129***<br>(0,0137)   | -0,141*<br>(0,013)   |
| Political system | -0,132***<br>(0,0314)    | -0,146***<br>(0,0311)    | -0,184***<br>(0,0308)   | -0,168***<br>(0,0315)   | -0,160***<br>(0,0312)   | -0,197***<br>(0,0310)    | -0,151***<br>(0,0310)   | -0,177*<br>(0,031)   |
| cath80           |                          | 0,00894***<br>(0,00235)  |                         |                         |                         |                          | 0,00876***<br>(0,00239) |                      |
| musl80           |                          | 0,00492***<br>(0,00189)  |                         |                         |                         | -0,00142<br>(0,00108)    | 0,00282<br>(0,00190)    | -0,00524<br>(0,0010) |
| Nocpm            |                          | 0,00765***<br>(0,00255)  |                         |                         |                         | 0,00161<br>(0,00145)     | 0,00375<br>(0,00254)    | -0,00483<br>(0,0015) |
| prot80           |                          |                          |                         |                         |                         | -0,00248<br>(0,00247)    |                         | -0,0121<br>(0,0025)  |
| Fragment         |                          | -0,261***<br>(0,0434)    |                         |                         |                         | -0,222***<br>(0,0449)    | -0,259***<br>(0,0432)   | -0,253*<br>(0,044)   |
| EDI              | -0,00866***<br>(0,00256) | -0,00998***<br>(0,00248) |                         |                         |                         |                          |                         |                      |
| Human            | 0,00777***<br>(0,00122)  | 0,00797***<br>(0,00118)  |                         |                         |                         |                          |                         |                      |
| Fbcf             |                          |                          | 0,0248***<br>(0,00295)  |                         |                         | 0,0233***<br>(0,00318)   |                         |                      |
| Opening          |                          |                          | -0,000778<br>(0,000725) |                         |                         | -0,00160**<br>(0,000742) |                         |                      |
| GDP              |                          |                          | -0,00166<br>(0,00396)   |                         |                         | -0,00129<br>(0,00390)    |                         |                      |
| egal_orig        |                          |                          |                         | -0,153***<br>(0,0496)   |                         |                          |                         | -0,266*<br>(0,054)   |
| Urba             |                          |                          |                         |                         | 0,0106***<br>(0,00154)  |                          | 0,0126***<br>(0,00152)  |                      |
| Latitude         |                          |                          |                         |                         | 0,00496<br>(0,00354)    |                          | 0,0104***<br>(0,00383)  |                      |
| Constant         | -2 164***<br>(0,166)     | -2 970***<br>(0,287)     | -2 694***<br>(0,170)    | -2 138***<br>(0,178)    | -2 256***<br>(0,166)    | -2 730***<br>(0,195)     | -2 781***<br>(0,287)    | -1 782*<br>(0,201)   |
| Comments         | 874                      | 874                      | 874                     | 874                     | 874                     | 874                      | 874                     | 874                  |
| ID number        | 38                       | 38                       | 38                      | 38                      | 38                      | 38                       | 38                      | 38                   |

Standard errors in brackets; \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

**Source:** Author, based on estimates.

According to the new institutional economics, countries with a universally accepted democracy limit internal crises through the participatory approach. These countries have

become able to accumulate institutional capital that is conducive to the implementation of policies aimed at increasing the well-being of the population.

Our study shows that the institutional framework of sub-Saharan African countries is fundamentally political. To support this argument, robustness tests are carried out with other databases, notably those of the Heritage Foundation. This involves changing the dependent variable, which is the index of institutional capital integrated through the data of Kaufmann *et al.* (2004), by those of the Heritage Foundation, while keeping the proxy variables of the different approaches.

#### 4.2. Testing the robustness of the results: Using the Legacy Foundation database and the nonnested hypothesis test

In this section, the results of the estimations and of the non-nested hypothesis are presented successively. The robustness of our results is achieved by replacing the proxy variable of the institutional capital index with the governmental integrity of the Heritage Foundation. However, to avoid a possible double interpretation of the results, only the results of the likelihood ratio and the Akaike and Bayesian information criteria are presented in Table 7.

**Table 7.** Results of identifying the most relevant approach

| Approaches Data | Type of tests | Political approach | Cultural Approach | Economic approach | Historical approach | Geographical approach |
|-----------------|---------------|--------------------|-------------------|-------------------|---------------------|-----------------------|
| Heritage        | L/R           | -3361 345          | -3362 451         | -3367 493         | -3369 238           | -3366 451             |
| Foundations     | AIC           | 6732.69            | 6736.902          | 6744.986          | 6744.476            | 6740.902              |
|                 | BIC           | 6737.3975          | 6739.6095         | 6743.801          | 6747.2426           | 6744.5908             |

**Source:** Author, on the basis of test results.

The results of the different tests on the Heritage Foundation database confirm the predominance of the political approach over the other approaches. The political approach would be the most suitable for understanding institutional capital in sub-Saharan Africa. Our results are in line with those of Acemoglu *et al.* on the determinants of institutions in developing countries.

The results on the Heritage Foundation data are presented in Table 8.

**Table 8.** Robust results with heritage foundation data

| VARIABLES        | integrity_gouv       | integrity_gouv        | integrity_gouv       | integrity_gouv | integrity_gouv | integrity_gouv        |
|------------------|----------------------|-----------------------|----------------------|----------------|----------------|-----------------------|
| Demo             |                      | 1.812**<br>(0.746)    |                      |                |                | 1.522**<br>(0.763)    |
| Autoc            |                      | -0.510**<br>(0.244)   |                      |                |                | -0.420*<br>(0.240)    |
| Political system |                      | -1.298**<br>(0.537)   |                      |                |                | -1.072*<br>(0.552)    |
| Gini             |                      | -0.335***<br>(0.0747) |                      |                |                | -0.224***<br>(0.0597) |
| annuity_res      |                      | -0.101**<br>(0.0483)  |                      |                |                | -0.131***<br>(0.0412) |
| Equal origin     | 4.374<br>(3.038)     |                       |                      |                |                | 1.098<br>(0.903)      |
| L.Human          | 0.195***<br>(0.0265) |                       | 0.129***<br>(0.0329) |                |                | 0.0276<br>(0.0218)    |
| L.IDE            | 0.118***<br>(0.0328) |                       | 0.186***<br>(0.0384) |                |                | 0.130***<br>(0.0460)  |
| L.latitude       |                      |                       | 0.256<br>(0.200)     |                |                | 0.162**<br>(0.0655)   |

| VARIABLES | integrity_gouv      | integrity_gouv      | integrity_gouv       | integrity_gouv            | integrity_gouv     | integrity_gouv       |
|-----------|---------------------|---------------------|----------------------|---------------------------|--------------------|----------------------|
| Urba      |                     |                     | 0,225***<br>(0,0729) |                           |                    | 0,105***<br>(0,0266) |
| Opening   |                     |                     |                      | -0,00361<br>(0,0128)      |                    | 0,0202<br>(0,0136)   |
| GFCF      |                     |                     |                      | 0,188***<br>(0,0506)      |                    | 0,0117<br>(0,0541)   |
| Pepin     |                     |                     |                      | -0,0627862<br>(0,0468818) |                    | -0,0597<br>(0,0642)  |
| cath80    |                     |                     |                      |                           | 0,292**<br>(0,144) | 0,250***<br>(0,0444) |
| musl80    |                     |                     |                      |                           | 0,238**<br>(0,114) | 0,204***<br>(0,0341) |
| Nocpm     |                     |                     |                      |                           | 0,251<br>(0,154)   | 0,227***<br>(0,0431) |
| Fragment  |                     |                     |                      |                           | -0,839<br>(0,590)  | -0,563<br>(0,763)    |
| GDP       |                     |                     |                      |                           |                    |                      |
| Constant  | 16,44***<br>(2 628) | 37,10***<br>(4 053) | 15,31***<br>(3 638)  | 24,00***<br>(1 191)       | 5 016<br>(11,47)   | 9 968**<br>(4 830)   |
| Comments  | 836                 | 874                 | 836                  | 874                       | 874                | 836                  |
| ID number | 38                  | 38                  | 38                   | 38                        | 38                 | 38                   |

Typical errors in brackets

\*\*\* p<0.01, \*\* p<0.05, \* p<0.1

The results of the different estimations show that the political approach remains the most relevant of the other approaches. Thus, our study confirms some of the findings in the neoinstitutional literature regarding the preponderant role of political factors in the establishment or repeal of laws in SSA.

Institutional capital in sub-Saharan Africa is therefore based mainly on political positions. They are therefore the result of a number of conflicts of interest that lead power-holders to establish or maintain institutions that are in their own interests.

### Nonnested hypothesis testing

Among all the tests after the estimations, the political approach is found to be the most relevant of the approaches, as it offers the best fit. In this section, the Davidson and McKinnon (1981) nonnested hypothesis test is applied to clarify the supremacy of the policy approach in determining institutional capital in sub-Saharan Africa. Thus, we estimate different equations with variables common to all approaches with the political approach. The vector  $Z$  represents the common variables. This involves estimating the following equations:

$$cap_{inst_{it}} = \alpha + \beta P_{it} + \phi Z_{it} + \varepsilon_{it} \quad (1.7)$$

$$cap_{inst_{it}} = \partial + \lambda Z_{it} + \delta X_{it} + \varepsilon_{it} \quad (1.8)$$

Equation (1.7) represents the model estimating the policy approach, whereas equation (1.8) corresponds to one of the other approaches. Compared with the policy approach, the vector  $X$  represents the proxies of the approach in question, and the proxies of the policy approach are represented by the vector  $P$ . For the Davidson and McKinnon (1981) test, the decision criterion is the Student statistic associated with the predicted value of the institutional capital index by one of the approaches.

The principle of the test is to first estimate equation (1.7), then recover the predicted value, and finally estimate the following equation (1.9):

$$cap_{inst_{it}} = \omega + \psi X_{it} + \varphi Z_{it} + \theta cap_{inst^{prédite}_{it}} + \varepsilon_{it} \quad (1.9)$$

Thus, the political approach is always relevant if the coefficient  $\theta$  in equation (1.9) is statistically nonzero and positive and if the coefficient associated with the value of the institutional capital index predicted by one of the other three approaches must be statistically zero. According to the above assumption, the following solutions can be obtained: 1) both approaches tested are applicable; 2) neither approach is relevant; 3) the policy approach is more relevant than the adversarial approach is; and 4) the adversarial approach is more relevant than the policy approach is.

The results of the test are summarised in Table 9. These results show that the political approach is the most relevant of the approaches used in this work. This result is in line with that reported by Acemoglu *et al.* (2005). It can be argued that institutional capital in sub-Saharan African countries is the result of a number of commitment problems inherent in the use of political power. This commitment problem of political power holders can create an inseparability between efficiency and resource distribution, as they are likely to use power in their interests. The other element is that sufficiently organised individuals can influence institutional decisions by establishing their visions through collective action.

**Table 9.** Davidson & Mackinnon's (1981) J test for noninterlocking

| APPROACHES                | Political approach<br>VS<br>Economic approach  |                          | Political approach<br>VS<br>Cultural approach  |                          | Political approach<br>VS<br>Geographical approach |                                  | Political approach<br>VS<br>Historical approach |              |
|---------------------------|------------------------------------------------|--------------------------|------------------------------------------------|--------------------------|---------------------------------------------------|----------------------------------|-------------------------------------------------|--------------|
| HYPOTHESES                | H1:<br>Economic<br>approach                    | H0: Economic<br>approach | H1: Cultural<br>approach                       | H0: Cultural<br>approach | H1:<br>Geographical<br>approach                   | H0:<br>Geographica<br>l approach | H1:<br>Historical<br>approach                   | H<br>H<br>ap |
| H0: Policy<br>approach    | 2,3e+16 ***                                    |                          | 9,3e+15 ***                                    | -                        | 1,4e+16 ***                                       |                                  | 2,1e+16 ***                                     |              |
| H1: Policy<br>approach    | -                                              |                          | -                                              | -                        | -                                                 |                                  | -                                               |              |
| Conclusion of<br>the test | The political approach is<br>the most relevant |                          | The political approach is<br>the most relevant |                          | The political approach is<br>the most relevant    |                                  | The political appr most<br>relevant             |              |

Source: Author, on the basis of test results.

The results of the nonnested hypothesis test confirm the primacy of the political approach. Indeed, only the coefficients associated with the predicted value of the political approach resulting from the estimation are significant and nonzero. Thus, it remains the most relevant of the five estimated approaches.

## 5. Conclusion

The objective of this chapter was to analyse the foundations of institutional change in sub-Saharan Africa through a comparison of institutional theories. It involves modelling institutional variables grouped into approaches: the political approach, the economic approach, the cultural approach, the geographical approach and the historical approach. The results of our estimations show that the different approaches proposed in this chapter

on the basis of the neoinstitutional literature are necessary to understand institutional stocks in sub-Saharan African countries. However, the political approach differs from the others in terms of primacy.

Moreover, the other approaches are politically sensitive, especially the cultural approach, which is necessary for institutional change.

The sensitivity of institutional capital in SSA lies mainly in political factors. Inequality, income democracy strengthens institutional capital, whereas autocracy, regime characteristics, and natural resource rents deteriorate institutional capital in SSA. The economic component of institutional capital in SSA is based on investment. Notably, cultural factors are also important in the constitution of institutional capital in SSA, particularly in relation to ethno-linguistic fragmentation.

Human capital and foreign direct investment are not conducive to the development of institutional capital in SSA. Emerging markets favour an institutional environment that makes business relationships more complex (He and Zhang, 2018).

From an economic perspective, it would make sense to strengthen the democratic capital stock, reduce income inequality, and eliminate authoritarian rule. However, the contribution of all actors, which is the mainstay of all actors, is imperative for reducing corruption. Regardless of the policy or approach, corruption affects the behaviour of policy-makers and thus biases the establishment of an institutional stock adapted to the reality of the environment.

The collection of field data on informal institutions will allow us, in our future research, to determine the institutional balance between the cultural and political aspects to have the institutional capital necessary for the adoption of policies that favour economic development.

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