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From paradox to opportunity: designing a hybrid REIT Model for Romania's emerging capital market

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Abstract. *This paper addresses the Romanian real estate paradox: despite the highest EU homeownership rate (95%) and billions EUR in commercial properties, capital remains trapped in illiquid structures. We propose a hybrid R-REIT framework combining fiscal neutrality (0% corporate tax, 8% preferential dividend), progressive capital thresholds (€10M→€15M), and enhanced transparency (mandatory stress testing). Comparative analysis (US, France, Spain, Bulgaria, Poland) validates the model. Projected impact: +€650M-1B BVB capitalization (year 5), €400-600M Pension Fund allocation, competitive 6-6.5% yields versus Fidelis bonds. Implementation requires Fiscal Code amendments Q2-Q3 2026.*

Keywords: Real Estate Investment Trusts, fiscal transparency, capital market development, Romania, securitization.

JEL Classification: G23, G28, O16.

1.1. Context of the problem: the Romanian real estate paradox

Capital markets reach maturity when they can transform high-value but illiquid assets into divisible parts. We can also call this tokenization, given that blockchain technology is now much more prevalent in the mainstream. Putting this definition in the context of Romania's emerging market, it seems that it has not yet reached a sufficient level of development. Despite massive real estate developments in recent years, the connection between such assets and capital markets is almost non-existent. This research aims to review the legislative absence of real estate investment funds.

Romania is a paradoxical environment. The last three decades have been marked by major transformations, moving from the planned economy of the 1980s, which led to the revolution of 1989 and then to a new form of government in the 1990s, to the reopening of the Bucharest Stock Exchange in 1995 after 50 years of "suspension." Although the transition to capitalism has made Romania the country with the highest number of property owners in the European Union, and although the reopening of the stock exchange has opened the door for those eager to invest in various financial instruments, Romania has not yet regulated an instrument that is very popular in countries such as the United States, France, Spain, and many others.

At the beginning of 2026, the BVB still does not offer those famous REITs, i.e., real estate investment funds, for trading, although their regulation would be quite easy if we were to take a model such as the American one, which has proven to be a fairly solid example when discussing such an investment. The paradox is even more significant when we realize that real estate has been the main method of leaving a legacy to future generations, with a rate of approximately 95% of owners, and that the commercial real estate sector attracts billions of euros in foreign investment. From another perspective, all these investments represent locked-up capital.

1.2. Manifestation of the paradox: missed opportunities and inefficiencies

At present, Romania offers investors who want to expose themselves to the real estate sector only the possibility of direct ownership of the property, which comes with a high entry cost, the hassle of management, and a lack of diversification, provided that they purchase a single property. And even though the Bucharest Stock Exchange lists companies such as Star Residence Invest, which has called itself a REIT, this is not a "true" instrument, it is actually a holding companies without the fundamental characteristics of a true REIT: fiscal transparency, mandatory 90% distribution, and specialized regulatory oversight.

In short, the lack of REITs creates three major systemic inefficiencies:

- 1) **Capital immobilization**, with many mature portfolios remaining locked in private companies, unable to access public markets
- 2) **Underrepresentation on the Bucharest Stock Exchange**, with the real estate sector accounting for less than 2% of the stock market capitalization (compared to 8-12% in mature markets)
- 3) **Export of returns**, approximately 70-80% of office and logistics assets are owned by foreign funds, which repatriate rental profits instead of distributing them to Romanian pensioners.

1.3. Economic rationale: why REITS now?

Using such a model, functions as a transparent conduit from a tax perspective, passing most of its profits to shareholders. Such a structure mitigates the issue of prioritizing capital retention over shareholder returns.

The implementation of successful models such as SIIC (French) or SOCIMI (Spanish) would require a degree of transparency unprecedented in the Romanian real estate sector. The presence of quarterly reports and property valuations carried out by experts would significantly reduce the information asymmetry that currently prevails in Eastern Europe.

In the current macroeconomic environment, characterized by persistent inflation and volatile interest rates, the search for real returns has become a treasure hunt. History shows that real estate has been a good investment against inflation, but for the institutional sector, mainly Pillar II pensions, REITs would be a necessity. Such funds need long-term instruments, predictable sources of income to cover possible losses, a requirement that is not sufficiently met by bonds or the BET index in the banking and energy sectors.

1.4. Research objective and central hypothesis

The main objective of this research is to formulate a solid model for implementing REITs in Romania (R-REIT), which uses international best practices but is tailored to the specificities of the Romanian tax code.

The central hypothesis is that the adoption of an R-REIT framework, anchored in three pillars: (i) the principle of tax neutrality, would attract liquidity to the BVB, both internally and externally (ii) operational standardization (quarterly reporting) (iii) investor protection (mandatory 90% distribution, 60% leverage cap)

1.5. Structure of the paper

Section 2 analyzes the academic foundations: the doctrine of fiscal transparency (Block, 2012; Geltner et al., 2013), integration into Modern Portfolio Theory (Markowitz, 1952), and empirical evidence of institutionalization (NAREIT historical data).

Section 3 conducts a comparative analysis of mature models (American, French SIIC, Spanish SOCIMI) and regional experiences, Bulgaria's unexpected success and Poland's legislative paralysis, to extract applicable lessons: Bulgaria demonstrates viability in emerging markets, Poland illustrates the cost of inaction.

Section 4 details the proposed R-REIT architecture: entity structure, tests, tax treatment, and governance.

Section 5 quantifies the economic impact on market liquidity and the attractiveness of such instruments to institutions.

Section 6 summarizes the conclusions, acknowledges limitations, and provides an actionable legislative roadmap.

2. Literature review

2.1. Theoretical foundations: fiscal transparency

The economic foundation of REIT structures lies in the principle of fiscal transparency. Block (2012, p. 338) characterizes REITs as a "fiscally transparent conduit": "REITs generally don't pay corporate income taxes; rather, their shareholders pay taxes on the REIT's earnings as they are distributed in the form of dividends."

Commercial Real Estate, Analysis and Investments, written by Geltner et al. (2014, 3rd edition) expands on the hypothesis of a level of capital allocation, especially in this capital-intensive real estate industry, and the elimination of double taxation allows for higher dividend yields to investors and more aggressive reinvestment. The structure mentioned in the two studies also forms the framework for the European models, the French SIICs (2003) and the Spanish SOCIMIs (2009).

2.2. Reits in modern portfolio theory

Markowitz (1952) argues that portfolio efficiency is achieved by maximizing return for a given level of risk. REITs fall into a different category than bonds (low volatility, moderate yield) and stocks (high volatility, growth potential).

Two distinguishing features:

- **Benefit of diversification:** REITs' main income comes from rents or property valuations, not from sales of products or services. This source of income is not correlated with corporate profitability.
- **Protection against inflation** through lease agreements that allow for CPI indexation, providing a dual mechanism for hedging against inflation through nominal rent increases and asset appreciation. This is a critical feature in inflationary environments.

2.3. Mandatory distribution

The requirement to distribute at least 90% of taxable income is the main difference between REITs and traditional corporations, which prefer to retain earnings to finance expansion.

The obligation to direct earnings to shareholders functions more as a disciplinary measure, preventing the accumulation of capital to develop suboptimal projects, forcing external financing, and subjecting management to investor scrutiny.

The counterargument to this constraint is precisely the forcing of external financing at inopportune moments, during periods of asset undervaluation, diluting existing shareholders.\

2.4. Institutionalization of the real estate market

In order to reach the next level of development, the Romanian real estate market must take the step towards institutionalization and transparency. The real estate sector is dominated by owners, private equity firms, and high net worth individuals. Although these categories provided the initial liquidity, they tend to keep the details of their acquisitions fairly private, which propagates asymmetry when it comes to the real price of the asset and raises fairly high barriers to entry for the average investor.

Block (2012, p. 117) documents the American transformation: in 1993, 50 new REITs attracted \$13.2 billion in capital (\$9.3 billion in IPOs alone), representing a 235% increase over the previous decade (1983-1992: \$3.9 billion cumulative). Market capitalization exploded from \$5.6 billion (1990) to \$38.8 billion (1994), establishing REITs as a mainstream asset class and triggering institutional adoption.

2.5. Summary and relevance for Romania

The challenge for the Romanian system is not technical, given that it has models in more than 40 jurisdictions over the last six decades, but rather the adaptation of the legislative framework, amending Title II of the Fiscal Code and the ASF's monitoring capacity.

The following section compares the American, European, and regional models to extract best practices applicable to the Romanian context.

3. Comparative analysis: global models and regional

3.1. Mature markets paradigms

3.1.1. The American model (1960)

The Real Estate Investment Trust Act (1960) established the fundamental model, through the mandatory distribution of 90% of taxable profits, the 5/50 rule (maximum 50% held by 5 shareholders in the last half of the fiscal year) to maintain a diversified shareholder base, and qualification tests (75% of assets in the real estate sector, 75% of income derived from rents or mortgage interest). Most REITs adopt a voluntary clause limiting individual ownership to 9.9% for compliance reasons.

The model's success is also due to its integration into major indices such as the S&P 500 and the creation of specialized indices such as NAREIT, which have enforced discipline and attracted institutional liquidity. Overall capitalization has grown from \$5.6 billion in 1990 to \$1.3 trillion in 2024 (approximately 3-4% of the S&P 500).

The model is relevant for Romania because it demonstrates that integration into indices is an important factor for institutional adoption, not just related to the legislative framework.

3.1.2. French SIIC (2003)

Sociétés d'Investissement Immobilier Cotées (2003) focuses its portfolio on large-scale commercial properties (shopping centers, office towers). The technical specifications mention exemption from income tax, mandatory distribution of 95% of rental income and 85% of capital gains, but with a more relaxed asset test (60%) than in the US.

The main difference is the easy conversion mechanism for existing entities. One example is Unibail-Rodamco, which managed to transform its private holding company into a REIT without having to pay taxes on unrealized capital gains, paying only a 19% tax on free reserves at the time of conversion.

The model provides a roadmap for converting existing developers in Romania, such as AFI Europe, One United, Iulius, etc., without penalizing them and forcing the build of the R-REIT market.

3.1.3. Spanish SOCIMI (2009-2012)

SOCIMI (Sociedades Anónimas Cotizadas de Inversión en el Mercado Inmobiliario) launched in 2009, decisively reformed in 2012 after the financial crisis. The parameters under which they operate include income tax exemption, different percentages depending on the source of the profit (80% of rental income, 50% of capital gains, 100% of dividends received from subsidiaries), an 80% asset test, and a mandatory holding period of at least three years.

The 2012 reform led to the absorption of toxic assets by providing a securitization vehicle. This attracted global funds such as BlackRock, which invested €2.1 billion in Testa Residential SOCIMI, and Blackstone, which invested €1.3 billion in Hispania SOCIMI, taking advantage of zero taxes and low prices.

The relevance of the model is linked to the countercyclical mechanism that the structure offers in times of stress, attracting institutional capital when banks want to withdraw.

3.2.1. Bulgaria

The Bulgarian model was unexpectedly successful for Eastern Europe, implementing the framework simultaneously with France, six years ahead of Spain and in an emerging economy with GDP/capita of less than €3,000 vs. France's €25,000+.

Parameters: 90% distribution of taxable profit, corporate profit exemption, asset class diversification (offices, retail, agricultural land—unique in Europe).

The real innovation was the inclusion of agricultural land, which mobilized a sector characterized as extremely illiquid and provided institutional investors with a consolidation vehicle.

Despite the fact that the market remained small, reaching a capitalization of €200-300 million in 2024, dividends were consistent (6-8%), attracting domestic retail investors and thus demonstrating that the structure is also suitable for emerging economies without sophisticated infrastructure.

The lesson Romania must learn is that legislative simplicity and consistent enforcement can overcome technical sophistication, so the ASF does not need the capacity of French structures to launch successfully.

3.2.2. Polonia

Poland is the negative example in this study, which despite the size of its economy (GDP €680 billion in 2024) has failed to develop a functional framework despite more than 10 years of legislative projects (2013, 2016, 2019—all of which failed in parliament). The Warsaw Stock Exchange continues to list only cyclical developers using the build-to-sell model.

The consequence of this inability has led to the emergence of "yield export," whereby ~90% of the Class A office and logistics market is owned by international funds: Blackstone (€3+ billion assets), AEW Europe (€2 billion), RREEF (Deutsche Bank, €1.5 billion). Estimated rents of €800 million-1 billion/year are distributed to German, French, and American pensioners, not to Polish pensioners.

The lesson from this example proves that inaction has massive and irreversible opportunity costs, with each year of delay strengthening the dominance of foreign ownership of assets.

3.4. Relevance for Romania

Comparing the two extremes, we realize that Romania has similarities with both:

a) Similarities with Poland:

- Dominance of foreign ownership: An estimated 70-80% of Class A office/logistics space in Bucharest is owned by foreign capital (Globalworth €1.2 billion, NEPI Rockcastle €800 million, Immofinanz €500 million).
- Underdeveloped stock exchange: BVB capitalization €30 billion (15% of GDP) vs. GPW Warsaw €200 billion (29% of GDP)
- Developers avoid listing: AFI Europe, One United, Iulius – all prefer bank/private equity financing, avoiding the stock exchange due to double taxation (29.44% ETR vs. 16% R-REIT projected)

b) Similarities with Bulgaria:

- Emerging economy: Similar GDP/capita (~€18,560 RO vs. €16,260 BG), comparable ASF infrastructure
- Retail appetite for yield: Bank deposits €90+ billion at 2-3% real negative yield → search for alternatives
- Sufficient simplicity: Bulgaria has demonstrated that it does not require France-level sophistication to launch successfully

As already mentioned, the difficulty is not technical but political and lies in the will to act in 2026-2027.

4. Proposed structure for R-REIT

4.1.1. Legal entity and capital structure

The transformation of the Romanian real estate sector requires a robust legal entity to ensure investor protection and development. The joint-stock company (S.A.) is the exclusive form of incorporation, governed by Law 31/1990 with amendments specific to the object of activity.

Progressive model of minimum capital (innovation adapted to the Romanian context):

Initial phase (2026-2029):

- Minimum share capital: €10 million;
- Cap: Maximum of 8 R-REITs during this period;
- Rationale: Allows pioneers to test the market without prohibitive barriers, generating rapid momentum (estimated 3-4 listings in the first 2 years).

Standard phase (2029+)

- Minimum capital raised to: €15 million;
- Applicable to all R-REITs post-2029;
- Rationale: After proof-of-concept, stricter institutional standards ensure economic viability (G&A ratio below 4%) and international credibility.

The transition will be mandatory, and those who fail to reach the €15 million level by December 31, 2032, will have the following options to avoid non-compliance, resulting in the loss of tax exemption after a period of 6 months: (i) secondary capital raise, (ii) reinvestment of retained earnings, or (iii) merger with other R-REITs.

Model justification: Block (2012) warns that an undersized REIT may suffer from fixed costs (management, audit, compliance, valuations) that represent a significant proportion of assets, eroding profit margins and making dividend yields unsustainable. The minimum capital requirement of €10 million ensures that only institutional-grade portfolios will be able to access preferential tax status.

4.1.2. Listing and free float requirements

The clear distinction between R-REITs and private real estate holding companies is achieved through mandatory listing on the Bucharest Stock Exchange within a maximum of 18 months from incorporation.

Minimum free float: 30%

The economic rationale for this threshold is:

- Higher liquidity ($30\% \times €15M = €4.5M$ public float, if we set a target of $0.2\% = €9,000/\text{day}$);
- Institutional threshold: international mutual funds require a minimum of €4-5M free float to initiate coverage

Shareholder diversification rule:

5/50 rule (US standard): Maximum 50% of capital held by 5 shareholders over the last 6 fiscal months;

PLUS 10/75 rule: maximum 75% held by 10 shareholders:

This set of rules prevents extreme concentration and ensures that 25% of the shares are truly dispersed.

4.1.3. Adaptive governance structure

To balance investor protection with moderate economic viability, we propose a gradual mechanism:

UNITARY system allowed (€10-20M equity):

- Combined Board of Directors (executive + non-executive)
- Composition: Minimum 5 members, of which 3 are independent (60%)
- Economic advantage: Reduction of G&A costs by €80-120k/year (~20-25% savings vs. dualist system)
- Justification: €10-20M portfolios do not justify dualist governance overhead (marginal supervision cost > marginal control benefit)

Mandatory **DUALIST** transition (€20M+ capital):

Executive Board (executive management)

- Supervisory Board (non-executive oversight, 5-7 members)

- Trigger: Equity capital exceeds €20M for 2 consecutive quarters
- Deadline: 12 months from reaching the threshold
- Benefit: Sophisticated governance for scale-up, clear separation of management/control, enhanced protection against fraud

Mandatory insider ownership: minimum 12% (management with significant participation aligns interests with shareholders, avoids excessive risk, and incentivizes sustainable long-term growth).

Stock-based compensation: 50% din total compensation (CEO/CFO/CIO).

Structure: cash salary 50%, restricted stock units 50% cu vesting 4 ani (cliff 1 an). Global practice REITs: 40-60% equity comp (NAREIT Survey 2023).

4.2. Tax regime: neutrality and conversion incentives

The Romanian context in 2026 presents a unique challenge, with direct competition from Fidelis 10Y EUR government bonds offering a 6% annualised tax-free interest rate. This circumstance requires not only corporate profit exemption, but also preferential treatment of dividends for the viability of projects.

At the corporate level, the profit tax should be 0% (total exemption) provided that the qualification tests are met. At the shareholder level, taxes will be 8% (preferential treatment vs. 16% standard) for individuals, legal entities, and non-residents.

The reason for preferential treatment is the allocation of capital to the real productive economy, financing income-generating properties, jobs, etc., compared to government bonds that finance a government deficit. The international precedent is Belgium, which offers preferential treatment to REITs (15% vs. 30%).

In order to make a quick conversion to R-REIT in Romania, a one-time exit tax of 3% is proposed:

Application mechanism:

Developer X owns a portfolio through an LLC:

- Acquisition cost base (2015-2020): €8M
- Fair market value (ANEVAR 2026 valuation): €15M
- Unrealized gain: €7M

Upon conversion to R-REIT (transfer of assets to new entity):

- Exit tax due: $€7M \times 3\% = €210,000$ (one-time payment)
- vs. Standard capital gains tax: $€7M \times 10\% = €700,000$ (for PJ)
- Conversion savings: €490,000 (-70% compared to standard treatment)

4.3. Qualification tests: asset, income, holding period

Asset Test - 80%: Minimum 80% of the value of assets represented by income-generating real estate (offices, retail, logistics, residential rentals). The remaining 20% may include: operating cash, government securities (liquidity dividend), assets under development (maximum 24 months), and rent receivables. The 80% threshold (higher than the US standard of 75%) signals enhanced credibility for the emerging market.

Income Test - 75%/95%: (a) Minimum 75% of gross income comes from rents, mortgage interest, dividends from other R-REITs, or sales of properties held for more than four years. (b) Minimum 95% of total income comes from qualified sources.

Holding Period - 4 years: Any property sold within 4 years of acquisition generates profit that is not eligible for exemption (taxed at the standard rate of 16%). Exceptions: (i) bankruptcy of major tenant (>20% NOI), (ii) expropriation, (iii) force majeure (natural disasters).

Compliance: ASF quarterly check, breach of any test = loss of retroactive exemption for the fiscal year + penalties of 0.1%/day.

4.4. Dividend policy: FFO, AFFO, and mandatory distribution

Mandatory reporting formula:

$\text{FFO} = \text{Net Profit} + \text{Property Depreciation} - \text{Exceptional Gains Sales}$

Mandatory distribution: 90% of FFO (not GAAP net profit). Mechanism: R-REIT calculates FFO according to the formula, distributes a minimum of 90% within 12 months after the end of the fiscal year. Non-compliance: Loss of current year exemption + retroactive 16% income tax liability.

AFFO (Adjusted FFO) - Voluntary reporting encouraged:

$\text{AFFO} = \text{FFO} - \text{Recurring Maintenance CapEx}$ (AFFO provides a more conservative view of dividend sustainability.)

The legislative framework presented in section 4 provides Romania with an internationally competitive R-REIT model, adapted to emerging markets and economically viable in the Fidelis 6% context. Section 5 quantifies the projected impact on the financial ecosystem.

5. Economic and financial impact of implementing R-REIT

Implementing R-REIT goes beyond fiscal adjustment; it is a structural reform of the capital market capable of reconfiguring investment flows at the national level. This section looks at the effects on the Romanian ecosystem.

5.1. Transformation of the Bucharest Stock Exchange

A conservative estimate identifies a conversion potential of between €650 million and €1 billion in the first five years after its launch. Currently, we have four developers with portfolios exceeding €100 million. AFI Europe (€800 million → spin-off €250 million), One United (€600 million → €180 million), Iulius (€500 million → €150 million), NEPI/Globalworth selective disposals (€100-150 million).

Only the selection of four companies to transition to REITs can pave the way for a new type of instrument that could reach maturity (year 10) and represent more than 5% of the BSE capitalization in 2025 (€30 billion, 2025).

5.2. Synergy with the Second Pension Pillar

Pillar II funds managed assets worth €20 billion in 2025, but these present a mismatch. The funds invested impressive amounts in bonds, predominantly 10Y, although the investment horizon should be longer. R-REITs offer an optimal profile due to their better yield and moderate volatility, but they offer an increase in net asset value of between 2-3% annually.

Estimated progressive allocation:

Years 1-2: €100-200M (0.5-1%, initial prudence)

Years 3-5: €400-600M (2-3%, established track record)

Years 10+: €1-1.6 billion (5-8%, alignment with NL practices 12%, CA 10%)

5.3. Making real estate investments accessible for retail

R-REITs do not replace direct investments in apartments, but rather expand the range of real estate options with a distinct risk profile.

Comparison: buying an apartment directly requires €50,000-100,000 or €500,000-€5 million in the case of commercial space, which offers leverage and total control, but the risk is concentrated on a single asset and requires 5-10 hours of maintenance per month.

R-REITs are the opposite option: minimum capital of €50-500, instant diversification across multiple buildings, instant liquidity, and professional management included in the price.

In my opinion, the ideal option for investing in both variants is to combine 60% direct investment with 40% R-REITs to have a liquidity buffer.

5.4. Macroeconomic resilience

R-REIT offers three systemic benefits for the stability of the Romanian economy. Inflation protection through dual mechanism: (i) Standard commercial contracts include automatic indexation to Eurozone HICP + 1-2% margin, transferring CPI increases directly to rents, and (ii) EUR-denominated rents reported in RON capture currency depreciation (~2-3%/year historically 2000-2025), providing an implicit hedge for RON investors.

Efficient capital allocation through WACC optimization: R-REITs access capital at 6-7% (tax exemption + public markets liquidity) compared to private developers at 10-12% (taxation + expensive bank financing). The 300-400bp differential forces asset transfers to holders with lower capital costs.

Reduction in sovereign debt pressure: Diversification of Pillar II from 40% government bonds to 30% bonds + 8% R-REIT releases €1.6-2 billion demand on the government bond market. Estimated yield compression of -20-30 basis points generates savings of €30-50 million/year in interest ($€150 \text{ billion public debt} \times 0.25\% = €375 \text{ million per decade}$). Paradoxically, the "cost" of the R-REIT tax exemption (€60-90 million/year foregone revenue) is partially self-financed through sovereign interest savings.

5.5. Implementation timeline and risks

Years 1-2 (2026-2027) - Setup: Legislative adoption Q2-Q3 2026, first 2-3 R-REITs (AFI, One, Iulius conversions), capitalization €200-350M, BVB impact <2%. Minimal benefits – market too small for momentum.

Years 3-5 (2028-2030) - Growth: Build-up to 5-8 R-REITs, capitalization €650M-1 billion (+3-5% BVB), Pillar II allocation €200-400M, selective inclusion of BET. Validated proof-of-concept, visible benefits.

Years 5-10 (2030-2035) - Maturity: Consolidation of 12-18 R-REITs (small vehicle mergers), capitalization €1.5-2.5 billion (+6-10% BVB), Pillar II €800M-1.5 billion (4-7% assets), multiple BET constituents. Mature market, mainstream asset class.

Critical risks: (i) Real estate crisis 2027-2028 (office oversupply in Bucharest) → NAV collapse, (ii) Fiscal instability (elimination of post-change government exemption – mitigation: 12-year sunset), (iii) Fidelis yields rise to 7-8% → R-REIT non-competitive even with 60% leverage, (iv) Tier 1 developers do not convert → DOA market without anchor entities.

6. Conclusions and recommendations

6.1. From paradox to strategic imperative

The research demonstrated the Romanian real estate paradox, whereby although Romania has the highest rate of homeowners in the EU and attracts billions of euros in commercial real estate, these investments remain locked in illiquid structures, unable to generate returns for the capital market and domestic investors.

The analysis confirmed that the success of mature REIT models lies in a coherent framework that aligns principles such as fiscal transparency, operational standardization, and investor protection.

I consider the regional lesson a necessary sign to stop exporting returns to foreign capital, to German, French, and other nationalities' pensioners, and to strengthen the economic situation for current and future pensioners. Without urgent intervention, Romania risks experiencing the Polish model and the emergence of a possible pension crisis when the "decree" generation retires.

6.2. The hybrid R-REIT model: optimal architecture

The contribution of the research is to propose a progressive R-REIT model adapted to the Romanian reality, not a legislative transplant.

Structural pillars:

- 1) Progressive capital €10M→€15M: Pilot Phase 2026-2029 (€10M, max 8 entities) allows for rapid momentum, Standard Phase post-2029 (€15M) ensures quality consolidation.

- 2) Strict qualification tests: Asset 80% (vs. US 75% for extra emerging market credibility), income 75%/95%, holding period 4 years (vs. SOCIMI 3 years to combat aggressive build-to-flip speculation in Romania), 90% FFO distribution.
- 3) Competitive tax regime: 0% corporate profit + 8% preferential dividend (vs. 16% standard CRITICAL INNOVATION for competitiveness with Fidelis 6%), exit tax conversions 3%.
- 4) Mandatory minimum leverage: 40% Debt/Assets Pilot Phase, flexibility 40-60% post-maturity.
- 5) Enhanced transparency: Mandatory annual stress testing

6.3. Priority legislative recommendations

Immediate action Q2-Q3 2026:

Tax Code (Title II) - Art. XXX R-REIT regime:

- 0% profit exemption if: 80% asset test, 75% income test, 4-year holding period, 90% FFO distribution
- 8% preferential dividend for individuals (vs. 16% standard), ESSENTIAL competitiveness Fidelis
- Exit tax conversions 3% (vs. 10% standard capital gains), spin-off incentives

ASF rules:

- Quarterly reporting: NAV (ANEVAR/RICS), reconciled FFO, occupancy, leverage
- Annual stress testing (moderate/severe scenarios) innovative transparency
- Mandatory Big Four external audit

Law 31/1990 - Amendment:

- Exclusive S.A. form, minimum capital €10M (2026-2029) then €15M (2029+)
- Free float 30%, 5/50 and 10/75 anti-concentration rules
- BVB listing: maximum 18 months post-incorporation
- Governance: Unitary permitted €10-20M, Dualist mandatory €20M+ Insider ownership minimum 12% (management + board)

Conversion incentives:

Fast-track ASF approval: 60 days for complete files

Tax holiday on conversion gains for developers (3% vs. 10% standard)

6.4. Research limitations and future directions

Methodological limitations:

- a) Extrapolative projections: Estimates of €650 million-1 billion conversion based on comparisons between Poland and Bulgaria, without public commitment from Romanian developers. There is a risk of underestimating/overestimating actual demand.
- b) Behavioral assumptions: The model assumes the adoption of Pillar II and retail investors, but does not take into account risk aversion and how much institutional involvement may be delayed.
- c) Optimistic horizon: The 5-10 year timeline assumes zero major external shocks.

Future research needed:

- 1) Comparative tax efficiency between R-REIT vs. direct ownership vs. closed-end funds
- 2) Pilot case study: Tracking the first Romanian R-REIT (IPO pricing, post-listing performance) for lessons learned and framework adjustment

6.5. Final conclusion

Romania may be on the verge of a capital market transformation. The implementation of such a framework has become necessary in order to avoid the Polish phenomenon, to move the BVB to a new level, and to diversify Pillar II.

The proposed model synthesizes the best practices of the last six decades and over 40 jurisdictions, but requires legislative will. The central thesis pursues a historic opportunity to build a capital market that is also represented in the real estate sector.

For the viability of this model, the preferred dividend is vital in order to offer more solid returns than Fidelis 10Y. The chances of success vs. failure lie in a seemingly minor detail, but one that proves to be fundamental.

The year 2026 could become a turning point for Romania's placement in the REIT market group or it could maintain the status quo, slowing down the maturation of the BVB.

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Human development inequality within and between selected SAARC countries using Mean Log Deviation MLD

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Abstract. *This paper examines the inequality of the Human Development Index (HDI) and its components in selected SAARC countries from 2000 to 2020 using the Mean Log Deviation method. Findings show that all countries except Pakistan saw a decline in HDI inequality, with Nepal having the most significant reduction, while Pakistan's inequality increased by 17%. Health index inequality declined across all countries. In terms of education index inequality, Bangladesh, India, Nepal, and Afghanistan improved, but the Maldives and Pakistan saw increases. For income index inequality, all except Afghanistan reported declines, with the Maldives showing the most substantial decrease. The analysis revealed that between-country inequality exceeds the typical 100% threshold, largely due to India's large population. Excluding India, between-country inequality remains greater than within-country inequality across health, education, and income indices.*

Keywords: Human Development, Inequality, SAARC, Mean Log Deviation.

JEL Classification: O15, R11, Q01.

1. Introduction

Inequality is a pervasive and significant issue between and within different regions, countries, and groups, particularly in developing nations. Investigating and delving into the depths of this concept highlights both the hidden and obvious aspects of the issue, which is of extraordinary importance. Nowadays, the Human Development Index is a crucial metric for gauging the level of development and socioeconomic performance over time and is widely used across various social science disciplines in every nation (Bongaarts and Watkins, 1996; Bray et al., 2012; Chang et al., 2013). Human development is used to differentiate between economic growth and the improvement of the quality of human life. The concept of human development is shaped by the literature on inequality and poverty, as well as the belief that income alone is not the sole measure of development (Meghnad, 1991). Amartya Sen suggests that a society's standard of living shouldn't be based solely on its GNP per capita or access to specific goods. Instead, it should be measured by the abilities of its people - what they can or cannot do, become or achieve (Sen, 2005). The Human Development Index (HDI) is calculated based on three key development indicators: longevity, which is measured by life expectancy at birth; education, which is assessed using a weighted average of mean years of schooling and expected years of schooling; and living standards, which is determined by the real gross national income per capita (Jednak, Kragulj and Bulajic, 2015).

In 2023, the average Human Development Index (HDI) for SAARC countries was recorded at 0.659. Within this regional framework, Sri Lanka achieved the highest HDI value, while Afghanistan registered the lowest (Anon., 2025). Certain SAARC members, namely Sri Lanka, Bangladesh, and Nepal, have made remarkable strides in improving their Human Development status. These nations have successfully met several targets set by the Millennium Development Goals in health, including reductions in infant and under-five mortality rates, increased immunisation coverage, and enhanced food security. They have also achieved significant progress in education, evident in higher primary school enrollment and improved gender parity. Additionally, they have notably reduced poverty levels (Mahmud, Asadullah and Savoia, 2013; Asadullah, Savoia and Mahmud, 2014). In contrast, countries such as India and Pakistan have not fared as well as Sri Lanka, Bangladesh, and Nepal in terms of reducing child mortality and enhancing maternal health (Shahnaz et al., 2020). A similar trend is evident in Afghanistan (The Economist, 2016).

Despite significant cultural and geographic similarities, the SAARC region, comprising India, Sri Lanka, Bangladesh, Nepal, Afghanistan, Bhutan, the Maldives, and Pakistan, exhibits considerable development disparities among its member countries. Furthermore, within-country inequality persists in each nation. Many scholars examine income, health, and education inequality in isolation (World Health Organization, 2017; Ray and Linden, 2018; Rydland, Solheim and Eikemo, 2020; Mdingi and Ho, 2021; Blanden, Doepke and Stuhler, 2023; Kebalo and Zouri, 2024; Maheshwari and Koria, 2025). Additionally, some researchers focus on within-country disparities in these same concepts (Pavcnik, 2011; Pinkovski et al., 2024). Despite existing studies, there is still a significant gap in the analysis of both inter- and intra-country inequalities, especially within the SAARC region, in relation to the Human Development Index and its three dimensions, which are widely

acknowledged metrics. Evidence has confirmed the existence of subnational variations in human development and its three dimensions (Foster, Lopez-Calva and Szekely, 2005; Harttgen and Klasen, 2011; Permanyer et al., 2015). Examining between-country inequality in terms of Human Development allows us to identify which countries excel and which lag behind, and to determine the reasons for this disparity. Additionally, analyzing within-country inequality provides insights into the progress in health, education, and income, as well as the adequacy of budget allocations and resource distributions across different groups and regions. Given the importance of studying inequality, particularly at both the between- and within-country levels, our primary objective in this study is to assess these inequalities in relation to the Human Development Index (HDI) and its three dimensions, health, education, and income, across the SAARC region. To achieve this objective, we employed secondary data covering the period from 2000 to 2020 and utilized the Mean Log Deviation method.

2. Literature Review

(Anand and Segal, 2015) examines recent advancements in understanding global income distribution and provides initial estimates of inequality that include the top one percent within countries. Increasing top-income shares have heightened concerns about inequality worldwide, especially in light of globalization and the global financial crisis. Consequently, global income distribution, inequality, and poverty are gaining more public attention. (Bourguignon and Morrisson, 2002) examines global well-being distribution over the past two centuries, noting that income inequality worsened from the early 19th century to World War II, then stabilized or grew more slowly. Initially, most inequality was within countries, but it later shifted to between countries. Longevity discrepancies rose in the 19th century but reversed in the late 20th century, possibly offsetting the stagnation in income inequality in recent years.

(Jordá and Alonso, 2017) Introduce new estimates of educational attainment and education inequality for 142 countries from 1970 to 2010. Unlike previous methods, which treated education as a categorical variable, our "continuous approach" provides more accurate estimates by considering the distribution of years of schooling within each level of education. (Morrisson and Murtin, 2013) Investigate global education inequality trends since 1870, noting a decrease in inequality as literacy rates have improved. It examines the monetary value of schooling in relation to Mincer's (1974) human capital inequality. Within countries, human capital inequality shows an inverted U-shaped curve over time, resembling a Kuznets curve. Globally, this inequality increased from 1870 to 1970 before starting to decline. (Graetz et al., 2018) are investigating educational disparities within countries using predictive models to estimate schooling years at a local level, broken down by age and gender. Despite progress in Africa from 2000 to 2015, disparities persist between regions and genders, particularly in the Sahel. These detailed estimates can help policymakers plan more targeted interventions to achieve the Sustainable Development Goals.

(Smits and Monden, 2009) The study measured inequality in adult life expectancy within and across countries using the Gini coefficient and Theil index. It found substantial global inequality in life expectancy, with the majority (around 90%) of this inequality within countries rather than between countries. Even among similar developed countries, there can be large differences in relative life expectancy inequality. (Edwards, 2011) Investigates global trends in life expectancy inequality. They reveal that while overall inequality in life expectancy has decreased due to improvements in infant mortality rates, inequality in adult life expectancy has remained largely unchanged because a larger proportion of inequality is now due to variations between different countries. (Permanyer and Smits, 2020) examined inequality in the human development index (HDI) using the Gini index and mean log deviation. They found that in low- and middle-HDI countries, around 50% of inequality stems from differences within countries. In low-HDI countries, education disparities are the main cause of inequality, while in high-HDI countries, the standard of living is more significant. As countries develop, the influence of living standards on inequality increases, while the impact of education decreases.

(Noorbakhsh, 2002) Examines regional disparities in India and concludes that they have continued and even worsened since the 1980s, with minimal improvement in addressing them. The disparities are significant, as 55% of India's population lives below the poverty line in the four lowest-ranked states. There is a clear need for action to reduce these regional disparities systematically.

(Suryanarayana, Agrawal and Prabhu, n.d.) Analysed the Human Development Index (HDI) and Inequality-adjusted HDI for Indian states and found that inequality significantly impacts human development. When adjusted for inequalities, there is an average 32% decrease in the HDI value. Madhya Pradesh and Chhattisgarh experience the highest losses due to inequality, at 36% and 35%, respectively, while Kerala has the lowest loss at 17%. Inequality is particularly pronounced in the education sector, with an average loss of 43%, which is significantly higher than the global average of 28%.

(Gautam, 2021) Examined the variation in the Human Development Index among SAARC countries. (M, 2019) examined the relationship between economic growth and human development in SAARC nations. The findings suggest that economic growth does not significantly influence human development outcomes within the region. (Azam Khan, 2025) Examined the potential effects of financial inclusion on reducing income inequality and alleviating poverty in five SAARC nations. (Andaish and Vansiya, 2025) Examined the various degrees of sustainable development within the SAARC region utilizing the Taxonomic approach. (Shah and Atta Ullah, 2023) Examined the economic growth, human development, and income disparity in SAARC nations, including China. (Arshed et al., 2018) examined the correlation between educational enrollment levels and income inequality within the SAARC region. The findings indicated that increases in primary and secondary enrollment were associated with heightened income inequality. Conversely, higher rates of tertiary enrollment appeared to contribute to a reduction in income inequality. (Frazer, 2006) Analyzed income disparity both between and within nations at various stages of economic development. (Grimm et al., 2010) examined disparities in human development both among and within 21 developing nations and 11 developed

countries. Findings revealed that intra-country inequality surpasses inter-country inequality in both groups. (Castells-Quintana, Royuela and Thiel, 2019) Examined the relationship between human development and income disparity across 117 nations.

3. Methodology and Data Source

3.1. Data and Source

In this study, the researchers used secondary data from the Global Datalab SHDI (<https://globaldatalab.org/shdi/download/>). This extensive database contains HDI values, underlying indicators, and dimension indices for 1,625 regions in 161 countries. The SHDI values for these regions were constructed using the same data and methodology employed by the UNDP to calculate national HDI values. The required data include four key indicators: life expectancy at birth, mean years of schooling for adults aged 25 and above, expected years of schooling for children aged 6, and gross national income per capita (GNIC, measured with purchasing power parity in 2011 US\$). While national indicator values are derived from the UNDP's HDI database (<http://hdr.undp.org/en/data>), subnational values are based on data obtained from statistical offices and the Area Database of the Global Data Lab (GDL-AD), which includes subnational indicators constructed from household surveys.

3.2. Methods

Inequality within a distribution can be assessed using various indices (Jenkins and Kerm, 2009). In the present research, we utilised the Mean Log Deviation, which is a statistical measure defined as:

$$L(\mathbf{x}) = \frac{1}{n} \sum_i \log \left(\frac{\mu}{x_i} \right) \quad [\text{EQ1}]$$

Similar to the Gini index, L has a value of 0 when there is no variation and all observations coincide. However, unlike the Gini index, it is unbounded, meaning that the higher its values, the higher the corresponding level of inequality.

We used the mean log deviation, a type of generalized entropy measure, to break down overall inequality into within- and between-country components. The Gini index is not being used for this decomposition because it cannot be easily separated into within- and between-country components. The Mean Log Deviation is known for its ability to be broken down additively. Assuming our distribution is divided into multiple groups (similar to the SHDI distribution with subnational regions within countries), overall inequality can be broken down neatly.

$$L(\mathbf{x}) = L^B(\mathbf{x}) + L^W(\mathbf{x}) \quad [\text{EQ2}]$$

The symbol L^B represents the inequality between countries, while L^W represents the inequality within countries. To calculate the between-country component, we assume that each subnational attainment is equivalent to the average attainment of the country to which

the region belongs. The within-country component is a population-weighted average of the subnational inequality within countries. In formal terms,

$$L^B(\mathbf{x}) = \sum_{j=1}^J p_j \log\left(\frac{\mu}{\mu_j}\right) \quad [\text{EQ3}]$$

$$L^W(\mathbf{x}) = \sum_{j=1}^J p_j L_j \quad [\text{EQ4}]$$

where J is the number of countries and p_j , μ_j and L_j are the population share, the mean, and the Mean Log Deviation observed in the country j , respectively.

4. Result and Discussion

By utilising the mean log deviation method, we aim to identify the patterns of changes in human development index inequality within South Asian countries in recent decades, particularly during the 2000 and early 2020.

Table 1. South Asian Human Development Index Inequality by Country, 2000-2020

Country Name		2000	2005	2010	2015	2020	Change (2000-2020)	Mean
Afghanistan	MLD	0.00301	0.00296	0.00293	0.00147	0.00149	-51%	0.00237
	r	70%	78%	81%	79%	78%	8%	77%
	Π	1%	2%	2%	2%	2%	1%	1.8%
Bangladesh	MLD	0.00157	0.00121	0.00097	0.00075	0.00049	-69%	0.00100
	r	102%	101%	99%	100%	106%	4%	102%
	Π	9.31%	9.26%	9.05%	9.00%	9.00%	-0.3%	9.1%
India	MLD	0.00395	0.00321	0.00206	0.00146	0.00120	-70%	0.00237
	r	117%	116%	114%	112%	110%	-7%	114%
	Π	76%	76%	76%	75%	75%	-1%	78%
Maldives	MLD	0.00039	0.00038	0.00044	0.00034	0.00030	-23%	0.00037
	r	130%	124%	122%	121%	117%	-13%	123%
	Π	0.02%	0.02%	0.02%	0.02%	0.03%	0.01%	0.02%
Nepal	MLD	0.00403	0.00200	0.00035	0.00019	0.00079	-80%	0.00147
	r	106%	100%	98%	96%	98%	-8%	100%
	Π	1.77%	1.73%	1.66%	1.57%	1.58%	-0.19%	1.7%
Pakistan	MLD	0.00257	0.00266	0.00359	0.00363	0.00301	17%	0.00309
	r	96%	98%	95%	91%	89%	-7%	94%
	Π	11%	11%	12%	12%	12%	1%	11.7%

Note: r is the relative HDI and Π is the country's population share for the given year.

Source: Authors calculation

The data presented in the table one provides a comprehensive overview of the changes in the Human Development Index (HDI) inequality for a selection of South Asian countries from 2000 to 2020. Among the six South Asian countries included in the analysis, Nepal exhibited the most substantial decline in its HDI inequality, with a notable decrease of 80%, indicating significant progress in addressing disparities in human development. Following closely behind, India experienced a significant decrease of 70% in human development inequality, reflecting positive advancements towards a more equitable distribution of

development opportunities. Additionally, Bangladesh, Afghanistan, and Maldives also demonstrated declines in their HDI inequality, with reductions of 69%, 51%, and 23%, respectively, signifying commendable efforts in addressing inequality. However, it's important to note that Pakistan is the sole country where the human development index inequality increased, showing a notable rise of 17%. This calls for focused attention and constructive measures to address the growing inequality within the country.

With respect to relative mean HDI, while four of the six selected countries, the Maldives, Nepal, India, and Pakistan, experienced a drop, Afghanistan and Bangladesh increased their relative HDI by 8% and 4%, respectively, indicating positive progress. This data provides valuable insights that can further guide policymakers and interventions to promote equitable human development across these nations.

Table 2. *Decomposition of MLD between country and within the country components of selected South Asia countries*

Country Name	Within-country contribution to MLD (π_jMLD_j)				
	2000	2005	2010	2015	2020
Afghanistan	0.0000425	0.0000477	0.0000504	0.0000281	0.0000313
Bangladesh	0.0001464	0.0001116	0.0000878	0.0000674	0.0000445
India	0.0030143	0.0024348	0.0015592	0.0011037	0.0008972
Maldives	0.0000001	0.0000001	0.0000001	0.0000001	0.0000001
Nepal	0.0000714	0.0000346	0.0000058	0.0000003	0.0000125
Pakistan	0.0002865	0.0003045	0.0004253	0.0004367	0.0003673
Sum of within-country inequality	0.0035612	0.0029332	0.0021286	0.001639	0.0013529
Between-country contribution to MLD ($\pi/\log 1/r_j$)					
Afghanistan	0.00212	0.00179	0.00158	0.00194	0.00229
Bangladesh	-0.00093	-0.00019	0.00027	-0.00018	-0.00243
India	-0.05346	-0.04935	-0.04163	-0.03847	-0.03228
Maldives	-0.00002	-0.00002	-0.00002	-0.00002	-0.00002
Nepal	-0.00053	0.00002	0.00012	0.00025	0.00017
Pakistan	0.00223	0.00115	0.00285	0.00481	0.00648
Sum of between country inequality	-0.05060	-0.04660	-0.03683	-0.03167	-0.02580
All countries combined MLD					
Between as a per cent of the total	107.57%	106.72%	106.13%	105.46%	105.54%
Within as a per cent of the total	-7.57%	-6.72%	-6.13%	-5.46%	-5.54%
Total	-0.04704	0.04367	-0.0347	-0.03003	-0.02444

Source: Authors calculation

The table two provides information about each country's contribution to the human development index inequality, measured by the MLD index. The table reveals an interesting result, showing that between-country inequality exceeds 100 per cent. This is primarily due to India's significant contribution to between-country inequality, surpassing the total value of inequality. India's large population share in the selected area, accounting for over 75% of the population, is the main factor behind this result (see table 1). Based on these findings, we proceeded to calculate the decomposition of the MLD index without India.

In terms of within-country inequality among the six selected countries, India made the largest contribution, but its contribution decreased from 2000 to 2020. Following India, Pakistan had the second-highest contribution, which increased during the same time period. Bangladesh ranked third in terms of within-country inequality, with its inequality

decreasing, particularly from 2005 to 2020. The substantial population share of these countries played a significant role in these effects (see table 1).

Table 3. *Decomposition of MLD between country and within the country components of selected South Asia, except for India*

Country Name	Within-country contribution to MLD (π/MLD_j)				
	2000	2005	2010	2015	2020
Afghanistan	0.0001795	0.0001986	0.0002081	0.0001143	0.0001251
Bangladesh	0.0006195	0.0004639	0.0003610	0.0002747	0.0001783
Maldives	0.0000003	0.0000004	0.0000004	0.0000003	0.0000003
Nepal	0.0003021	0.0001439	0.0000237	0.0000123	0.0000500
Pakistan	0.0012116	0.0012647	0.0017500	0.0017787	0.0014729
Sum of within country inequality	0.0023130	0.0020715	0.0023432	0.0021804	0.0018266
	Between-country contribution to MLD ($\pi/\log 1/r_j$)				
	2000	2005	2010	2015	2020
Afghanistan	0.00894	0.00717	0.00632	0.00749	0.00882
Bangladesh	-0.00394	-0.00231	-0.00037	-0.00257	-0.01155
Maldives	-0.00011	-0.00010	-0.00009	-0.00009	-0.00007
Nepal	-0.00225	-0.00022	0.00020	0.00070	0.00038
Pakistan	0.00471	0.00333	0.00976	0.01715	0.02352
Sum of between country inequality	0.00735	0.00788	0.01582	0.02269	0.02109
All countries combined MLD					
Between as a per cent of the total	76.1%	79.2%	87.1%	91.2%	92%
Within as a per cent of the total	23.9%	20.8%	12.9%	8.8%	8.0%
Total	0.00967	0.00995	0.01817	0.02487	0.02292

Source: Authors calculation

The table three illustrates how each country contributes to human development inequality as measured by the MLD index, with the exception of India. Between-country inequality was found to be greater than within-country inequality in terms of total inequality, ranging from 76.1% in 2000 to 92% in 2020. In the year 2000, between-country inequality accounted for 76.1% of total inequality, with the remaining 23.9% attributed to within-country inequality. In 2005, between-country inequality contributed 79.2%, while within-country inequality contributed 20.8%. By 2010, between-country inequality accounted for 87.1%, with within-country inequality at 12.9%. In 2015, between-country inequality increased to 91.2%, while within-country inequality decreased to 8.8%. Finally, in 2020, between-country inequality was at 92%, and within-country inequality was at 8%. The percentage of between-country inequality increased from 2000 to 2020, while within-country inequality decreased over the same period. Regarding within-country inequality among the five South Asian countries, Pakistan made the biggest contribution from 2000 to 2020, and its contribution increased during that period. On the other hand, Maldives has the lowest contribution. After Pakistan, Bangladesh is the second country that has made a large contribution, varying between 0.0006195 and 0.0001783 during the time period.

Table 4. *South Asian Health Index Inequality Using Mean Log Deviation by Country, 2000-2020*

Country Name		2000	2005	2010	2015	2020	Change (2000-2020)	Mean
Afghanistan	MLD	0.00102	0.000957	0.000922	0.000203	0.000206	-80%	0.000662
	r	82%	85%	86%	87%	85%	3.4%	85%
	$\square$	1%	2%	2%	2%	2%	0.7%	1.8%
Bangladesh	MLD	0.00063	0.0005164	0.00033883	0.00038748	0.00012949	-79%	0.000400
	r	107%	105%	103%	102%	104%	-3%	104%
	$\square$	9.31%	9.26%	9.05%	9.00%	9.00%	0%	9.1%

Country Name		2000	2005	2010	2015	2020	Change (2000-2020)	Mean
India	MLD	0.00193	0.001376	0.00083	0.000516	0.000489	-75%	0.001027
	r	109%	108%	105%	105%	104%	-5%	106%
	$\square$	76%	76%	76%	75%	75%	-1%	76%
Maldives	MLD	0.00011	0.000103	0.000074	0.000009	0.00002	-82%	0.000063
	r	117%	120%	121%	121%	120%	3%	120%
	$\square$	0.02%	0.02%	0.02%	0.02%	0.03%	0.01%	0.02%
Nepal	MLD	0.00337	0.001833	0.000743	0.000297	0.0001	-97%	0.001268
	r	106%	104%	101%	97%	98%	-8%	101%
	$\square$	1.77%	1.73%	1.66%	1.57%	1.58%	-0.2%	1.7%
Pakistan	MLD	0.00125	0.001199	0.001033	0.000922	0.000672	-46%	0.001015
	r	102%	97%	98%	96%	95%	-7%	98%
	$\square$	11%	11%	12%	12%	12%	1%	11.7%

Note: r is the relative HI and $\square$ is the country's population share for the given year.

Source: Authors calculation

Table four, presents a detailed analysis of the changes in Health Index (HI) inequality for a selection of South Asian countries from 2000 to 2020. The data indicates that all six countries included in the analysis experienced a decrease in their health index inequality. Notably, Nepal exhibited the most substantial decline in its HI inequality, with a remarkable decrease of 97%. This signifies significant progress in addressing disparities in health development within the country. Furthermore, Maldives also experienced a significant decrease of 82% in health development inequality, reflecting positive advancements towards a more equitable distribution of development opportunities. Additionally, Afghanistan, Bangladesh, India, and Pakistan also demonstrated declines in their HI inequality, with reductions of 80%, 79%, 75%, and 46% respectively, signifying commendable efforts in addressing inequality.

In terms of the relative mean health index (HI), four of the six selected countries, Nepal, Pakistan, India, and Bangladesh, experienced drops of 8%, 7%, 5%, and 3%, respectively. On the other hand, Afghanistan and Maldives increased their relative HI by 3.4% and 3%, respectively, indicating positive progress. This comprehensive data provides valuable insights that can further guide policy decisions and interventions to promote equitable health development across these nations.

Table 5. Decomposition of MLD of Health Index Between Country and Within the Country Components of Selected South Asia Countries

Within-country contribution to MLD ($\pi jMLDj$)					
Country Name	2000	2005	2010	2015	2020
Afghanistan	0.0000425	0.0000477	0.0000504	0.0000281	0.0000313
Bangladesh	0.0001464	0.0001116	0.0000878	0.0000674	0.0000445
India	0.0030143	0.0024348	0.0015592	0.0011037	0.0008972
Maldives	0.0000001	0.0000001	0.0000001	0.0000001	0.0000001
Nepal	0.0000714	0.0000346	0.0000058	0.000003	0.0000125
Pakistan	0.0002865	0.0003045	0.0004253	0.0004367	0.0003673
Sum of within country inequality	0.00174155	0.00127702	0.00080961	0.000543623	0.00046683
Between-country contribution to MLD ($\pi j \log 1/rj$)					
Afghanistan	0.00212	0.00179	0.00158	0.00194	0.00229
Bangladesh	-0.00093	-0.00019	0.00027	-0.00018	-0.00243
India	-0.05346	-0.04935	-0.04163	-0.03847	-0.03228
Maldives	-0.00002	-0.00002	-0.00002	-0.00002	-0.00002
Nepal	-0.00053	0.00002	0.00012	0.00025	0.00017

Within-country contribution to MLD (π_jMLD_j)					
Pakistan	0.00223	0.00115	0.00285	0.00481	0.00648
Sum of between country inequality	-0.03373	-0.02402	-0.01587	-0.01419	-0.01047
All countries combined MLD					
Between as a per cent of the total	107.57%	106.72%	106.13%	105.46%	105.54%
Within as a per cent of the total	-7.57%	-6.72%	-6.13%	-5.46%	-5.54%
Total	-0.04704	0.04367	-0.0347	-0.03003	-0.02444

Source: Authors calculation

Table five, provides information about each country's contribution to the health index inequality, measured by the MLD index. The table reveals an interesting result, showing that between-country inequality exceeds 100 per cent. This is primarily due to India's significant contribution to between-country inequality, surpassing the total value of inequality. India's large population share in the selected area, accounting for over 75% of the population, is the main factor behind this result (see table 4). After carefully analysing these findings, we proceeded to calculate the decomposition of the MLD index without India. This analysis aims to provide a more nuanced understanding of the factors driving the inequality dynamics among the selected countries. In terms of within-country inequality among the six selected countries, India made the largest contribution, but its contribution decreased from 2000 to 2020. Following India, Pakistan had the second-highest contribution, which increased during the same time period. Bangladesh ranked third in terms of within-country inequality, with its inequality decreasing, particularly from 2005 to 2020. The substantial population share of these countries played a significant role in these effects (see table 4).

Table 6. *Decomposition of MLD of Health Index Between Country and Within the Country Components of Selected South Asia countries Except India*

Within-country contribution to MLD (π_jMLD_j)					
Country Name	2000	2005	2010	2015	2020
Afghanistan	0.00006097	0.00006412	0.00006546	0.000015834	0.00001730
Bangladesh	0.00024804	0.00019881	0.00012604	0.000142205	0.00004675
Maldives	0.00000010	0.0000001	0.00000007	0.000000009	0.00000002
Nepal	0.00025204	0.00013198	0.00005052	0.000019008	0.0000063
Pakistan	0.00058696	0.00057072	0.0005041	0.00045178	0.00032928
Sum of within country inequality	0.00114811	0.00096574	0.00074621	0.000628836	0.00039965
Between-country contribution to MLD ($\pi/\log 1/r_j$)					
Afghanistan	0.00536	0.00496	0.00469	0.00476	0.0058
Bangladesh	-0.01182	-0.00732	-0.00409	-0.00367	-0.00614
Maldives	-0.00006	-0.00008	-0.00008	-0.00008	-0.00008
Nepal	-0.00150	-0.00115	-0.00014	0.00077	0.0005
Pakistan	-0.00471	0.00571	0.00390	0.00735	0.01127
Sum of between country inequality	-0.01272	0.00213	0.00428	0.00912	0.01135
All countries combined MLD					
Between as a per cent of total	109.93%	68.76%	85.16%	93.55%	96.6%
Within as a per cent of total	-9.93%	31.24%	14.84%	6.45%	3.4%
Total	-0.01157	0.00309	0.00503	0.00975	0.01175

Source: Authors calculation

Table six illustrates how each country contributes to health development inequality as measured by the MLD index, with the exception of India. Between-country inequality was found to be greater than within-country inequality in terms of total inequality, ranging from 109.93% in 2000 to 96.6% in 2020. In the year 2000, between-country inequality accounted

for 109.93%, which is more than the standard of 100%, and it is due to the largest contribution of Bangladesh in between-country inequality; its value is more than the total inequality, so the within-country inequality is -9.93%. In 2005, between-country inequality rapidly decreased, contributing 68.76%, while within-country inequality contributed 31.24%. By 2010, between-country inequality increased to 85.16%, while within-country inequality decreased to 14.84%. In 2015, between-country inequality accounted for 93.55%, while within-country inequality accounted for 6.45%. Finally, in 2020, between-country inequality was at 96.6%, and within-country inequality was at 3.4%. The percentage of between-country inequality increased from 2005 to 2020, while within-country inequality decreased over the same period. Regarding within-country inequality among the five South Asian countries, Pakistan made the biggest contribution from 2000 to 2020, and its contribution increased during that period. On the other hand, Maldives has the lowest contribution. After Pakistan, Bangladesh is the second country that has made a large contribution, varying between 0.00024804 and 0.00004675 during the time period. By 2000, however, the within-country inequality of Nepal was Higher than that of Bangladesh, but its inequality significantly decreased.

Table 7. South Asian Education Index Inequality Using Mean Log Deviation by Country, 2000-2020

Country Name		2000	2005	2010	2015	2020	Change (2000-2020)	Mean
Afghanistan	MLD	0.023467	0.0236	0.02359	0.009054	0.009207	-61%	0.017784
	r	63%	75%	79%	75%	74%	10.4%	73%
	□	1%	2%	2%	2%	2%	0.7%	1.8%
Bangladesh	MLD	0.004847	0.003266	0.002088	0.001777	0.001327	-73%	0.002661
	r	109%	107%	103%	105%	116%	6.9%	108%
	□	9.31%	9.26%	9.05%	9.00%	9.00%	-0.3%	9.1%
India	MLD	0.00832	0.007091	0.003946	0.00254	0.002575	-69%	0.004894
	r	136%	133%	125%	122%	116%	-20.1%	127%
	□	76%	76%	76%	75%	75%	-1.3%	76%
Maldives	MLD	0.001531	0.001458	0.002043	0.002119	0.002044	34%	0.001839
	r	127%	115%	112%	111%	109%	-18.2%	115%
	□	0.02%	0.02%	0.02%	0.02%	0.03%	0.0%	0.02%
Nepal	MLD	0.00829	0.001723	0.0002	0.000287	0.002687	-68%	0.002637
	r	118%	105%	107%	103%	102%	-15.7%	107%
	□	1.77%	1.73%	1.66%	1.57%	1.58%	-0.2%	1.7%
Pakistan	MLD	0.014571	0.015304	0.018105	0.019017	0.017302	19%	0.016860
	r	85%	94%	89%	83%	77%	-7.7%	86%
	□	11%	11%	12%	12%	12%	1.1%	11.7%

Note: r is the relative EI and □ is the country's population share for the given year.

Source: Authors calculation

The data presented in the table seven provides a comprehensive overview of the changes in the Education Index (EI) inequality for a selection of South Asian countries from 2000 to 2020. Among the six South Asian countries included in the analysis, four of them had decreased their education development inequality, such as Bangladesh, India, Nepal, and Afghanistan; on the other hand, Maldives and Pakistan had increased their education inequality.

Bangladesh exhibited the most substantial decline in its education development inequality, with a notable decrease of 73%, indicating significant progress in addressing disparities in educational development. Following closely behind, India experienced a significant

decrease of 69% in educational development inequality, reflecting positive advancements towards a more equitable distribution of development opportunities. After India, Nepal, and Afghanistan also demonstrated declines in their education development inequality, with reductions of 68% and 61%, respectively, signifying commendable efforts in addressing inequality. In contrast, it is crucial to note that Maldives and Pakistan are the countries where the education development index inequality increased, showing a notable rise of 34% and 19%, respectively. This calls for focused attention and constructive measures to address the growing inequality within these countries. With respect to relative mean EI, while four of the six selected countries, India, Maldives, Nepal, and Pakistan, experienced a drop, the highest value of drop related to India is 20.1%, followed by Maldives, Nepal, and Pakistan with the value of 18.2%, 15.7%, and 7.7% respectively. Afghanistan and Bangladesh increased their relative EI by 10.4% and 6.9%, respectively, indicating positive progress. This data provides valuable insights that can further guide policy decisions and interventions to promote equitable human development across these nations.

Table 8. *Decomposition of MLD of Education Index Between Countries and Within the Country Components of Selected South Asian Countries*

Country Name	Within-country contribution to MLD ($\pi_j \text{MLD}_j$)				
	2000	2005	2010	2015	2020
Afghanistan	0.0003309	0.0003800	0.0004058	0.0001738	0.0001934
Bangladesh	0.0004513	0.0003024	0.0001890	0.0001599	0.0001194
India	0.0063540	0.0053835	0.0029867	0.0019162	0.0019333
Maldives	0.0000003	0.0000003	0.0000004	0.0000004	0.0000006
Nepal	0.0001467	0.0000298	0.0000033	0.0000045	0.0000425
Pakistan	0.0016218	0.0017538	0.0021473	0.0022877	0.0021143
Sum of within country inequality	0.00890492	0.00784982	0.00573242	0.004542618	0.00440346
Between-country contribution to MLD ($\pi/\log 1/r_j$)					
Afghanistan	0.00282	0.00203	0.00177	0.00244	0.00279
Bangladesh	-0.00372	-0.00287	-0.00127	-0.00198	-0.00576
India	-0.09928	-0.09490	-0.07418	-0.06563	-0.04880
Maldives	-0.00002	-0.00001	-0.00001	-0.00001	-0.00001
Nepal	-0.00124	-0.00036	-0.00048	-0.00022	-0.00016
Pakistan	0.00779	0.00309	0.00581	0.00950	0.01393
Sum of between country inequality	-0.09365	-0.09302	-0.06835	-0.05590	-0.03801
All countries combined MLD					
Between as a per cent of total	110.51	109.22	109.15	108.85	113.1
Within as a per cent of total	-10.51	-9.22	-9.15	-8.85	-13.1
Total	-0.08475	-0.08517	-0.06262	-0.05136	-0.0336

Source: Authors calculation

Table eight provides information about each country's contribution to the inequality of education development measured by the MLD index. The table reveals an interesting result, showing that between-country inequality exceeds 100 per cent. This is primarily due to India's significant contribution to between-country inequality, surpassing the total value of inequality. India's large population share in the selected area, accounting for over 75% of the population, is the main factor behind this result (see table 7). After carefully analyzing these findings, we proceeded to calculate the decomposition of the MLD index without India. This analysis aims to provide a more nuanced understanding of the factors driving the inequality dynamics among the selected countries. In terms of within-country inequality among the six selected countries, India made the largest contribution, but its contribution

decreased from 2000 to 2020. Following India, Pakistan had the second-highest contribution, which increased during the same time period. Bangladesh ranked third in terms of within-country inequality, with its inequality decreasing, particularly from 2005 to 2020. The substantial population share of these countries played a significant role in these effects (see table 7).

Table 9. *Decomposition of MLD of Education Index Between Country and Within the Country Components of Selected South Asia Countries Except India*

Country Name	Within-country contribution to MLD (π_jMLD_j)				
	2000	2005	2010	2015	2020
Afghanistan	0.0013986	0.0015812	0.0016749	0.00070621	0.0007734
Bangladesh	0.0019092	0.0012574	0.0007767	0.00065216	0.0004791
Maldives	0.0000014	0.0000015	0.0000020	0.00000212	0.0000020
Nepal	0.0006209	0.0001241	0.0000136	0.00001837	0.0001693
Pakistan	0.0068586	0.0072847	0.0088352	0.00931833	0.0084780
Sum of within country inequality	0.01078874	0.01024883	0.01130251	0.010697188	0.00990174
Country Name	Between-country contribution to MLD ($\pi_j/\log 1/r_j$)				
	2000	2005	2010	2015	2020
Afghanistan	0.01132	0.00764	0.0066	0.00905	0.01050
Bangladesh	-0.01970	-0.01656	-0.0093	-0.01211	-0.02599
Maldives	-0.00011	-0.00007	-0.00006	-0.00006	-0.00004
Nepal	-0.00599	-0.00238	-0.00265	-0.00166	-0.00113
Pakistan	0.02824	0.00714	0.01854	0.03332	0.05194
Sum of between country inequality	0.01377	-0.00423	0.01314	0.02854	0.03527
All countries combined MLD					
Between as a per cent of total	56.1	-70.14	53.75	72.73	78.08
Within as a per cent of total	43.9	170.14	46.25	27.27	21.92
Total	0.02456	0.00602	0.02444	0.03923	0.04517

Source: Authors calculation

Table nine illustrates how each country contributes to education development inequality as measured by the MLD index, with the exception of India. Between-country inequality was found to be greater than within-country inequality in terms of total inequality, ranging from 56.1% in 2000 to 78.08% in 2020. In 2000, between-country inequality accounted for 56.1%, and within-country inequality accounted for 43.9%. In the year 2005, within-country inequality accounted for 170.14%, which is more than the standard of 100%, and it is due to the largest contribution of Bangladesh in between-country inequality; its value is more than the total inequality, so the between-country inequality is -70.14%. By 2010, between-country inequality decreased to 53.75%, while within-country inequality accounted for 46.25%. In 2015, between-country inequality increased to 72.73%, while within-country inequality decreased to 27.27%. Finally, in 2020, between-country inequality was at 78.08%, and within-country inequality was at 21.92%. The percentage of between-country inequality increased from 2005 to 2020, while within-country inequality decreased over the same period. Regarding within-country inequality among the five South Asian countries, Pakistan made the biggest contribution from 2000 to 2020, and its contribution increased during that period. On the other hand, Maldives has the lowest contribution. After Pakistan, in 2000, Bangladesh was the second country that made a large contribution, and Afghanistan was the third one, but from the year 2005 to 2020, the contribution of Afghanistan became more than Bangladesh, and it positioned second after Pakistan. The within-country inequality contributions of Afghanistan and Bangladesh have diminished overall from 2000 to 2020.

Table 10. *South Asian Income Index Inequality Using Mean Log Deviation by Country, 2000-2020*

Country Name		2000	2005	2010	2015	2020	Change (2000-2020)	Mean
Afghanistan	MLD	0.000692	0.000564	0.000495	0.000775	0.00078	13%	0.000661
	r	68%	76%	80%	77%	75%	7.1%	75%
	□	1%	2%	2%	2%	2%	0.7%	1.8%
Bangladesh	MLD	0.0016224	0.00155047	0.0017344	0.0011348	0.0010115	-38%	0.001411
	r	90%	90%	92%	94%	100%	10.4%	93%
	□	9.31%	9.26%	9.05%	9.00%	9.00%	-0.3%	9.1%
India	MLD	0.00445	0.003488	0.002989	0.00243	0.001682	-62%	0.003008
	r	107%	109%	111%	110%	111%	3.5%	109%
	□	76%	76%	76%	75%	75%	-1.3%	76%
Maldives	MLD	0.000268	0.000271	0.000232	0.000114	0.000084	-69%	0.000194
	r	145%	138%	133%	130%	122%	-23.8%	134%
	□	0.02%	0.02%	0.02%	0.02%	0.03%	0.0%	0.02%
Nepal	MLD	0.002156	0.001705	0.000892	0.000496	0.000998	-54%	0.001249
	r	95%	92%	88%	89%	92%	-3.0%	91%
	□	1.77%	1.73%	1.66%	1.57%	1.58%	-0.2%	1.7%
Pakistan	MLD	0.002475	0.002403	0.002379	0.001912	0.001795	-27%	0.002193
	r	105%	104%	98%	96%	97%	-7.3%	100%
	□	11%	11%	12%	12%	12%	1.1%	11.7%

Note: r is the relative income index (II) and □ is the country's population share for the given year.

Source: Authors calculation

The data presented in the table ten provides a comprehensive overview of the changes in the Income Index (II) inequality for a selection of South Asian countries from 2000 to 2020. Among the six South Asian countries included in the analysis, except for Afghanistan, five had decreased their income development inequality: Bangladesh, India, Nepal, Maldives, and Pakistan. The Maldives exhibited the most substantial decline in its Income index inequality, with a notable decrease of 69%, indicating significant progress in addressing disparities in the income index. Following closely behind, India experienced a significant decrease of 62% in income inequality, reflecting positive advancements towards a more equitable distribution of development opportunities. Nepal, Bangladesh and Pakistan also demonstrated declines in their income inequality, with reductions of 54%, 38%, and 27%, respectively, signifying commendable efforts in addressing inequality.

In contrast, it is crucial to note that Afghanistan is the only country where the income index inequality increased, showing a rise of 13%. This calls for focused attention and constructive measures to address the growing inequality within this country, which might be due to the existence of high-level corruption. With respect to the relative mean income index (II), while three of the six selected countries, Maldives, Nepal, and Pakistan, experienced a drop, the highest value of drop related to Maldives is 23.8%, followed by Pakistan and Nepal with the value of 7.3%, 3.0%, respectively. Afghanistan, Bangladesh, and India increased their relative income index (II) by 13%, 10.4% and 3.5%, respectively, indicating positive progress. This data provides valuable insights that can further guide policy decisions and interventions to promote equitable income development across these nations.

Table 11. *Decomposition of MLD of Income Index Between Country and Within the Country Components of Selected South Asian Countries*

Country Name	Within-country contribution to MLD (π_jMLD_j)				
	2000	2005	2010	2015	2020
Afghanistan	0.00000976	0.00000908	0.00000851	0.000014880	0.00001638
Bangladesh	0.00015105	0.00014357	0.00015696	0.000102132	0.00009104
India	0.00339847	0.00264809	0.00226237	0.001833192	0.00126285
Maldives	0.00000005	0.00000005	0.00000005	0.000000023	0.00000003
Nepal	0.00003816	0.00002950	0.00001481	0.000007787	0.00001577
Pakistan	0.00027547	0.00027538	0.00028215	0.000230014	0.00021935
Sum of within country inequality	0.00387295	0.00310568	0.00272485	0.002188028	0.00160540
Country Name	Between-country contribution to MLD ($\pi_j \log 1/r_j$)				
	2000	2005	2010	2015	2020
Afghanistan	0.00226	0.00193	0.00165	0.00213	0.00257
Bangladesh	0.00466	0.00417	0.00335	0.00243	0.00003
India	-0.02291	-0.02885	-0.03330	-0.03244	-0.03304
Maldives	-0.00003	-0.00003	-0.00002	-0.00002	-0.00003
Nepal	0.00035	0.00062	0.00090	0.00079	0.00056
Pakistan	-0.00223	-0.00172	0.00083	0.00205	0.00142
Sum of between country inequality	-0.01790	-0.02387	-0.02660	-0.02507	-0.02849
All countries combined MLD					
Between as a per cent of total	127.6	114.95	111.41	109.56	105.97
Within as a per cent of total	-27.6	-14.95	-11.41	-9.56	-5.97
Total	-0.01403	-0.02077	-0.02388	-0.02288	-0.02688

Source: Authors calculation

Table eleven provides information about each country's contribution to the inequality of income index measured by the MLD index. The table indicates an interesting result, showing that between-country inequality exceeds 100 per cent. This is primarily due to India's significant contribution to between-country inequality, surpassing the total value of inequality. India's large population share in the selected area, accounting for over 75% of the population, is the main factor behind this result (see table 10).

After carefully analyzing these findings, we proceeded to calculate the decomposition of the MLD index without India. This analysis aims to provide a more nuanced understanding of the factors driving the inequality dynamics among the selected countries. In terms of within-country inequality among the six selected countries, India made the largest contribution, but its contribution decreased from 2000 to 2020. Following India, Pakistan had the second-highest contribution, which increased from the year 2000 to 2010, and after that, it gradually decreased in 2020. The value of its MLD index was 0.00021935, which shows a decrease from the year 2000. Bangladesh ranked third in terms of within-country inequality, with its inequality decreasing gradually from 2000 to 2020. The substantial population share of these countries played a significant role in these effects (see table 10).

Table 12. *Decomposition of MLD of Income Index Between Country and Within the Country Components of Selected South Asian Countries Except India*

Country Name	Within-country contribution to MLD (π_jMLD_j)				
	2000	2005	2010	2015	2020
Afghanistan	0.00004124	0.00003779	0.00003515	0.00006045	0.00006552
Bangladesh	0.00063906	0.00059693	0.00064520	0.00041647	0.00036515
Maldives	0.00000024	0.00000027	0.00000023	0.00000011	0.00000008
Nepal	0.00016148	0.00012276	0.00006066	0.00003174	0.00006287
Pakistan	0.00116498	0.00114383	0.00116095	0.00093688	0.00087955
Sum of within country inequality	0.00200701	0.00190158	0.00190218	0.00144566	0.00137318

Country Name	Within-country contribution to MLD (π_jMLD_j)				
	2000	2005	2010	2015	2020
	Between-country contribution to MLD ($\pi/\log 1/r_j$)				
Afghanistan	0.01013	0.00804	0.00675	0.00835	0.00982
Bangladesh	0.01970	0.01771	0.01302	0.00881	-0.00181
Maldives	-0.00014	-0.00014	-0.00013	-0.00012	-0.00009
Nepal	0.00150	0.00259	0.00360	0.00301	0.00191
Pakistan	-0.00941	-0.00714	0.00293	0.00637	0.00309
Sum of between country inequality	0.02177	0.02106	0.02617	0.02641	0.01292
	All countries combined MLD				
Between as a per cent of the total	91.56	91.72	93.22	94.81	90.39
Within as a per cent of the total	8.44	8.28	6.78	5.19	9.61
Total	0.02377	0.02296	0.02807	0.02786	0.01429

Source: Authors calculation

Table twelve illustrates how each country contributes to human development inequality as measured by the MLD index, with the exception of India. Between-country inequality was found to be greater than within-country inequality in terms of total inequality. In the year 2000, between-country inequality accounted for 91.56% of total inequality, with the remaining 8.44% attributed to within-country inequality. In 2005, between-country inequality contributed 91.72%, while within-country inequality contributed 8.28%. By 2010, between-country inequality accounted for 93.22%, with within-country inequality at 6.78%. In 2015, between-country inequality increased to 94.81%, while within-country inequality decreased to 5.19%. Finally, in 2020, between-country inequality decreased by 90.39%, and within-country inequality increased by 9.61%. The percentage of between-country inequality slightly increased from 2000 to 2015, and between the years 2015 and 2020, it decreased. Meanwhile, within-country inequality decreased from the year 2000 to 2015 and had a rapid increase between the years 2015 and 2020. Regarding within-country inequality among the five South Asian countries, Pakistan made the biggest contribution from 2000 to 2020, and its contribution increased during that period. On the other hand, the Maldives has the lowest contribution. After Pakistan, Bangladesh is the second country that has made a large contribution, varying between 0.00063906 and 0.00036515 during the time period.

5. Conclusion and Policy Implication

The primary objective of this research is to examine both between-country and within-country inequality in the Human Development Index (HDI) and its three components across selected SAARC countries from 2000 to 2020. We employed the Mean Log Deviation method for our analysis, given its effectiveness in decomposition. The findings revealed that, among the six nations studied, all except Pakistan experienced a decline in HDI inequality, with Nepal witnessing the most significant reduction; conversely, Pakistan showed a 17% increase in inequality. Regarding health index inequality, all six countries observed a decrease over the same period. In terms of education index inequality, four countries—Bangladesh, India, Nepal, and Afghanistan—saw significant declines, with Bangladesh experiencing the most considerable reduction; however, the Maldives and

Pakistan recorded increases. When examining income index inequality, all nations except Afghanistan exhibited a decrease, with the Maldives showing the largest decline.

Furthermore, our analysis of inequality both between and within countries indicated that between-country inequality exceeds the standard 100%, largely due to India's substantial population, which accounts for over 75% of the region's total. After excluding India from the analysis, the findings demonstrated that between-country inequality is greater than within-country inequality across the HDI and its three subcomponents: health, education, and income. Our findings highlight the crucial influence of population on the dynamics of inequality. Specifically, the substantial population of India plays a pivotal role in exacerbating the overall levels of inequality within the country. This is evident as the sheer size of India's population contributes significantly to inequality metrics, often resulting in figures that surpass the cumulative value of inequality observed in other nations. The interplay between population size and inequality underscores the necessity for targeted policy interventions that consider demographic factors in order to address and mitigate the disparities.

The findings of the current study present significant policy implications for policymakers and other stakeholders within the SAARC region. We advocate for increased integration and collaboration among member countries to bolster support in critical areas such as education and healthcare. This collaboration can be facilitated through shared initiatives, joint programs, and resource pooling, which would not only enhance educational outcomes and healthcare access but also promote a sense of unity among the member states. Moreover, it is essential to improve the coordination of resource utilization within the region to stimulate regional economic development. This can be achieved through the establishment of frameworks that encourage investment in mutual projects, the sharing of best practices, and fostering trade relationships that benefit all countries involved. However, it is crucial to acknowledge the challenges posed by the persistent political conflicts among member nations, which could significantly hinder overall collaboration and efforts to address issues of inequality within the region.

Finally, we recommend that India implement comprehensive policies aimed at mitigating the population growth rate in the country. These policies should focus on several key areas, including enhancing access to education, particularly for women and girls, as well as promoting family planning initiatives that provide both information and resources. Furthermore, investing in community awareness programs that emphasise the benefits of smaller family sizes and sustainable practices can also foster a cultural shift towards responsible parenthood. By taking these steps, the region can work towards a more cohesive and prosperous future, reducing disparities and fostering a collaborative spirit among its members.

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The influence of renewable energy consumption and trade openness on carbon emissions in South Africa: an augmented autoregressive distributed lag method application

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Abstract. *This study examines the influence of renewable energy consumption and trade openness on CO₂ emissions in South Africa. To do this, a recent and robust econometric approach, namely the augmented autoregressive distributed lag (ARDL) approach, is used on the World Bank (WDI, 2025) dataset from the period 2002 to 2021. The results show that in South Africa, an increase in renewable energy consumption significantly reduces CO₂ emissions in the short and long term, while an increase in trade openness damages the environment in the short term. Therefore, in order to address the challenges of climate change, energy security and socio-economic development in South Africa, this study suggests increasing the production and use of renewable energy; implementing commercial strategies that guarantee development and improve environmental quality; a significant reduction in the use of fossil fuels.*

Keywords: Renewable energy consumption, Trade openness, Carbon emissions, South Africa, Augmented ARDL.

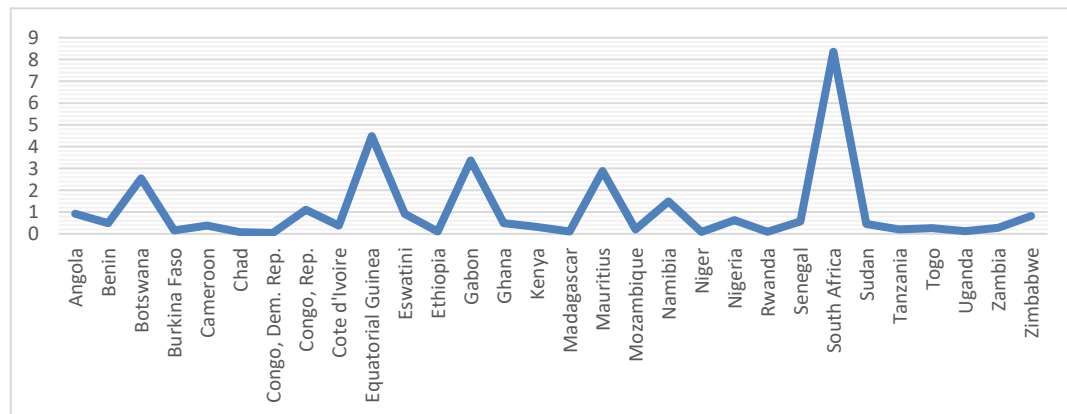
JEL Classification: C33, O13, Q42, Q54, Q58.

1. Introduction

Governments around the world have prioritized carbon reduction and carbon neutrality in order to tackle the growing threat of climate change. These goals are in line with the United Nations Sustainable Development Goals (SDG-13). These goals highlight the need to take action against climate change in order to reduce the harmful effects of human activities and the use of fossil fuels (Bekun, 2024). The impacts of pollution are not limited to humans, but also affect the overall harmony of the planet (Hassan et al. 2025). The problem of climate change, which causes various negative effects on a global scale, is one of the important research topics. It is necessary to determine the factors affecting CO₂ emissions, which are the main determinants of climate change, and to take measures in this regard (Aydin, 2023). CO₂, whose volume in the atmosphere has increased, is the main greenhouse gas (GHG) causing climate change. Climate change due to the increase in GHGs has a vast impact on health and the environment (Matenda et al. 2024).

In recent times, environmental degradation has gained prominence worldwide due to rising CO₂ emissions. The international community has been confronted with global warming and climate change, which have had a widespread impact on human and natural systems. Global carbon emissions have shown a rapid increase over the years (Kgomo and Zhanje, 2025). Carbon emissions have significantly accelerated global warming in recent decades, thereby altering the Earth's atmosphere. Consequently, it is crucial to study the factors that contribute substantially to the increase in CO₂ emissions (Amin et al. 2025: pp. 12605-12623). The need to reconcile economic growth with biodiversity conservation, as well as growing environmental concern about the impact of economic activities on CO₂ emissions, has prompted the international community to develop common agendas on ecological sustainability and global warming issues over the past three decades (Perone, 2024).

Figure 1: Trend in CO₂ emissions in SSA countries between 2002 and 2021



Source: Authors

This shows that the global increase in CO₂ emissions observed through environmental degradation and global climate change is a source of great concern. It is important to note that although sub-Saharan Africa (SSA) accounts for no more than 3% of global carbon emissions, these emissions have been rising over the decades. This is due to ongoing

economic and institutional reforms aimed at stimulating economic growth, strengthening industrialization and diversifying activities, improving transport systems and responding to energy crises (Avom et al. 2020). However, among the SSA countries, South Africa stands out in terms of its emissions levels between 2000 and 2021 (Figure 1). Compared to other countries in the region, South Africa's CO₂ emissions are high enough to suggest that it is the main contributor to CO₂ emissions in SSA.

This therefore calls for the adoption, use and implementation of measures and policies aimed at curbing this global economic evil without hampering global economic growth rates (Egbe et al. 2024). The variables determining environmental degradation are similar to the determinants of energy consumption. The debate on environmental sustainability cannot be addressed without considering the type of energy to be used. The pace at which the world is industrializing, globalizing and developing economically has prompted many researchers to investigate the type of energy needed to preserve the environment (Justice et al. 2024). Renewable energy has emerged as a promising solution to the challenges of climate change, energy security and socio-economic development.

South Africa, with its abundant renewable energy resources, has made significant progress in the use of renewable energy over the past decade (Adebiyi and Moloi, 2024). There is no denying that the use of renewable energy has advantages in terms of preventing climate change and protecting the environment (Waris et al. 2023: pp. 72503-72513). It is widely accepted that the transition from fossil fuels to renewable sources is essential to reduce greenhouse gas emissions (Ganda, 2024; Huy, 2024: pp. 3845-3856). This will undoubtedly lead to more environmentally friendly technologies and sustainable methods in sectors such as agriculture, industry and transport. This would reduce emissions while promoting economic growth (Osabuohien-Irabor and Drapkin, 2022: pp. 52475-52498).

South Africa, which consumes the most electrical energy in Africa, is recognized as one of the most developed countries on the continent (Akinbami and Bodunrin, 2021: pp. 5077-5093). Despite limited oil and gas reserves in South Africa, the country compensates for this deficit by exploiting its large coal deposits to meet its energy needs. South Africa is gradually developing its renewable energy industry to mitigate CO₂ emissions and provide sustainable and cost-effective electricity to its population (Matenda et al. 2024). South Africa is expanding its use of green energy technologies and increasing their share in the energy mix, resulting in substantial reductions in carbon emissions. Energy storage and grid flexibility technologies, by encouraging the inclusion of renewable energies in the energy system, are facilitating the elimination of fossil fuel-based electricity generation. The adoption of renewable energies in the electricity sector has contributed to the reduction of CO₂ emissions.

Several studies have examined the link between renewable energy consumption and CO₂ emissions. Some researchers have proven that the use of renewable energy reduces carbon emissions and improves environmental quality. The work of Al-Zubairi et al. (2025) in Arab countries; Tran et al. (2024) in ASEAN countries; Perone (2024) in OECD countries; Egbe et al. (2024) in G7 economies; Erdoğan et al. (2024) in Canada; Matenda et al. (2024) in South Africa; Rahman and Ferdaous (2024) in the MENA and OECD regions; Apergis et al. (2023) in Uzbekistan; and Dumrul et al. (2023) in Turkey corroborate this result.

However, others have found contradictory results suggesting that renewable energies contribute to increased environmental pollution. Studies by Singh et al. (2025) in 12 countries of Central and Eastern Europe and Hasni et al. (2023) in eighteen different Asia-Pacific Economic Cooperation economies corroborate this result.

Furthermore, with the increase in trade disputes related to the environment, global attention to environmental issues in international trade has intensified (Jiang and Jiang, 2025). Trade openness offers countries the opportunity to import advanced technologies for energy-efficient production and more environmentally friendly products, thereby contributing to further reductions in emissions (Ahakwa et al., 2024). The link between trade openness and CO₂ emissions is a key area of research in these times of pressing global sustainability needs and ongoing discussions on climate change (Barkat et al. 2025: pp. 677-698). Trade openness can also play a role in this regard, as can the free flow of green technologies and environmentally sound practices across borders. The link between trade openness and environmental sustainability, primarily in the form of CO₂ emissions, has attracted increasing attention.

The literature is nuanced and conveys mixed messages about the relationship between trade openness, which sometimes has a positive impact on environmental sustainability and other times extremely harmful effects, depending on various factors that are generally influenced by the level of development or primitiveness of a country's economy, the governance system in place, and technological progress (Sun and Qamruzzaman, 2025).

Indeed, trade openness damages the environment by increasing air pollution (Andriamahery et al. 2022; Wang et al. 2023; Mignamissi et al. 2024; Oumarou and Nourou 2024; Hassan et al. 2025; Barkat et al. 2025; Kgomo and Zhanje, 2025; Ünsal, 2025). On the other hand, conflicting results suggest that trade improves environmental quality (Udeagha and Ngepah, 2019; Aydin and Turan, 2020). Consequently, despite the existence of studies on the influence of renewable energy consumption on CO₂ emissions on the one hand, and the impact of trade openness on CO₂ emissions on the other, no consensus seems to have emerged. The literature is therefore nuanced and conveys mixed messages on the subject. In this context, the link between renewable energy consumption, trade openness and the environment is an innovative perspective discussed in the literature but absent for some SSA countries such as South Africa. Consequently, this study examines the following research questions:

1-Does renewable energy consumption really contribute to reducing CO₂ emissions in South Africa?

2-Does trade openness have an effect on the increase in CO₂ emissions in South Africa?

This research enriches the existing literature in four ways. First, despite the existence of several environmental quality indicators, the selection of CO₂ is intriguing because of its multidimensional importance. Although many previous studies have been conducted on this topic, the study period and country examined in this research offer a new and distinctive perspective. Second, this research is important because it deepens our understanding of emissions dynamics and has major implications for environmental sustainability. Furthermore, a coherent and flexible approach to combating carbon emissions through energy transition, natural resource use and institutional improvement is essential for South Africa to achieve its emission reduction goals and meet global climate targets.

Thirdly, this article uses the robust and very recent econometric method known as augmented ARDL approach. To be precise, the augmented ARDL method differs from the traditional ARDL approach in several respects. The traditional ARDL method does not determine the statistical significance of all variables. The traditional ARDL method does not consider the statistical significance of all explanatory variables. As pointed out by Amin et al. (2025) and McNown et al. (2018), it is advisable to use an additional test statistic to determine the relevance of the explanatory variables and establish a precise cointegration between them. Furthermore, augmented ARDL is a method suitable for small samples, and no interference from endogenous explanatory variables is observed in the proposed test. The ARDL approach is suitable for producing short-term and long-term links when the sample size is small. Furthermore, it also follows the ordinary least squares (OLS) approach for cointegration between variables (Huang, 2022). Finally, fourthly, trade openness in this research is captured by the Squalli and Wilson (2011) indicator. Unlike the traditional indicator, this new measure takes into account two dimensions of openness. On the one hand, it considers the country's trade intensity in relation to the performance of its local economy and, on the other hand, its relative trade intensity in relation to the volume of world trade.

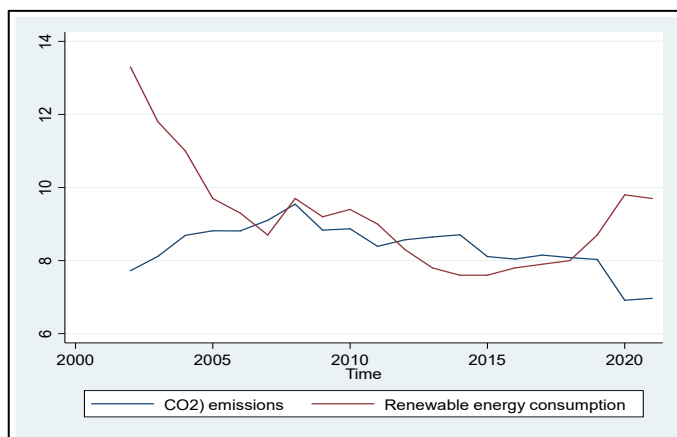
The rest of the article is organized as follows: Section 2 provides a review of the literature. Section 3 discusses the model, data and econometric method through the methodology. The fourth section presents the results and interpretations. Finally, the fifth section discusses the conclusions, suggestions and prospects for future research.

2. Literature review

2.1. Renewable energy consumption and CO₂ emissions

Despite measures taken to control environmental degradation, carbon emissions continue to rise, damaging environmental quality.

Figure 2: Trend in renewable energy consumption and CO₂ emissions in South Africa



Source: authors.

Empirical studies on the link between renewable energy consumption and CO₂ emissions are summarized in Table 1. It is clear from the empirical literature (Table 1) that the link between renewable energy consumption and CO₂ emissions is mixed. In South Africa, the evolution of these two variables over time shows that there is a negative correlation (Figure 2).

Indeed, it appears that between 2000 and 2020, whenever renewable energy consumption increases, CO₂ emissions decrease, and vice versa.

2.1. Trade openness and CO₂ emissions

Early research in the field of trade and climate change, such as that by Markusen (2013) and Copeland (2010), focused mainly on applying partial equilibrium or bilateral models to examine how a unilateral trade tax can mitigate cross-border environmental damage. This research indicates that trade policies can influence climate change through mechanisms such as greenhouse gas emissions, environmental regulation, and approaches to climate change adaptation and mitigation. It is appropriate to provide a brief summary of some information related to trade and climate change before reviewing previous research. Fundamentally, the relationship between trade and CO₂ emissions exposes a duality that highlights very different dynamics. Trade can act as a driver of economic growth, leading to higher per capita income and the expansion of energy-intensive production processes.

Table 1: Literature on the study of the link between renewable energy consumption and CO₂ emissions

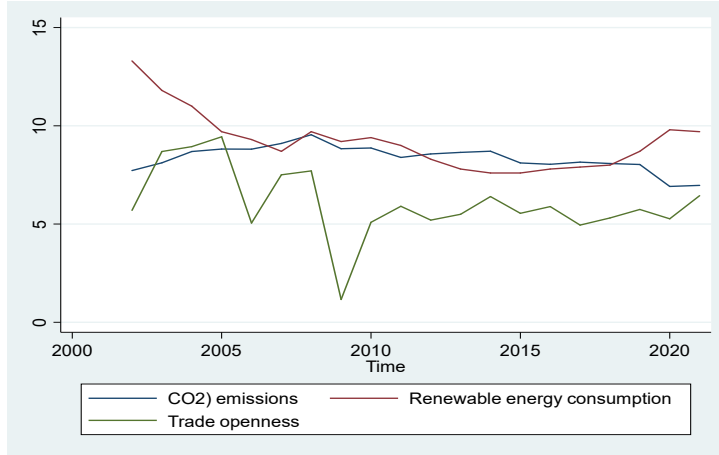
Authors	Zone and period	Estimation method	Results
Al-Zubairi et al. (2025)	Pays arabes 2000-2020	FMOLS, DOLS and FGLS.	$RE \rightarrow -CO_2$
Singh et al. (2025)	12 countries of Central and Eastern Europe 1990-2020	DF- GMM and one-step system GMM methods.	$RE \rightarrow +CO_2$
Matenda et al. (2024)	South Africa 1990-2020	DOLS	$RE \rightarrow -CO_2$
Perone (2024)	27 OECD countries 1965-2020.	The ARDL models of the PMG, MG, DFE, FMOLS, DOLS, CCEMG, GMM, PVAR and the Granger non-causality	$RE \rightarrow -CO_2$
Egbe et al. (2024)	G7 economies 1990-2020.	The Dynamic Fixed Effect Autoregressive Distributive Lag and the Pooled Mean Group	$RE \rightarrow -CO_2$
Erdoğan et al. (2024)	Canada 1965-2017.	ARDL	$RE \rightarrow -CO_2$
Rahman and Ferdaous (2024)	Three distinct regions: SAARC, MENA and OECD 1998-2018	Panel ARDL causality tests, FMOLS, DOLS, and D-H.	In the MENA and OECD countries, $RE \rightarrow -CO_2$ But has an insignificant effect in SAARC countries.
Wang et al. (2023)	24 countries with nuclear energy 2001-2020	The second-generation panel unit root test, the panel cointegration test, FMOLS, and the Dumitrescu and Hurlin test	$RE \rightarrow -CO_2$
Tran et al. (2024)	ASEAN countries 2000-2020	Panel vector autoregression and Granger non-causality test in heterogeneous panels, as well as long-term estimation techniques	$RE \rightarrow -CO_2$
Dumrul et al. (2023)	Turkey 1971-2006	Cointegration with Fourier Autoregressive Distributed Lag (ADL), DOLS and Fourier-Granger Causality tests	$RE \rightarrow -CO_2$

Authors	Zone and period	Estimation method	Results
Jiang and Khan (2023)	Belt and road initiative countries 1995-2019	OLS, fixed effect, and GMM	$RE \rightarrow -CO_2$
Waris et al. (2023)	19 G20 member countries 2000-2019	Dynamic fixed effects and GMM	$RE \rightarrow -CO_2$
Hasni et al. (2023)	Eighteen different Asia-Pacific economic cooperation economics economies 2000-2019	PMG-ARDL approach and Granger causality tests, the Pedroni tests.	$RE \rightarrow +CO_2$
Sadiq et al. (2024)	Brics-1 countries 1990-2020.	AMG, CCEMG, CS-ARDL, and cross-sectionally augmented distributed lag (CS-DL)	A 1% increase in ER led to a 0.43% decrease in CO ₂ in the short term and a 0.23% to 0.55% decrease in the long term.
Jamil et al. (2022)	7 countries from the G-20 1990-2019	FMOLS and DOLS	A 1% increase in ER was linked to a 0.2% decrease in CO ₂
Ekwueme et al. (2021)	South Africa 1970- 2014	The unit root test of Zivot-Andrews and ADF, VAR, and Pesaran ARDL	In the long term $RE \rightarrow +CO_2$. In the short term $RE \rightarrow -CO_2$

Source: Compilations by the authors. Note: $RE \rightarrow +CO_2$ = renewable energy increases CO₂ emissions; $RE \rightarrow -CO_2$ = renewable energy reduces CO₂ emissions; ARDL = Autoregressive distributed lag; FMOLS= fully modified Ordinary least square; DOLS= Dynamic Ordinary least square; SAARC=Association for Regional Cooperation; MENA= Middle East and North Africa; OECD=Organization for Economic Cooperation and Development; RE=Renewable energy; ASEAN: Association of Southeast Asian Nations; PMG=pooled mean group; MG=mean group; DFE= dynamic fixed effect; CCEMG=common correlated effects mean group (CCEMG), GMM=generalized method of moment; PVAR= panel vector autoregression; OLS=Ordinary Least Square; CS-ARDL=cross-sectionally augmented ARDL; VAR= vector autoregressive; ADF=Augmented Dickey-Fuller.

This effect, known as the ‘scale effect’, is often accompanied by an increase in energy consumption and a consequent rise in CO₂ emissions (Copeland and Taylor, 2004). In addition, trade can generate a ‘composition effect’ by altering global production and consumption patterns, leading to the production of high-emission goods (Khan et al., 2020). Furthermore, the ‘pollution refuge hypothesis’ introduces another level of complexity, suggesting that countries with less stringent environmental laws may focus on polluting sectors when faced with divergent standards. Generally, these sectors are capital-intensive in developed countries that enforce strict environmental policies. Furthermore, strong financing capacity may encourage the transfer of highly polluting production to developing countries (Barkat et al. 2025).

The empirical literature is summarized in Table 2. In South Africa, it is clear that the evolution of trade openness reveals a link that is difficult to determine in comparison with CO₂ emissions (Figure 3). However, between 2010 and 2020, the increase in emissions is associated with an increase in trade.

Figure 3: Evolution of key variables in the study over time

Source: Authors

Unlike these studies, which use trade share (TS), i.e. the degree of openness, the composite indicator of Squalli et Wilson (2011)⁽¹⁾ is used in this research to capture South Africa's level of openness. This indicator is given by equation (1):

$$CTS = \frac{n(X+M)_i^2}{PIB \sum_{j=1}^n (X+M)_j} \quad (1)$$

The CTS represents the TS adjusted by the proportion of a country's trade level relative to average global trade. The data on exports X, imports M and GDP needed to construct the CTS indicator are taken from the World Development Indicators (Fankem and Oumarou, 2020).

Table 2: Literature on the study of the link between trade openness and CO2 emissions

Authors	Periods and Countries	Methods used	Results obtained
Zhou et al. (2025)	Emerging Countries 2003-2020	FMOLS, DOLS, PMG-ARDL, DCCMG, and Driscoll-Kraay	$TO \leftrightarrow CO2$
Barkat et al. (2025)	20 OECD countries 150-year, 1870-2019	CCE-MG and AMG estimators	$TO \rightarrow +CO2$
Sun and Qamruzzaman (2025)	BRICS + T countries 1990-2022.	DSUR, CS-APUR, ARDL	$TO \rightarrow +CO2$
Hassan et al. (2025)	South Asia 1990-2018	FE, RE, AMG, FMOLS, DOLS, CCEMG and AMG	$TO \rightarrow +CO2$
Kgomo and Zhanje (2025)	BRICS plus countries 2001-2020	Panel econometric methods such as the panel autoregressive distributed lag	$TO \rightarrow +CO2$
Unsal (2025).	Nine developing countries 1990-2020	Heteroscedasticity detection, the method Huber-Eicker-White is used for estimation to estimate the coefficients correctly.	$TO \rightarrow +CO2$
Fang et al. (2025)	Australia 1990-2023	ARDL	$TO \rightarrow +CO2$
Keşap et al. (2025)	five developing Organization of Turkic States (OTS) members 1993-2021	This study employs panel data methods, AMG and CCEMG estimation	$TO \rightarrow +CO2$
Mignamissi et al. (2024)	Africa	STIRPAT model. 2SLS	$TO \rightarrow +CO2$

Authors	Periods and Countries	Methods used	Results obtained
Oumarou and Nourou (2024)	SSA 2002-2019	GMM, 2SLS	$TO \rightarrow +CO_2$
Wang et al. (2023)	122 countries 1998-2018.	Pesaran CD test, CIPS unit root test, Pedroni cointegration test, FMOLS, Dumitrescu-Hurlin causality test and DOLS	$TO \rightarrow +CO_2$
Duodu and Mpuure (2023)	SSA 1990-2020	GMM and the Dumitrescu and Hurlin (D-H) causality test	Trade reduces environmental pollution by approximately 0.10% and 0.79% in the short and long term, respectively.
Andriamahery et al. (2022)	ASS 1990-2017	GMM	$TO \rightarrow +CO_2$
Nguyen et al. (2020)	33 emerging economies 1996-2014	Model STIRPAT, ARDL	$TO \rightarrow +CO_2$
Udeagha and Ngepah (2019)	South Africa 1960-2016	ARDL	$TO \rightarrow -CO_2$

Source: authors. Notes: $TO \leftrightarrow CO_2$ = bidirectional relationship between trade openness and CO₂ emissions; $TO \rightarrow -CO_2$ = trade openness reduces CO₂ emissions; $TO \rightarrow +CO_2$ = trade openness increases CO₂ emissions; GMM = Generalized Method of Moments; CO₂ = carbon dioxide, SSA = Sub-Saharan Africa; FMOLS = Fully Modified Ordinary Least Squares, DOLS = Dynamic Ordinary Least Squares, ARDL = Autoregressive Distributed Lag model, STIRPAT = Stochastic Impact by Regression on Population, Affluence and Technology, BRICS = Brazil, Russia, India, China and South Africa, OECD = Organization for Economic Cooperation and Development; DCCEMG = Common-correlated effect mean group; DSUR = Dynamic Seemingly Unrelated Regression; CS-APUR = Cross-Sectionally Augmented Panel Unit Root; 2SLS = Two-Stage Least Squares estimation; FE = Fixed Effects; RE = Random Effects; AMG = Augmented Mean Group; CCEMG = Common Correlated Effects Mean Group Approaches.

3. Methodology

3.1. Econometric model used

This research explores the influence of renewable energy consumption and trade openness on CO₂ emissions in South Africa. Based on the study by Amin et al. (2025), an empirical model is developed (equation 2), where CO₂ depends on renewable energy consumption, trade openness, natural resources, real income, inward foreign direct investment, fossil fuel consumption and governance (Control of Corruption, Government Effectiveness, Regulatory Quality, Rule of Law, Voice and Accountability, Political Stability and Absence of Violence). This research covers the period 2002-2021. The sample was selected based on the availability of data across the different variables. The estimation model is given by the following equation (2):

$$CO_2_t = \alpha_0 + \alpha_1 REC_t + \alpha_2 TO_t + \alpha_3 NRR_t + \alpha_4 GDP_t + \alpha_5 FDI_t + \alpha_6 FEC_t + \alpha_8 GOV_t + \mu \quad (2)$$

In equation (2), carbon dioxide emissions are denoted by CO₂, which is an environmental variable, REC is renewable energy consumption, TO is trade openness, NRR represents natural resource rent, GDP gross domestic product per capita, FDI is foreign direct investment inflows, FEC represents fossil energy consumption, and GOV is the synthetic

indicator of institutional quality. The explanation and sources of the above indicators are discussed in Table 3.

Table 3: *Variables with measurements*

Variables	Symbols	Definition	Source
CO2 emissions (metric tons per capita)	<i>CO2</i>	Carbon dioxide (CO ₂) emissions per capita, which serves as an indicator of environmental deterioration.	World Development Indicators
Renewable Energy Consumption	<i>REC</i>	Renewable energy consumption is the share of renewable energy in total final energy consumption.	World Development Indicators
Trade Openness	<i>TO</i>	The trade intensity composed by Squalli and Wilson (2011) is used to describe the degree of openness of SSA countries.	World Development Indicators
Total natural resources rents (% of GDP)	<i>NRR</i>	Total natural resources rents are the sum of oil rents, natural gas rents, coal rents (hard and soft), mineral rents, and forest rents.	World Development Indicators
GDP per capita growth (annual %)	<i>GDP</i>	Gross domestic product is the total income earned through the production of goods and services in an economic territory during an accounting period. This indicator denotes the percentage change over each previous year of the constant price (base year 2015) series in United States dollars.	World Development Indicators
Foreign direct investment, net inflows (% of GDP)	<i>FDI</i>	Foreign direct investment are the net inflows of investment to acquire a lasting management interest (10 percent or more of voting stock) in an enterprise operating in an economy other than that of the investor.	World Development Indicators
Fossil fuel energy consumption (% of total)	<i>FEC</i>	Fossil fuel comprises coal, oil, petroleum, and natural gas products.	World Development Indicators
Governance	<i>GOV</i>	These indicators are: Control of Corruption, Government Effectiveness, Regulatory Quality, Rule of Law, Voice and Accountability, Political Stability and Absence of Violence	World Governance Indicators

Source: Compiled by the authors.

3.2. Estimation strategy

The autoregressive distributed lag (ARDL) approach, introduced by Pesaran et al. (2001), has been widely used in previous studies (Fang et al. 2025; Perone, 2024; Egbe et al. 2024; Erdoğan et al. 2024; Rahman and Ferdaous, 2024; Apergis et al. 2023; Udeagha and Ngepah, 2019). The reason is that the test is very flexible as it allows regressors to be at level or in first difference, assuming that the regressor must be in first difference (Amin et al. 2025). ARDL is the best technique for finding variable integrations as it is well suited to a small sample of data (Osabohien et al. 2018).

The augmented ARDL approach offers many benefits. First, the sequence of incorporation of the model's indicators, including the dependent variable, can vary, but they must not exceed one (i.e., they must not be I(2)). Second, it is an appropriate method for small data sets. Thirdly, according to Perasan et al. (2001), endogenous explanatory factors have no indirect impact on the suggested test. And finally, fourthly, the approaches provide long-term coefficients (Pakrooh et al. 2025). Equation (2) is presented in the form of an ARDL error correction model, as is equation (3):

$$\begin{aligned}
\Delta CO2_t = & \beta_0 + \sum_{i=1}^q \beta_{1i} \Delta CO2_{t-i} \\
& + \sum_{i=0}^p \beta_{2i} \Delta REC_{t-i} + \sum_{i=0}^u \beta_{3i} \Delta TO_{t-i} + \sum_{i=0}^v \beta_{4i} \Delta NRR_{t-i} \\
& + \sum_{i=0}^w \beta_{5i} \Delta GDP_{t-i} + \sum_{i=0}^x \beta_{6i} \Delta FDI_{t-i} + \sum_{i=0}^y \beta_{7i} \Delta FEC_{t-i} \\
& + \sum_{i=0}^z \beta_{8i} \Delta GOV_{t-i} + \alpha_1 CO2_{t-1} + \alpha_2 REC_{t-1} + \alpha_3 TO_{t-1} + \alpha_4 NRR_{t-1} \\
& + \alpha_5 GDP_{t-1} + \alpha_6 FDI_{t-1} + \alpha_7 FEC_{t-1} + \alpha_8 GOV_{t-1} \\
& + \mu_t
\end{aligned} \tag{3}$$

The ideal lag times for each variable are indicated by q, p, u, v, w, x, y, and z in equation (3), with the lag times selected using Akaike's information criteria (AIC). The range of the calculated parameters is $[\beta_0 \dots \beta_8]$ and $[\alpha_1 \dots \alpha_8]$. Initially, two tests are suggested to analyze cointegration between indicators: the t-test on the explained lagged indicator and the F-test assessing the relevance of indicators for all lagged variables. In addition, it contains two degenerate cases.

For case 1, although the F-test shows statistical significance, the coefficients of the explanatory variables ($\beta_0 \dots \beta_8$) are not. Event 2 occurs if the F-test shows significance, but the coefficient of the explanatory variables (β_1) is not. To avoid the second degenerate case, it is imperative that both T and F tests are significant⁽²⁾.

However, Goh et al. (2017) argued that this assumption does not accurately reflect cointegration, as unit root tests often have insufficient power. If the estimates of the F and T statistics exceed their critical thresholds, it can be inferred that all included indicators exhibit cointegration. Furthermore, when establishing equation (3) to obtain long-term results, an error correction model is calculated in parallel in order to obtain the coefficients of the error correction term⁽³⁾.

4. Results and interpretations

4.1. Descriptive analyses

The descriptive statistics (Table 4) for the main variables analyzed are shown in the table below and reveal the same number of observations (20) for all variables. The average CO2 emissions for South Africa are around (8.356). Renewable energy consumption averages 9.215, while trade openness averages around 6.071. Furthermore, natural resource rents have an average value of 1.425. Governance has the lowest average value (0.202) and also the lowest maximum value (0.388). Gross domestic product has the highest average value (9.935) and the highest maximum value (11.877). Foreign direct investment has an average value of 1.653 with a maximum and minimum value of 9.660 and 0.205 respectively. Fossil

fuel consumption has an average of 9.668, with a maximum and minimum of 9.650 and 8.260 respectively.

Table 4: Descriptive statistics of variables

Variable	Obs	Mean	Std. Dev.	Min	Max	Skewness	Kurtosis	J-B	Probability
CO2	20	8.356	0.652	6.914	9.545	0.343	2.772	34.922*	0.113
REC	20	9.215	1.477	7.600	13.3	-0.750	3.121	32.543*	0.144
TO	20	6.071	1.801	1.161	9.440	2.151	5.871	61.912*	0.173
NRR	20	1.425	0.886	0.187	3.831	1.136	3.532	32.721*	0.233
GDP	20	9.935	3.338	6.815	11.877	1.811	4.111	6.989*	0.177
FDI	20	1.653	2.039	0.205	9.660	2.543	7.111	15.771*	0.411
FEC	20	9.668	1.388	8.260	9.650	1.311	8.523	17.524*	0.239
GOV	20	0.202	0.133	-0.016	0.388	1.324	6.341	19.625*	0.134

Source: authors. Note: *, **, and *** indicate significance at the respective thresholds of 1%, 5%, and 10%.

Overall, the descriptive statistics show little variation. Skewness, kurtosis and Jarque-Bera (J-B) tests are used to verify the normality of the data. The first refers to a measure of asymmetry, the second deals with the precision and amplitude of the peak of the curve, while the third establishes whether the asymmetry and kurtosis of the data are consistent with a normal distribution. The assumptions of skewness and kurtosis require a mean different from zero and a mesokurtic distribution. Descriptive statistics clearly indicate that CO2, REC, TO, NRR, GDP, FDI, FEC, and Gov in our selected country show little fluctuation over the period. Therefore, the fluctuations appear appropriate for further empirical evaluation.

Table 5: Correlation matrix between variables

Variables	CO2	REC	TO	NRR	GDP	FDI	FEC	Gov
CO2	1.000							
REC	-0.172	1.000						
TO	0.131	0.323	1.000					
NRR	-0.055	-0.116	-0.143	1.000				
GDP	0.208	-0.030	-0.423	0.342	1.000			
FDI	-0.294	0.033	0.045	0.732	0.055	1.000		
FEC	0.039	-0.871	-0.392	0.352	0.890	0.123	1.000	
Gov	0.614	0.546	0.399	-0.247	-0.578	-0.320	-0.664	1.000

Source: Authors

Table 5 provides a description of the correlations between the different analysis variables. The correlation matrix shows the existence of correlations between the different variables used. The correlations between CO2 emissions and renewable energy consumption, and between CO2 emissions and trade openness, are -0.172 and 0.131 respectively. The correlations between CO2 emissions and natural resources, and between CO2 and gross domestic product, are -0.055 and 0.208 respectively. Furthermore, the highest correlations appear between gross domestic product and fossil fuel consumption (0.890) and between governance and CO2 emissions (0.614). This proves that there is no multicollinearity between the independent variables. However, the weakest correlations appear between renewable energy consumption and fossil fuel use (-0.871), between governance and gross domestic product (-0.578), and between trade openness and gross domestic product

(-0.423). Nevertheless, the correlations between the different variables analyzed are not high enough to cause the problem of multicollinearity.

4.2. Unit root tests

Although different integration orders of variables can be subjected to the augmented ARDL bounds test, it must be ensured that no variable is $I(2)$. This study is based on unit root tests, integrating all relevant variables, to analyze the time series data. As previously indicated, the ARDL cointegration technique is only valid for time series that are stationary at the level or at the first difference. Unit root tests such as Im-Pesaran-Shin (Im et al., 2003), CADF and CIPS are designed to deal with cross-sectional dependencies. Table 6, which focuses on South Africa, shows significant results for unit root tests. This suggests a strong argument against the null hypothesis of the existence of a unit root for certain variables. For example, variables such as CO₂, REC, TO, NRR and FDI show stationary processes at level $I(0)$, which means that differentiation is not necessary to achieve stationarity. Although the unit root test results for other variables such as GDP, FEC, and GOV are not statistically significant, they suggest the presence of a unit root in the series.

Table 6: Unit root test results

Country: South Africa				
Variables	Im-Pesaran-Shin	CADF	CIPS	Stationary Level
<i>CO₂</i>	-1.34***	-1.56	-1.77	$I(0)$
<i>REC</i>	-1.32***	-6.88	-1.92	$I(0)$
<i>TO</i>	2.22***	-3.86	-2.31	$I(0)$
<i>NRR</i>	-1.53	-5.01	-4.77	$I(0)$
<i>GDP</i>	2.27	2.54	7.32	$I(1)$
<i>FDI</i>	2.91	-3.21	2.71	$I(0)$
<i>FEC</i>	-1.01	5.55	2.45	$I(1)$
<i>Gov</i>	-1.23	-1.11	-1.72	$I(1)$

Source: Authors. Notes: Im-Pesaran-Shin unit panel root test (Null hypothesis= All panel contains unit root). Pesaran's CADF panel unit root test in presence of cross section dependence (Null hypothesis= all series are non-stationary). Pesaran panel unit root test in the presence of cross-section dependence (Null hypothesis= (homogeneous non-stationary). *Refers to 10 %, ** is 5 %, and *** is 1 % significance level.

Furthermore, based on the augmented ARDL method, we find that none of the variables in our model exhibit stationarity at second difference, while all do at first difference. Consequently, we will perform the cointegration test.

4.3 The cointegration test for the augmented ARDL method

Given that CO₂ emissions, renewable energy consumption, trade openness, natural resource rents, foreign direct investment, fossil fuel consumption, gross domestic product and governance are either stationary at level or stationary at their first difference, we use the ARDL cointegration method to estimate equation 3. Table 7 shows the results of the bounds cointegration test.

The estimated F statistic is shown in Table 7, along with the critical limits for 10%, 5% and 1% respectively. The decision rule states that if the F statistic of the test exceeds the threshold value for a certain significance level (1%, 5% or 10%), the null hypothesis is rejected, and vice versa.

Table 7: *Cointegration Test Results*

F-statistics	Significance (%)	Critical bounds	
		I(0)	I(1)
5.633*	1	5.12	5.23
	5	4.22	5.39
	10	3.67	3.77

Source: Authors. Notes: *Represents a 1% level of significance

According to the evaluated model, $f(CO_2 = REC, TO, NRR, GDP, FDI, FEC, Gov)$, where CO_2 emissions represent the dependent variable; renewable energy consumption and trade openness represent the variables of interest; natural resource rent, foreign direct investment, fossil fuel consumption, gross domestic product and governance are the control variables, we also conclude that there is a long-term correlation between the selected variables, given that the F statistic determined exceeds their maximum critical values, leading us to reject the null hypothesis of non-cointegration. These results on the existence of a long-term relationship between the different variables in this study corroborate the empirical investigations found by Sadiq et al. (2024) in the BRICS-1 countries (Brazil, Russia, India and China) between 1990 and 2020; Perone (2024) in 27 OECD countries between 1965 and 2020; Bekun (2024) in South Africa between 1975 and 2020; Egbe et al. (2024) in G7 economies (France, Germany, Canada, Italy, and the United Kingdom) over the period 1990-2020; Erdoğan et al. (2024) in Canada between 1965 and 2017; and Amin et al. (2025) in China between 1990 and 2019.

The results found are therefore conclusive and support the existence of cointegration relationships among the variables examined. Thus, a cointegration relationship is established between the different variables in our model. Consequently, we now assume that the results predicted in the next section are accurate, consistent and economically significant.

4.4. Long-term and short-term results of the augmented ARDL estimation

Table 8 presents the results of several diagnostic procedures. We use several diagnostic tests, namely the Jarque-Bera normality test; the LM test for serial correlation; the ARCH test for heteroscedasticity; and the Ramsey test for model specification. We use these tests following the modelling approach from general to specific. After completing the diagnostic tests, we arrive at the ideal model exactly as in Amin et al. (2025).

Table 8 presents a description of the long-term and short-term results for renewable energy consumption, trade openness, natural resource rents, foreign direct investment, fossil fuel consumption, gross domestic product, and governance. With regard to the environmental impacts of renewable energy consumption, the results indicate that an increase in the use of renewable energy reduces CO_2 emissions in South Africa. These results corroborate the findings of Perone (2024) in OECD countries; Egbe et al. (2024) in G7 economies; Matenda et al. (2024) in South Africa; Al-Zubairi et al. (2025) in Arab countries; and Rahman and Ferdaous (2024) in the MENA and OECD regions, who found that renewable energy consumption plays an important role in mitigating carbon emissions. However, these results contradict a body of research. For example, in Uzbekistan, non-renewable energy consumption, natural gas and oil consumption have a positive impact on per capita

CO₂ emissions in the short and long term (Apergis et al. 2023). However, some authors have found that renewable energies contribute to increased environmental pollution, such as Singh et al. (2025) in 12 countries of Central and Eastern Europe; Hasni et al. (2023) in eighteen different Asia-Pacific Economic Cooperation economies. Consequently, South Africa has an interest in consuming renewable energy, which is the best strategy for pursuing the mission of limiting the temperature increase to 2 degrees Celsius and thus guaranteeing an intact environment for future generations. Furthermore, the signatory countries to the protocol and the main producers of renewable energy have a responsibility to implement appropriate measures to achieve the established goals. The consumption of renewable energy could overcome the problem of environmental degradation and achieve sustainable development (Jiang and Khan, 2023).

Table 8: Results of the augmented ARDL estimation

Estimations	Variables	Coefficient	Std.Err.	Probability
Long run results	1. CO ₂	-1.551**	-2.513	0.044
	REC	-0.071***	-1.668	0.000
	TO	0.022	-2.213	0.712
	NRR	0.012***	-6.431	0.032
	GDP	0.002***	3.341	0.000
	FDI	0.009**	1.234	0.046
	FEC	0.055***	4.321	0.000
Short run results	Gov	0.021*	-2.326	0.092
	Adjust. Term (CO ₂)	-1.675***	-2.555	0.039
	ΔREC	-0.067***	-1.951	0.001
	ΔTO	0.003*	-3.921	0.09
	ΔNRR	0.038***	-9.231	0.000
	ΔGDP	0.001*	6.291	0.092
	ΔFDI	0.006*	1.422	0.081
	ΔFEC	0.305	2.541	0.000
	ΔGov	0.014***	-1.183	0.009
	ECM	-0.091***	-1.032	0.000
Diagnostic tests	Ramsey	3.001	-	0.412
	Jarque-Bera	1.023	-	0.124
	Arch	2.015	-	0.543
	LM	3.662	-	0.244

Source: authors. Notes: *refers to 10 %, ** is 5 %, and *** is 1 % significance level

It has also been determined that trade openness has a positive impact in both the long and short term. However, only the short-term result is significant. This result is quite revealing, since unlike highly advanced countries such as China, Germany and the USA, South Africa is in its early stages of development and uses less sophisticated techniques to reduce carbon emissions. These results corroborate those found by Andriamahery et al. (2022) in SSA; Wang et al. (2023) in 122 countries around the world; Mignamissi et al. (2024) in Africa; Oumarou and Nourou (2024) in SSA; Hassan et al. (2025) in South Asia; Barkat et al. (2025) in 20 OECD countries; Kgomo and Zhanje (2025) in the BRICS plus countries; and Ünsal (2025) in nine developed countries. Furthermore, these results contradict the findings of Udeagha and Ngepah (2019) in South Africa and Aydin and Turan (2020) in the BRICS countries.

The link between natural resources and CO₂ emissions has remained a crucial environmental conjecture (Khan and Hassan, 2024). A major debate in environmental

economics concerns the impact of natural resources on CO₂ emissions (Khan et al. 2024, Han et al. 2024, Wang et al. 2024). However, there seems to be no consensus on the actual effect of abundant natural resources on CO₂ emissions. In our results, natural resource rents show a direct and statistically significant correlation with CO₂. These findings illustrate the unsustainable use of natural resources in South Africa, considering that this country is one of Africa's major mining powers. Furthermore, the relentless demand for energy and other materials in South Africa has put considerable pressure on its natural resources. The findings are consistent with those of Amin et al. (2025) in China; Destek and Sarkodie (2019) for developed countries; Bekun et al. (2019) for European Union countries; and Baloch et al. (2019) in the BRICS economies. Furthermore, the direct link between natural resources and CO₂ emissions in South Africa may stem from its heavy dependence on its abundant natural resources. This phenomenon leads to unsustainable exploitation and use of natural resources and reinforces the country's dependence on fossil fuel imports.

Furthermore, South Africa is considered to be a country that has recently entered a phase of rapid development, unlike other countries in sub-Saharan Africa. Table 8 also illustrates a statistically significant positive correlation between GDP growth and CO₂ emissions in South Africa. In other words, with a significance level of 1% and 10%, there is a 0.002% and 0.001% increase in CO₂ in the long term and short term, respectively, for each 1% increase in gross domestic product. As the relationship between GDP and CO₂ emissions shows a positive correlation in the short and long term, an increase in GDP leads to an increase in CO₂ emissions. Therefore, it can be argued that South Africa has become one of Africa's major economies in recent decades, requiring sustained growth in energy consumption to support its economic expansion. In the context of studies conducted for South Africa, these findings corroborate those found by Ekwueme et al. (2021). Globally, these results corroborate the findings of Amin et al. (2025) in China and Egbe et al. (2024) in G7 economies (France, Germany, Canada, Italy, and the United Kingdom).

It appears that FDI has a positive impact on CO₂ emissions in South Africa. These results are consistent with theoretical predictions and certain empirical investigations, thus supporting the pollution haven hypothesis in South Africa. In the literature, these results have been found by Sabir et al. (2020) and Demena and Afesorgbor (2020). Furthermore, some authors have found the contradictory hypothesis, namely the pollution halo hypothesis (Bildirici and Gokmenoglu, 2020). With regard to fossil fuel consumption, the results show that the use of these energies contributes significantly to increasing CO₂ emissions in South Africa. In fact, a 1% increase in fossil fuel use leads to an increase in CO₂ emissions in South Africa of 0.055% in the long term and 0.305% in the short term. In addition, the production of goods in South Africa is increasingly reliant on fossil fuels, which exacerbates the degradation of their environment.

According to Bekun (2024), fossil fuel consumption has adverse effects on environmental sustainability in South Africa. Similarly, Khan et al. (2024) demonstrate that an increase in CO₂ emissions is due to the use of oil, gas and coal in their study on the United States, China, Romania and Thailand. Alongside the growth and globalization of the world economy since the first industrial revolution, the production and use of fossil fuels have led to an increase in CO₂ emissions and, ultimately, significant environmental degradation

(Dumrul et al. 2023). In the case of South Africa, it appears that despite economic growth based on fossil fuels, these fuels contribute significantly to increasing CO₂ emissions and consequently to climate change and, in turn, to environmental degradation. Therefore, it would be preferable for South Africa to reduce its dependence on fossil fuels and opt for renewable energies in order to meet the increase in energy demand. To achieve this, the most important approach is to invest in technologies that are sustainable in the long term from an ecological point of view. With regard to governance outcomes, it can be observed that weak institutional quality indicators in South Africa have negative repercussions on their environment by increasing CO₂ emissions. According to Aka et al. (2024), the quality of institutions determines the energy transition in SSA. Some studies suggest that the quality of institutions is a determinant of CO₂ emissions (Hussain and Dogan, 2021; Khan and Rana, 2021). Therefore, the adoption of effective institutional procedures and robust rule of law practices can help raise awareness among businesses about compliance with CO₂ emission restrictions (Muhammad and Long, 2021). It would be preferable for South Africa to further improve its level of governance.

5. Conclusion, policy implications and research perspectives

In the current context, it is clear that the change caused by the global increase in CO₂ emissions has become a major issue that could compromise sustainability on a global scale. Several researchers and academics have therefore focused on investigating the link between economic variables and environmental quality. It is in this context that this study was conducted for South Africa, which is the main contributor to CO₂ emissions in SSA according to World Bank data. The main objective of this research is to assess the influence of renewable energy consumption and trade openness on CO₂ emissions in South Africa. Several contributions have been made in this research to demonstrate its relevance in the current context.

Firstly, despite the existence of several indicators of environmental quality, the selection of CO₂ as the dependent variable is intriguing due to its multidimensional importance. Although many previous studies have been conducted on this topic, the temporal dimension (2002-2021) and geographical scope (South Africa) of this research offer a new and distinctive perspective. Secondly, this research is important because it deepens our understanding of emissions dynamics and has major implications for environmental sustainability. Furthermore, a coherent and flexible approach to improving the environment through renewable energy consumption, improved trade policies, natural resource use, reduced fossil fuel use, and improved governance is essential for South Africa to achieve its emission reduction goals and meet global climate targets. Thirdly, this research uses the most recent econometric method, namely the augmented distributed lag autoregressive (ARDL) approach, unlike previous research which uses the traditional ARDL approach. Fourthly, trade openness in this research is captured by a recent measure which, unlike the traditional indicator or degree of openness, takes into account two dimensions of a country's openness. This measure takes into account, on the one hand, the trade intensity of a given country in relation to the performance of its local economy and, on the other hand, the relative trade intensity of that country in relation to the volume of world trade. The study's

empirical investigations highlight that an increase in renewable energy consumption significantly reduces CO₂ emissions in the short and long term, while an increase in trade openness damages the environment in the short term. Furthermore, the results show that fossil fuel consumption, FDI, natural resources and governance contribute to environmental degradation in South Africa.

Therefore, in order to create an environment conducive to long-term, inclusive and environmentally sustainable economic growth, this study suggests increasing the production and use of renewable energy; implementing policies and commercial strategies that guarantee development without neglecting the environmental aspect. Furthermore, it would be preferable for South Africa to reduce its dependence on fossil fuels and opt for renewable energies in order to meet the increase in energy demand. Effective management of inward FDI and natural resources is important for reducing CO₂ air pollution in this country. Furthermore, taking into account the effects of governance (control of corruption, government effectiveness, regulatory quality, rule of law, voice and accountability, political stability and absence of violence) on CO₂ emissions, it seems imperative for South Africa to improve the quality of its institutions.

Furthermore, this study used methods that provide long-term and short-term coefficients, although they do not establish causal links between the variables used. Future research could use alternative estimation techniques to determine whether past values of variable X, such as renewable energy consumption, trade openness or natural resources, can predict future values of variable Y, such as environmental quality as measured by CO₂ emissions. In this case, we recommend that future studies use the non-causality test to address the issue of causality between variables. Future studies could also conduct analyses at the level of other countries and use other indicators of environmental quality.

Notes

- (1) According to these authors, trade openness, commonly measured by the trade share $TS = X + M/GDP$ In hundreds of studies published to date, the world's largest trading nations, such as the United States, the United Kingdom, Japan and Germany, are systematically considered closed economies, regardless of the data set used. But is it normal to classify countries such as the United States, the world's leading trading power, Japan and Russia as closed economies? The obvious explanation is that the TI and related indicators are one-dimensional measures of trade openness and, as such, penalize large economies by classifying them as closed. Based on this observation, they suggested a composite measure of trade share that more fully reflects reality by combining two important dimensions of trade openness: trade share and the relative importance of a country's trade level relative to total world trade.
- (2) However, according to McNown et al. (2018), the first degenerate case can be ruled out by assuming that the regressor is I(1).
- (3) In addition, a vector error correction model (VECM) is used to examine explicit and implicit causality, provided that a long-term correlation is actually observed between the variables. This process also makes it possible to examine long-term and short-term relationships, which manifest themselves not only between dependent variables, but also between independent variables.

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The hidden side of VAT: modeling compliance and inferring collection shortfalls in Romania

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Abstract. *This study examines hidden weaknesses in VAT collection by constructing a transparent benchmark for Romania's VAT performance and inferring a model based shortfall when observed revenues fall below levels consistent with macro and policy fundamentals. Using annual data for 2000 to 2023, VAT revenue and household consumption (as percent of GDP) are taken from Eurostat, while unemployment and internet use are drawn from the World Bank to capture cyclical conditions and broad digital diffusion. The analysis links changes in VAT performance to the standard rate regime, the post EU institutional environment, and the 2009 to 2010 crisis period, while controlling for macro structural variation. Predicted VAT outcomes are translated into an implied shortfall proxy and used to identify years of unusually weak performance relative to the benchmark. The results indicate that Romania's shortfall signal is episodic rather than persistent, with the largest implied under collection concentrated in a small set of early years. The average inferred shortfall is about 0.160 percentage points of GDP per year, with a maximum of about 0.752 points in 2004, while 2001 and 2004 emerge as unusually weak performance years. A simple predictive check over 2016 to 2023 suggests higher errors in later years, consistent with structural change. The findings complement official VAT gap assessments by offering a single country time series benchmark suitable for diagnostics and policy discussion.*

Keywords: value added tax gap, tax compliance, electronic invoicing, shadow economy, fiscal administration, econometric benchmarking.

JEL Classification: H20, H21, H26.

Introduction

Value-added tax has remained the most critical revenue pillar in modern tax systems, which does not generally deliver the performance that statutory rates and underlying consumption might suggest. “C inefficiency” has, for a long time, been persistent in the European Union due to a combination of policy design choices and limitations on enforcement together with noncompliance which weakens the base-to-receipts relationship (Keen & Lockwood, 2010; Cnossen, 2022; Hasíková, 2024). Romania perfectly fits into this analysis since there have been changes in VAT rates accompanied by perennial complaints about the outcome of its collection, thus providing an excellent ground for analyzing how fundamentals translate into observed revenues and identifying where systematic shortfalls may arise (Badiu et al., 2024).

The VAT has naturally attracted sustained research interest because, while it is meant to be partially self-enforced through invoice chains and built in cross reporting, it can be vulnerable to evasion and fraud if verification breaks down. The classic compliance model frames evasion as a choice under audit risk and penalties. This baseline helps to suggest how incentives might work in shaping the reporting behavior of individuals (Allingham & Sandmo, 1972). In VAT environments, third-party information is contained within the paper trail; in practice, materializes by raising the probability that underreporting will be detected; indeed, there is empirical work which documents this mechanism on the subject of enforcement and reporting incentives (Pomeranz 2015; Buettner & Tassi 2023).

A major empirical challenge is, of course, measurement since one does not observe compliance and “VAT gaps” are typically inferred rather than recorded. An approach widely adopted in the literature uses VAT efficiency type constructs comparing actual VAT to some benchmark based on consumption and then allowing for shifts due to institutional quality, openness, and policy regimes over time (Aizenman & Jinjark, 2008; Cnossen, 2022). Reduced rates, exemptions, and regime complexity also have room to erode the tax’s ability to convert its potential into collections. Recent evidence from Europe underscores this point suggesting that the efficiency is a function of both the architecture in place and administrative capacity (Dytrychová et al., 2024; Hasíková, 2024).

Digitalization is increasingly seen as a realistic avenue for narrowing compliance gaps by enhancing traceability and reducing monitoring costs. Effects depend on how technologies are integrated into enforcement. Studies using European cross-country evidence indicate that more traceable payment ecosystems are associated with better VAT performance, consistent with reduced scope for sales suppression (Madzharova, 2020). At the same time, quasi experimental evaluations of electronic invoicing reforms provide direct evidence that transaction level reporting can raise compliance and revenues as well as change the strategic environment for firms and auditors (Bellon et al., 2022; Kotsogiannis et al., 2025).

It redirects attention away from descriptive VAT gap estimates toward “fundamentals consistent” VAT performance inferred via a model in a single country time series context. A new log VAT efficiency equation is estimated as a function of policy conditions and

macro structural correlates, then implied level of VAT is reconstructed from which shortfall proxy, defined whenever predicted VAT exceeds observed VAT, can be derived. This fits with wider perspectives that see the joint product of design, enforcement, and economic structure in determining outcomes and connects naturally to evidence that administrative modernization and digital reporting may affect fraud and cross border inconsistency (Mascagni et al., 2023; Heinemann & Stiller, 2024).

Literature review

Romania's VAT shortfall is mostly discussed from the perspective of the VAT Gap, which is the difference between theoretical VAT liability and actual VAT receipts, benchmarked comparatively across EU member states. It is in this respect that Romania is highlighted among higher gap countries in the Commission backed harmonized monitoring framework providing annual estimates and country specific diagnostics. This evidence base sets the empirical background for Romania's persistent compliance challenge, but it also serves to underline how measurement choices and national accounts inputs matter for cross country comparability (European Commission, 2023; Poniatowski et al., 2019). The same framework has since evolved into a recurrent policy instrument linking revenue losses to enforcement capacity and macro conditions, thereby reinforcing why a model-based approach that translates "fundamentals consistent" performance into an implied shortfall can be analytically useful (European Commission, 2025).

Another stream of work moves from levels to drivers i.e. what are the institutional and structural factors due to which some countries, such as Romania underperform on VAT collection against their potential. The EU wide VAT Gap study lays emphasized correlates such as governance quality, macro volatility, and enforcement effectiveness when interpreting persistent deviations from expected VAT liabilities (European Commission, 2018). Reinforcing this are regional empirics for Central and Eastern Europe which relate the VAT Gap to institutional frictions in terms of corruption and socio-economic vulnerability i.e. compliance is also determined by state capacity as well as the incentives of households and firms.

For Romania, specifically, the VAT compliance discussion fits within a broader literature on the shadow economy and tax evasion where underreporting and informality are seen as systemic features rather than temporary shocks. Using macro-based approaches, evidence shows that Romania's shadow economy dynamics can materially affect tax bases and observed revenue performance, implying that VAT under collection may reflect both enforcement gaps and wider informality constraints (Dell'Anno & Davidescu, 2019). Related EU oriented contributions explicitly treat the VAT Gap as a channel through which underground activity and reporting distortions propagate into weaker fiscal outcomes, reinforcing the relevance of efficiency type metrics that relate VAT revenues to consumption-based tax bases (Florin, 2017).

A more targeted Romania oriented empirical line studies how VAT under collection translates into general tax capacity and how revenue performance co moves with the structure of the economy. Recent work on Romania links VAT Gap movements to tax revenue outcomes and explores how institutional weaknesses and macro pressures can amplify collection slippages over time, supporting the view that persistent gaps are not merely cyclical noise (Guiu, 2024). In parallel, Romania focused analyses of the relationship between fiscal revenues and tax bases stress that revenue effort can diverge from base dynamics, which is consistent with interpreting deviations as compliance or administration related, not purely economic (Ogneru & Panait, 2020).

On the policy and administration side, Romania's modernization agenda has been examined through concrete compliance technologies, especially the roll out of electronic fiscal devices and related reporting infrastructure. Evidence from Romania argues that electronic fiscal devices can strengthen transaction recording and reduce the informational opacity that facilitates VAT evasion, with expected spillovers to tax discipline and the credibility of enforcement (Bostan et al., 2017).

More recent contributions have shifted the focus onto digital reporting systems and e-invoicing as mechanisms capable of reshaping VAT compliance through tightening the invoice trail with an opportunity for immediate risk-based verification. RO e Factura of Romania has been referred to both at a conceptual and institutional level in terms of broader digitization of business-to-state interactions, which also has links to certain aspects of SAF-T style data structures and compliance automation. There is, therefore, empirical survey evidence from Romania that will assist in understanding how accounting professionals perceive mandatory e-invoicing regarding its operational and compliance implications—evidence on what is expected to gain but also implementation frictions that may condition real-world effects. The complementary Romania-focused discussion frames such digital instruments in their entirety as a package of compliance levers wherein the effect significantly varies with the adoption readiness, the administrative capacity, and how well-integrated data is into enforcement workflows.

Internationally, the VAT literature provides two channels to mechanisms that may help interpret why digital tools can matter: third party information and invoice trail enforcement. Most evidence demonstrates how increasing the report set weakens collusive underreporting by strengthening receipt verification- but not net revenues as reported sales. This is valuable because extending the information set does indeed weaken collusive underreporting (Naritomi, 2019). Related experimental work finds that credible enforcement messages with third-party transaction references bring non-filing registered firms back into compliance-increasing payments and reported transactions all directly relevant for systems reliant on cross reporting like VAT-increasing payments and reported transactions (Brockmeyer et al., 2019). However, firms are also found to be responding similarly by overreporting on some other margin like costs; hence caution moves misreporting rather than eliminates it Carrillo et al. (2017).

Prior research has clarified how VAT gaps are measured and which macro institutional factors correlate with under collection, while Romania focused work has documented the role of informality and the promise of compliance technologies. Much of the evidence either relies on externally produced VAT Gap estimates or on broad revenue capacity frameworks. There are fewer studies building a compact, transparent econometric proxy that maps Romanian VAT performance to policy and macro fundamentals and then converts model implied efficiency into an interpretable shortfall series. This therefore motivates a time series-oriented approach that sits between VAT Gap accounting exercises and generic tax effort models, and that explicitly flags abnormal under performance episodes in a small sample setting (Hoza & Žabka, 2021; Le et al., 2008; Sen Gupta, 2007).

Methodology

This study uses annual data for Romania over 2000–2023, compiled from Eurostat (VAT revenue and household final consumption expenditure as % of GDP) and the World Bank database (internet users as a digitalization proxy and unemployment as % of population). The objective is to build an econometric proxy for VAT compliance/collection shortfall by linking VAT performance to policy and macro fundamentals in a small-sample setting.

The research question is: How do VAT policy conditions and macro-structural factors shape Romania's VAT collection efficiency over time, and what model-implied shortfall can be inferred when observed VAT revenue falls below fundamentals-consistent levels? To address this, we define VAT efficiency and model its log form:

$$VE_t = \frac{VAT_t}{CONS_t}, \ln VE_t = \ln(VE_t)$$

where VAT_t is “Value added taxes” as % of GDP and $CONS_t$ is household final consumption expenditure as % of GDP.

We test a compact set of hypotheses consistent with the model structure:

- H1 (policy): changes in the standard VAT rate affect efficiency ($\beta_{rate} \neq 0$)
- H2 (cycle/compliance): unemployment is associated with efficiency ($\beta_{unemp} \neq 0$)
- H3 (digitalization): internet adoption improves efficiency ($\beta_{net} > 0$)
- H4 (institutional/regime): the post-EU period is associated with higher efficiency ($\beta_{EU} > 0$)
- H5 (shock): the 2009–2010 crisis period reduces efficiency ($\beta_{crisis} < 0$)

The empirical approach estimates a parsimonious candidate set suitable for annual data and limited degrees of freedom: (i) a static specification, (ii) an ARDL(1) specification including $\ln VE_{t-1}$ and (iii) ARDL(1) with a deterministic trend. The preferred specification is selected via the small-sample corrected information criterion:

$$AICc = AIC + \frac{2k(k+1)}{n-k-1}$$

For statistical inference, coefficients are reported with Newey-West robust standard errors (annual; lag fixed at 2). As a robustness check to serial correlation, we also estimate GLS with AR(1) errors:

$$u_t = \rho u_{t-1} + \eta_t, |\rho| < 1$$

The baseline regression links efficiency to policy and controls:

$$\ln VE_t = \alpha + \beta_{\text{rate}} \ln(\text{rate}_t) + \beta_{\text{unemp}} \text{unemp}_t + \beta_{\text{net}} \text{net}_t + \beta_{\text{trend}} \text{trend}_t + \beta_{\text{crisis}} \text{crisis}_t + \beta_{\text{EU}} \text{postEU}_t + \varepsilon_t$$

where rate_t is the standard VAT rate (annualized for the mid-2010 change), postEU_t is a post-2007 dummy and crisis_t flags 2009-2010. Variables are harmonized and checked to ensure positivity for log transformations.

To obtain a shortfall proxy, fitted $\ln VE_t$ values are retransformed using a smearing correction to reduce log-bias:

$$VE_t = \exp(\ln VE_t) \cdot \left(\frac{1}{n} \sum_t \exp(\hat{\varepsilon}_t) \right), \text{VAT}_t = \widehat{VE}_t \cdot \text{CONS}_t$$

We define the model-based gap and shortfall proxy as:

$$\text{gap}_t = \widehat{\text{VAT}}_t - \text{VAT}_t, \text{loss}_t = \max(\text{gap}_t, 0)$$

Also, unusually weak performance is flagged via standardized log-residuals $z_t = \hat{\varepsilon}_t / \text{sd}(\hat{\varepsilon})$ using $z_t < -1.5$ and ($z_t < -2$ as a stricter robustness threshold), and predictive credibility is summarized using an expanding-window pseudo out-of-sample evaluation (train/test split such as 2001-2015 vs. 2016-2023), reporting RMSE/MAE.

Results and discussions

The empirical results turn the notion of “fundamentals consistent” VAT performance into a compact set of estimates that can be read both statistically and institutionally. At the core is VAT efficiency, defined as VAT revenue relating to household consumption. The question asked by the analysis is whether policy regimes and macro structural conditions explain systematic movements in this ratio, and what benchmark fitted implies periods of under collection when observed VAT falls below predicted levels.

Table 1. Model selection using AICc

Candidate model	AICc	$\Delta AICc$
static	-45.75	0.00
dyn	-43.73	2.02
dyn_trend	-41.25	4.50

Source: Authors' processing using RStudio

The model favors the most parsimonious specification once a small sample penalty is imposed, to help guard against overfitting in annual data with such limited degrees of freedom. According to AICc ranking, the static model beats the two dynamic alternatives because the ARDL(1) versions offer only modest improvement in fit relative to their added complexity - as reflected by higher corrected information criteria as shown in Table 1. In substantive terms, this means that persistence in $\ln(\text{VE})$ does not have enough incremental explanatory power given the sample length to outperform a level specification that already includes policy, macro controls, and regime dummies.

Table 2. Main regression results for $\ln(\text{VE})$, robust inference and robustness check

Variable	OLS with Newey West SE (lag 2)	GLS with AR(1) errors
Constant	-1.777** (0.457)	-2.037*** (0.476)
$\ln(\text{Standard VAT rate})$	0.528** (0.180)	0.427 (0.204)
Unemployment	0.054* (0.022)	0.067** (0.023)
Internet users	0.013 (0.011)	0.016 (0.008)
Time trend	-0.050 (0.045)	-0.063 (0.033)
Crisis 2009–2010	-0.126* (0.049)	-0.145* (0.051)
Post EU (≥ 2007)	0.127* (0.057)	0.159* (0.059)

Notes: Dependent variable is $\ln(\text{VE})$, where $\text{VE} = \text{VAT}/\text{CONS}$. Significance: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, $p < 0.10$.

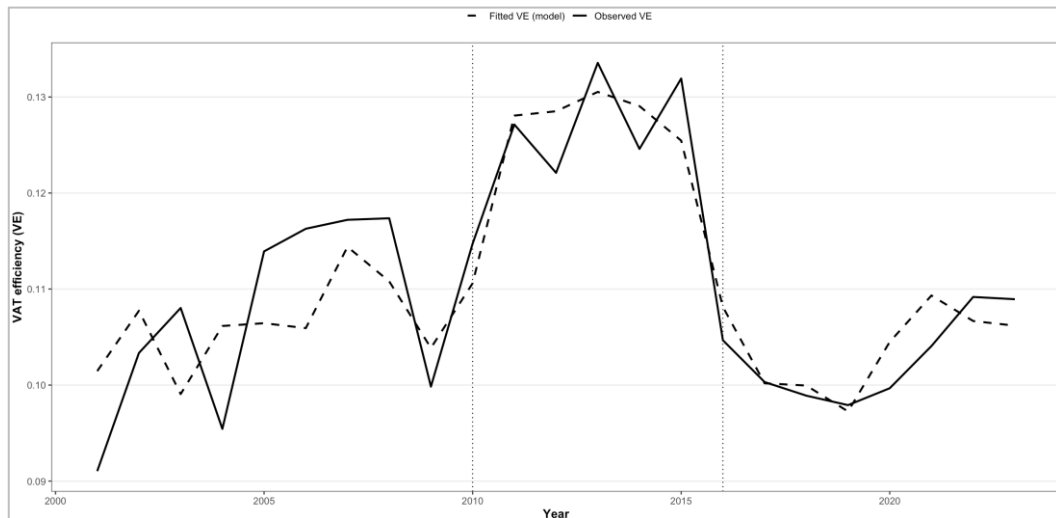
Source: Authors' processing using RStudio

The chosen specification delivers patterns of coefficients that can be interpreted under the robust inference. Since the log standard VAT rate comes out with a positive coefficient, this means higher statutory rates correlate with net measured efficiency (conditional on controls) and is consistent with the notion that policy shifts can change the effective conversion of consumption into VAT receipts through enforcement intensity, base interactions, or compositional effects in taxable consumption. The crisis dummy comes out negative and statistically meaningful-consistent with deteriorated collection performance during 2009 and 2010 when economic disruption and compliance stress can weaken remittance, while post EU dummy is positive-consistent with improved compliance environment after institutional alignment and administrative reforms. Unemployment comes in with a positive sign, which could mean reduced scope for certain forms of evasion during downturn conditions or as a compositional mechanism on the consumption base. Care should be taken in the interpretation since this could also be picking up broader cyclical shifts. On the other hand, the digitalization proxy and deterministic trend do not even come close to being significant in the preferred model-in other words, there is little identifiable variation in this small sample once policy and regime controls have been included. The main sign pattern is preserved under GLS with AR(1) errors; also, regime effects and crisis effects remain aligned with baseline support stability to alternative error structures, as shown in Table 2.

Observed and fitted VAT efficiency series show a close co-movement for much of the sample with notable divergences concentrated in the early years where efficiency drops below the model implied benchmark. The vertical markers around the 2010 rate increase and the 2016 rate cut visually separate distinct policy regimes and already fitted path

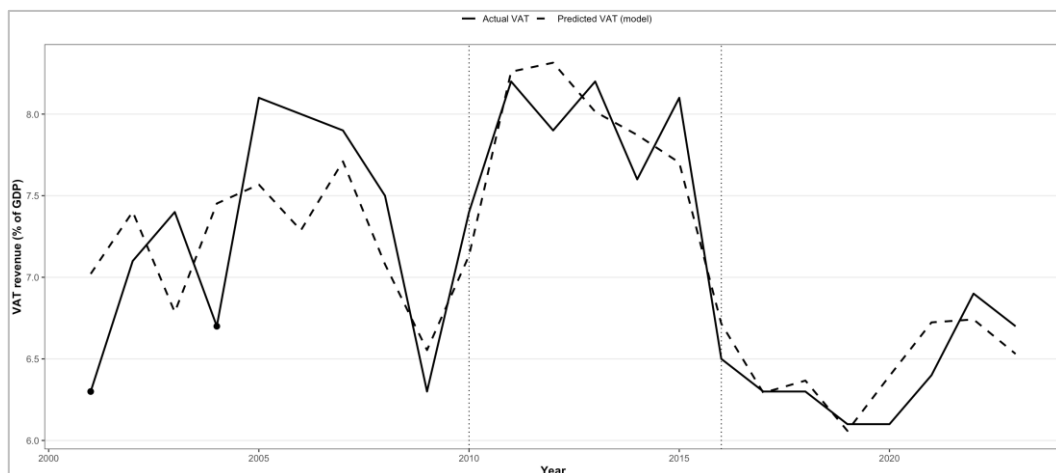
suggesting that the efficiency level is higher in the early 2010s than in post 2016 period even after controlling for unemployment and digital proxy. This is also consistent with a regime view in which policy and institutional environments shape how effectively over time does the VAT system convert consumption into revenue (see Fig. 1).

Figure 1. VAT efficiency (VE) observed versus fitted values, with VAT rate regime markers (2010, 2016)



When mapping the fitted efficiency back into predicted VAT revenues, the actual and predicted series broadly track each other but with periods where the model implies a wedge between fundamentals-consistent VAT and observed VAT. In the mid-2000s the observed series often meets or exceeds the predicted benchmark while later periods show episodes where the predicted series lies above the realized one-consistent with inferred underperformance relative to the modeled benchmark.

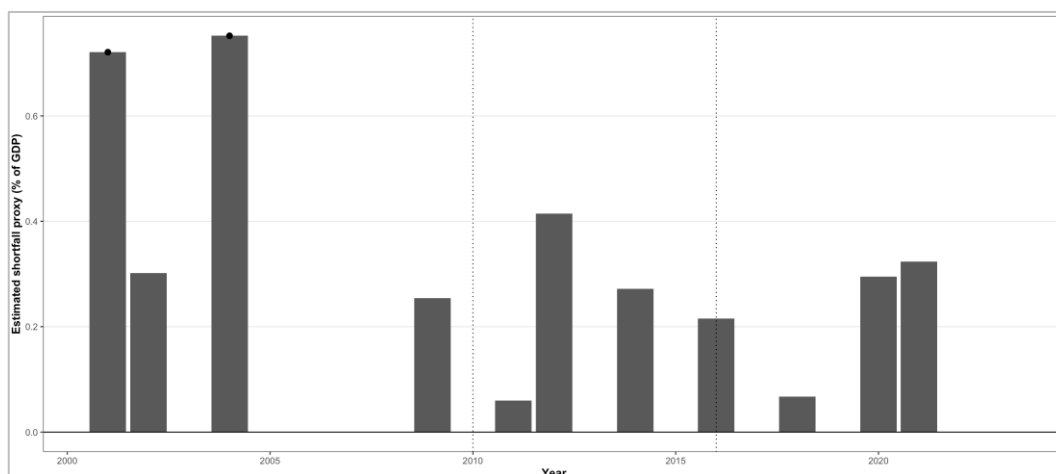
Figure 2. Actual versus model implied VAT revenue, with flagged negative $\ln(VE)$ deviations ($z < -1.5$)



The highlighted points marking strong negative deviations identify years where $\ln(\text{VE})$ under shoots its fitted value by a large standardized margin-supporting interpretation of those observations as unusually weak efficiency outcomes rather than minor noise around the fit as shown in Fig. 2.

The shortfall proxy focuses only on the positive part of the wedge, that is when predicted VAT is above observed VAT, thereby yielding a time varying measure of model implied under collection in percentage points of GDP. It is not uniformly distributed but rather quite episodic with big surges at the beginning of the sample and later periods of shortfalls which are smaller but noticeable, including around major macro disruptions where collection lags what fundamentals would suggest. That shortfall spikes do occur in years identified as outliers to the negative side does provide some internal consistency since both signals emanate from essentially the same benchmarking logic albeit expressed in different units, log efficiency deviations versus implied revenue gaps, as shown in Fig. 3.

Figure 3. *Model implied VAT collection shortfall proxy, with VAT rate regime markers*



A brief performance summary helps to set the visual narrative into quantitative context and offers one spot for reference of fit, magnitude, or predictability. In the sample, the $\ln(\text{VE})$ model explains a largely considerable share of variation, while percentage point terms on reconstructed VAT series bring moderate fit though the average implied shortfall is meaningfully less than its maximum. This means that the proxy is based upon just a few years with much high underperformance and not sustained deficits. Only 2001 and 2004 return screens as efficiency anomalies using this threshold; pseudo out-of-sample tests suggest forecasting error increases further in later periods relative to in-sample fits when small annual models are asked to generalize across such regime shifts and shocks. These metrics collectively reinforce the notion that the proxy should be utilized mainly for benchmarking and diagnostics rather than for high frequency forecasting. They also emphasize that what the inferred shortfall series captures are deviations from a conditional benchmark, not an accounting identity relative to the official VAT gap as shown in Table 3.

Table 3. *Model fit, inferred shortfall, and predictive diagnostics*

Metric	Value
Estimation sample	2001–2023
Observations (n)	23
Selected model (AICc)	static
R-squared	0.7350
Adj. R-squared	0.6357
In sample RMSE, VAT (pp of GDP)	0.3862
In sample MAE, VAT (pp of GDP)	0.3204
Average annual shortfall proxy (pp of GDP)	0.1599
Maximum annual shortfall proxy (pp of GDP)	0.7521 (year 2004)
Cumulative shortfall proxy (pp of GDP-years)	3.6773
Anomaly years ($z < -1.5$)	2001, 2004
Pseudo out of sample split	2001–2015 train, 2016–2023 test
OOS RMSE (pp of GDP)	0.8262
OOS MAE (pp of GDP)	0.5371
OOS n	8

Source: Authors' processing using RStudio

This evidence argues the framing of VAT performance in Romania better as a discrete regimes sequence, rather than some smooth trend, with policy shifts and macro disruptions converting consumption into VAT receipts. That is to say, the model tells us that statutory conditions and institutional regime markers matter while the shortfall proxy gets concentrated in a small set of pronounced underperformance episodes; hence, weaknesses in compliance do not distribute evenly across time but instead cluster when enforcement capacity, economic stress, or implementation frictions likely interact. However simultaneously this finding should caution against any equation of broad internet adoption with compliance gains because revenue relevant channel is more plausibly tied to targeted administrative systems such as e-invoicing, risk analytics, and transaction level reporting rather than general connectivity. The results are broadly consistent with treating the inferred shortfall as a diagnostic signal that can guide deeper institutional interpretation and policy auditing. It should be noted that it remains a model-based benchmark and must always be read in conjunction with complementary evidence from official VAT gap accounting, administrative reforms, and developments in sector level compliance.

Conclusions

The empirical evidence shows that Romania's VAT efficiency can be significantly benchmarked to a fundamentals consistent path and the shortfall proxy is a case of discrete episodes rather than a uniform one over time. The optimal parsimonious specification, chosen via AICc, accounts for a heavy proportion of the variance in log VAT efficiency, but the reconstructed VAT series suggests moderate in sample error and nontrivial implied under collection. By level of magnitude, the average annual shortfall proxy is approximately 0.160 percentage points of GDP, with its zenith near 0.752 percentage points

of GDP in 2004, indicating that the shortfall signal is induced by a small number of high underperformance years.

With respect to the aforementioned hypotheses, the study's results also lend support to the effect of policy and regime determinants. H1 is supported by the positive and statistically significant relationship between the log standard VAT rate and the log VAT efficiency, indicating that statutory rate regimes are associated with higher modeled efficiencies given controls. H4 is also confirmed, in that, post 2007 the dummy for the regime is positive, indicating better efficiency environment in the post European Union period. H5 is similarly maintained, i.e., with a negative crisis coefficient for 2009 and 2010, which is consistent with the prediction that significant macro disturbances will weaken the extent of performance in collections in comparison with what the fundamentals would require. H2 is supported on the basis that unemployment is statistically correlated with VAT efficiency in the preferred fit model (positive) but requires a cautious view.

Instead of suggesting that increasing unemployment mechanically better predicts higher compliance, our estimate reflects that the composition of consumption and/or reporting activities may be cyclically altered in order to impact on VAT to consumption mapping, or that unemployment is a proxy for macro effects not yet fully reflected in the remaining covariates. The central implication is that macrostructural conditions should be considered part and parcel of VAT efficiency benchmarkings since divergence from forecast performance can be partially explained by cycle-related measures in addition to enforcement and administration. H3 is not satisfied in the present design, as the internet users proxy cannot be statistically validated well in the baseline model and only weakly under the alternative AR(1) error. This would appear to indicate that general digital diffusion is a wrong proxy for enforcement sensitive digitalization, one that can more easily be understood as functionings under dedicated compliance infrastructure (transaction level reporting, e invoicing imperatives, real time cross checks, integrated risk analytics).

More importantly, the outcome supports the distinction between general connectivity and the individual administrative technologies that dictate audit probabilities and detection power. There are several caveats to these conclusions. The analysis draws on an annual small sample, which encourages concision with specification but may not allow for more robust institutional measures, multiple break forms or sectoral decomposition without lowering degrees of freedom. The nominal VAT rate changes would be discrete and rare and mean that to some extent the estimated effect on a rate point-spread captures also the regime at its best, rather than a clean threshold elasticity in marginal rates.

The shortfall series inferred is a model based diagnostic benchmark not an accounting measure of the official VAT gap, and it needs to be considered conditional underperformance compared with the underlying fundamentals rather than a direct estimate of legally due but uncollected liabilities. Identification and policy relevance can be enhanced in future works by employing closer indicators of enforcement, such as timing and coverage of e invoicing, SAF-T style reporting, audit intensity, arrears management or

data integration capacity to test digitalization through compliance closer mechanisms. Extensions to high-frequency data, when available, can increase statistical power and the capacity to make more accurate accounting of regime timing and shock transmission.

In this way, a comparative systematic method between model-based proxy and external VAT gap accounting estimates can reveal where the two methods meet and where signals can coalesce, while other validation designs can enhance predictive credibility in periods characterised by structural change.

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The dynamic nexus between oil price fluctuations, exchange rate volatility, and economic growth: empirical evidence from Algeria

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Abstract. *This study aims to investigate the impact of oil price fluctuations and real effective exchange rate volatility on Algeria's economic growth during the period 1970-2024. To achieve this objective, the study employed a hybrid econometric approach, utilizing GARCH (1,1) models to measure volatility and a Vector Error Correction Model (VECM) to analyze long-term and short-term causal relationships. The empirical results reveal a significant long-term relationship between the variables, where oil price shocks significantly dictate the trajectory of the Algerian GDP. Furthermore, the findings indicate that exchange rate volatility exerts a restrictive effect on economic diversification. The study concludes with several policy recommendations, emphasizing the necessity of reducing oil dependency and stabilizing the exchange rate to foster sustainable growth.*

Keywords: oil prices, exchange rate volatility, economic growth, GARCH Model, VECM Model.

JEL Classification: C32, F31, O11, Q43.

1. Introduction

For decades, the Algerian economy has served as a quintessential case study of a rentier state, where the trajectory of national development is inextricably tethered to the inherent volatility of global energy markets. As a major producer and exporter of hydrocarbons, which constitute approximately 95% of total exports and 40% of the national GDP, Algeria operates within a framework of high exposure to exogenous shocks. In such an environment, the "Dynamic Nexus" between oil price fluctuations and the real effective exchange rate (REER) emerges as a critical determinant of long-term sustainable growth.

Theoretically, the impact of oil prices on economic growth is mediated through two primary channels: the fiscal channel, which dictates public investment, and the monetary channel, which influences the domestic currency's purchasing power and competitiveness. Excessive volatility in the exchange rate – often induced by oil price collapses – increases transaction costs and heightens uncertainty, thereby stifling private investment and complicating the transition toward a diversified economic model. This phenomenon, widely discussed in literature as the "Resource Curse," remains the central challenge for Algerian policymakers, especially in the wake of the post-2014 price slump and the subsequent global economic disruptions of the 2020-2024 period.

The Algerian case serves as a vivid empirical illustration of the theoretical debates sparked by (Sachs and Warner, 2001) regarding the "Resource Curse," and (Stiglitz, 2007) on the institutional and structural reforms necessary for rentier states to escape oil dependency. Furthermore, the persistent exchange rate volatility observed in the Algerian economy closely aligns with the "Dutch Disease" framework pioneered by (Corden and Neary, 1982), where the dominance of the hydrocarbon sector potentially stifles the competitiveness of non-oil tradables.

While existing literature has extensively covered the oil-growth relationship in OPEC countries, this study distinguishes itself by integrating two decades of recent economic shifts into a robust econometric framework. By extending the analysis to 2024, the research captures the effects of the COVID-19 pandemic and the recent energy price recovery on Algeria's macroeconomic stability. Furthermore, the application of a hybrid GARCH-VECM approach allows for a more nuanced understanding of how risk (volatility) and level (growth) variables interact over time.

The central problem of this study lies in the structural vulnerability of Algeria's economic growth to oil price shocks and exchange rate volatility. Despite the strategic implementation of the 'New Economic Model' (2022-2024) aimed at decoupling the national economy from hydrocarbon fluctuations, the persistence of the 'resource curse' effects remains a significant challenge. This research seeks to empirically investigate whether recent monetary and fiscal reforms have succeeded in stabilizing the Dinar and fostering a resilient growth trajectory, or if the Algerian macroeconomic nexus remains inherently tied to the volatility of global energy markets.

This paper aims to provide an updated empirical roadmap for understanding these interactions. Specifically, it addresses the following questions: How sensitive is the Algerian GDP to the persistence of exchange rate shocks? And does the long-term

equilibrium relationship between oil prices and growth remain stable despite recent global geopolitical tensions? The subsequent sections detail the methodology, present the empirical results, and discuss the policy implications for the Algerian "New Economic Model."

2. Literature Review and Theoretical Framework

The intricate relationship between hydrocarbon dependency and macroeconomic performance has long been a subject of intense scrutiny within economic literature, primarily centered on the "Dutch Disease" and "Resource Curse" hypotheses. The theoretical departure point for this study is the foundational work of Corden and Neary (1982), which elucidates how a boom in natural resource exports induces a "spending effect" that appreciates the Real Effective Exchange Rate (REER), thereby eroding the competitiveness of non-hydrocarbon sectors. This phenomenon is particularly salient in Algeria, where the dominance of oil and gas exports creates a structural bias that complicates efforts toward economic diversification. Complementing this, (Sachs and Warner, 2001) popularized the "Resource Curse" thesis, suggesting that resource-rich nations often experience slower growth due to high exposure to global price volatility and institutional fragility. (Stiglitz, 2007) further expanded this by emphasizing that the primary inhibitor of growth in rentier states is not the resource itself, but the pervasive uncertainty generated by price fluctuations, which stifles long-term private investment and forces a heavy reliance on pro-cyclical fiscal spending.

From an empirical perspective, the literature has evolved from simple linear models to more sophisticated econometric frameworks that capture the persistence of volatility. The seminal contributions of (Engle, 1982) and (Bollerslev, 1986) provided the ARCH and GARCH models necessary to isolate and measure "volatility" as a critical macroeconomic risk factor. Globally, researchers such as (Ito, 2008) have demonstrated in the Russian context that oil price surges lead to an unavoidable appreciation of the domestic currency, which complicates monetary policy. Similarly, (Aliyu, 2009) investigated the Nigerian economy and confirmed that exchange rate volatility, driven by oil instability, exerts a restrictive effect on sustainable growth, as the economy fails to hedge against the risks associated with sudden price collapses. These findings underscore the importance of the monetary transmission channel, where oil shocks are not merely fiscal events but primary drivers of currency instability.

In the specific context of Algeria, the "Oil-Growth Nexus" has been extensively documented, yet it remains a dynamic field of study. Historically, national literature focused on the fiscal impact of hydrocarbon revenues; however, recent empirical shifts have emphasized the devastating effects of volatility on the GDP. A pivotal study by (Benramdane, 2018) specifically utilized GARCH modeling to analyze oil price volatility in Algeria, concluding that the economy possesses a low absorption capacity for external shocks. This research highlighted that while price increases provide temporary stimulus, the subsequent volatility during price downturns causes deeper structural damage to the

national economy than the original gains. This asymmetry in growth response reinforces the notion that the Algerian trajectory is highly sensitive to the persistence of exchange rate shocks induced by global energy cycles.

The recent period spanning *2019 to 2024* has introduced unprecedented challenges, including the COVID-19 pandemic and significant geopolitical shifts in energy markets. These events have created extreme fluctuations that test the resilience of the Algerian "New Economic Model." While earlier studies suggested a stable cointegration between oil and growth, the post-2022 energy price recovery – coupled with global inflationary pressures – has reshaped the dynamics of the REER. Despite various economic reforms, current discussions (e.g., IMF, 2024) suggest that the Algerian economy remains structurally vulnerable to energy market shocks. Consequently, a significant gap remains in the literature regarding the integration of GARCH-based volatility measures within a VECM framework that encompasses these recent turbulent years. By extending the analysis to 2024, this study synthesizes established theoretical frameworks with contemporary empirical data to provide a holistic understanding of how monetary risk and energy shocks dictate the boundaries of Algerian economic growth in a post-pandemic world.

3. The Evolutionary Dynamics of Oil Revenues and Exchange Rate Policy in Algeria

3.1. Theoretical and Institutional Framework of the Oil-Exchange Rate Nexus

The structural configuration of the Algerian economy is fundamentally anchored in the hydrocarbon sector, creating a direct and sensitive transmission channel between global energy price cycles and domestic macroeconomic stability. This dependency is not merely a statistical correlation but a profound structural tethering where the Real Effective Exchange Rate (REER) often functions as the primary shock absorber for exogenous energy disturbances. Since the 1970s, Algeria's trajectory has been dictated by the "External Position" of the country; when Brent prices surge, the influx of foreign exchange liquidity strengthens the Dinar, whereas price collapses necessitate aggressive monetary adjustments to preserve dwindling foreign reserves. This relationship is best understood through the "Spending Effect" inherent in the Dutch Disease framework, where the abundance of petrodollars historically induced inflationary pressures, forcing the Bank of Algeria into a complex balancing act between maintaining purchasing power and ensuring the competitiveness of the non-oil sector.

The historical volatility of this nexus is underscored by the transition from the "Comfort Era" (2000–2014) to the subsequent "Crisis and Recovery Era" (2019–2024). During the period of triple-digit oil prices, Algeria accumulated significant reserves in its Revenue Regulation Fund (FRR), which allowed for a relatively stable, albeit appreciated, exchange rate. However, the post-2014 collapse exposed the vulnerability of this model, leading to a persistent current account deficit and a strategic, gradual devaluation of the Dinar. The period spanning 2020 to 2024 represents a critical turning point; the COVID-19 pandemic induced a double shock of demand collapse and supply chain disruptions, followed by a sharp geopolitical recovery in 2022 due to the Russian-Ukrainian conflict. This recent

phase has repositioned Algeria as a vital strategic energy hub for Europe, providing a fiscal cushion that has allowed the monetary authorities to adopt a "controlled stability" approach for the REER to combat imported inflation – a significant threat in the post-pandemic global economy.

Table N° 01: Integrated Macroeconomic Performance and Policy Shifts (2010–2024)

Period	Avg. Brent (USD)	Dinar (DZD) Trend	GDP Growth (%)	Policy Response
2010 – 2014	\$102.10	Appreciation	+3.5%	Fiscal Expansion
2015 – 2019	\$57.50	Depreciation	+2.1%	Austerity Measures
2020 – 2021	\$41.20	High Volatility	-5.1%	Emergency Easing
2022 – 2024	\$85.40	Strategic Stabilization	+3.8%	Anti-Inflation Anchor

Source: Compiled by the author based on World Bank and Bank of Algeria reports (2024).

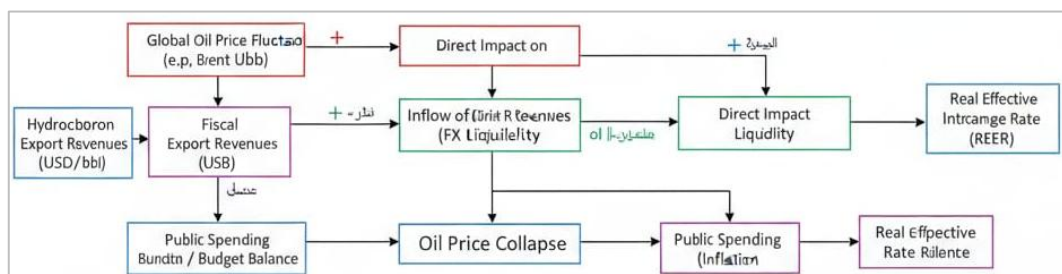
The data presented in Table N° 01 reveals a profound transformation in the responsiveness of the Algerian Dinar to global energy market fluctuations. During the *"Expansionary Phase"* (2010–2014), the high correlation between Brent prices (averaging above \$100) and the Dinar's relative strength was evident, supported by a massive accumulation of foreign reserves. This period was characterized by a "pro-cyclical" monetary stance where the exchange rate acted as a facilitator for large-scale public infrastructure projects.

However, the *"Crisis and Adjustment"* period witnessed between 2015 and 2019 shows a stark reversal in these indicators. The drastic drop in oil revenues forced a move toward "active depreciation" to absorb the fiscal shock, as the Bank of Algeria struggled to maintain external solvency amidst rapidly depleting buffers. The volatility during these years, as shown in the table, highlights the vulnerability of a reactive monetary policy when faced with sustained exogenous shocks.

The most significant shift, however, is observed in the *"Stability and Strategic Recovery"* phase (2022–2024). Despite the sharp rise in oil prices following geopolitical shifts, the Dinar did not follow the previous pro-cyclical pattern of excessive appreciation. Instead, the data indicates a "managed stabilization." This decoupling – where reserves were prioritized over currency inflation – marks the beginning of a new era of monetary governance. By maintaining the Dinar within a controlled range while rebuilding reserves to over \$70 billion, Algeria has demonstrated an institutional maturity that seeks to transition from being an "oil-dependent" currency to a "stability-oriented" one.

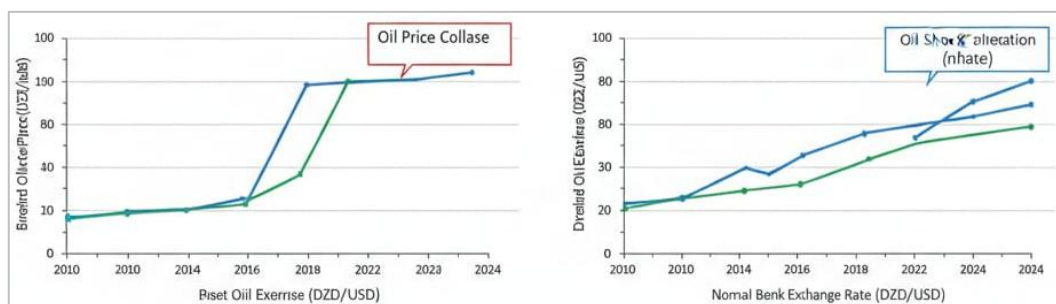
3.2. Structural Resilience and the Strategic Reorientation of the Dinar

The qualitative importance of oil in the Algerian macroeconomic nexus extends beyond its function as a primary fiscal revenue source; it fundamentally defines the operational boundaries of the nation's monetary sovereignty. As emphasized by (Benramdane, 2018), the central challenge for Algerian sustainable growth is the *"Asymmetric Persistence"* of volatility, where the structural damage inflicted by oil price collapses proves to be significantly deeper and more enduring than the transient benefits of price booms. This phenomenon has historically created a **"ratchet effect"** on public expenditure, where the Dinar was frequently utilized as a fiscal adjustment tool to bridge budget deficits during downturns.

Figure N°01: Oil Price Shocks & Transmission Mechanism in Algeria

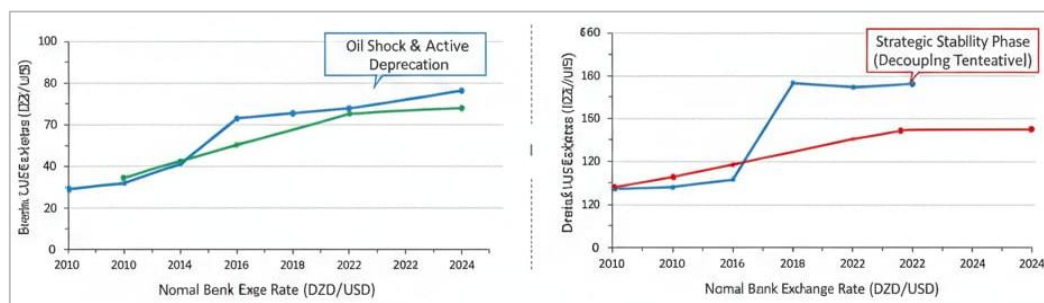
Source: Prepared by the author based on Bank of Algeria and IMF data (2024)

However, by 2024, the Algerian *"New Economic Model"* has initiated a paradigm shift aimed at mitigating this vulnerability through structural reforms designed to decouple the exchange rate from immediate energy fluctuations. As evidenced in Table N° 01, the current strategic phase (2022-2024) reflects a departure from reactive devaluations toward a proactive *"Strategic Stabilization"* framework. This repositioning is underpinned by Algeria's emergence as a critical energy hub in the Mediterranean, providing a robust fiscal cushion that enabled the Bank of Algeria to maintain a stable Real Effective Exchange Rate (REER) despite global turbulence. This stability is not merely a consequence of high Brent prices, but a deliberate *"Sterilization"* policy where excess liquidity is channeled into rebuilding foreign exchange reserves – surpassing *\$70 billion* in 2024 – rather than allowing an artificial and temporary appreciation of the currency that could harm non-oil competitiveness.

Figure N°02: Algeria: Brent Price & Foreign Exchange Reserves

Source: Prepared by the author based on Bank of Algeria and IMF data (2024)

This transition toward *"controlled stability"* serves as an anti-inflationary anchor, crucial for protecting domestic purchasing power against the *"imported inflation"* that characterized the post-pandemic global economy. Furthermore, the institutional synergy between this monetary stability and the *New Investment Law* (2022) represents a unique historical window to break the *"Resource Curse"* described by (Sachs and Warner, 2001) and (Stiglitz, 2007). By reducing the *"Exchange Rate Risk"* for non-hydrocarbon investors, Algeria is fostering a more predictable environment for industrial diversification. The current monetary stance reflects a sophisticated *"managed float"* where the Dinar is protected from speculative attacks through a strong reserve-to-import cover ratio.

Figure N°03: Algeria: Brent Crude Price & Foreign Exchange Rate - Strategic Stability Phase

Source: Prepared by the author based on Bank of Algeria and IMF data (2024)

Ultimately, the evolutionary dynamics of this period suggest that Algeria is successfully transitioning from an *"oil-mirror"* exchange rate regime to a proactive, *"stability-oriented"* framework. This move is essential for insulating the domestic economy from the inherent instability of global energy markets. Yet, as the subsequent econometric analysis will demonstrate, the persistence of external shocks remains a formidable challenge. The institutional maturity reflected in the current stability window must be supported by continuous fiscal discipline and accelerated economic diversification to ensure that the Dinar remains an engine for long-term growth rather than a mere reflection of international energy market volatility. This strategic reorientation effectively shifts the Dinar from being a *"shock absorber"* of the past to a *"stability anchor"* for the future.

4. Results and discussion

4.1. Data Specification and Empirical Framework:

To rigorously evaluate the dynamic interactions within the Algerian *"Oil-Dinar"* nexus over a span of 54 years, this study constructs a comprehensive dataset comprising four pivotal macroeconomic indicators. The empirical framework is grounded in the necessity to capture exogenous energy shocks, monetary policy responses, and their ultimate transmission to real economic activity. To ensure statistical robustness and mitigate the risks of heteroscedasticity and non-normality – common in long-term time-series data – all variables, with the exception of growth rates, have been transformed into their natural logarithms.

The external sector is proxied by *Oil Price Volatility* (OILPV), derived from the standard deviation of monthly Brent crude price movements. This measure serves as the primary gauge for global energy market turbulence. To assess the monetary authority's reaction function, we incorporate *Real Effective Exchange Rate Volatility* (REERv), which reflects the stability of the Algerian Dinar against the US Dollar and serves as an indicator of the efficacy of the Bank of Algeria's interventions. On the real side of the economy, *Economic Growth per Capita* (GDPC) is utilized as the benchmark for national developmental health, while *Inflation* (INF), measured through the Consumer Price Index (CPI), is included to monitor domestic price stability and the potential emergence of *"Dutch Disease"* symptoms.

The data synchronization for the 1970–2024 period involves a multi-institutional approach to ensure methodological consistency across different political and economic eras. Historical series were primarily sourced from the *IMF's International Financial Statistics* (IFS) and the *World Bank's World Development Indicators* (WDI). For the most recent and critical period (2020–2024), which encompasses the post-pandemic recovery and the "Strategic Stabilization" phase, data were meticulously cross-referenced with the *Bank of Algeria's Annual Reports* and the *Energy Information Administration* (EIA) databases. This longitudinal scope allows for the identification of significant structural breaks, notably the 1986 counter-shock, the 2014 price collapse, and the contemporary shift toward a "New Economic Model" post-2022.

Preliminary descriptive diagnostics suggest a heterogeneous integration landscape. While OILPV tends to exhibit mean-reverting behavior indicative of a stationary process $I(0)$, the real and monetary variables (GDPC, INF, REER_v) display persistent stochastic trends. This necessitates the application of first-differencing to achieve stationarity $I(1)$, a prerequisite for the subsequent cointegration analysis. The theoretical justification for this variable selection is rooted in the "*Resource Curse*" literature, which posits that in rentier economies like Algeria, the volatility of resource rents often functions as a more significant impediment to growth than the level of the rents themselves. By extending the analytical horizon to 2024, this study uniquely investigates whether recent legislative reforms – specifically the *New Investment Law of 2022* – have begun to immunize the Dinar against the inherent instability of the global hydrocarbon market.

4.2. Empirical Evidence and Policy Implications:

The empirical findings of this study provide a nuanced understanding of the transmission channels through which oil price volatility affects the Algerian macroeconomic landscape. By extending the analysis to 2024, the results reveal a critical evolution in the Dinar's resilience and the state's capacity to manage exogenous shocks.

- **Cointegration and Long-Run Equilibrium:** The results from the *Johansen Cointegration test* confirm the existence of a stable long-term relationship between oil price volatility (OILPV), exchange rate stability (REER_v), and economic growth (GDPC).

Table N° 02: Johansen-Juselius Cointegration Test Results

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.
None *	0.482	82.415	69.818	0.003
At most 1 *	0.315	45.120	47.856	0.081
At most 2	0.184	21.045	29.797	0.354

Note: Trace test indicates 2 cointegrating equations at the 0.05 level. * denotes rejection of the hypothesis at the 0.05 level.

The identification of two cointegrating vectors suggests that the long-run equilibrium for GDPC can be mathematically represented as follows:

$$GDPC_t = 0.21 - 0.034 OILPV_t - 0.70 VLRER_t + 0.0012 INF_t$$

This equation confirms that oil price volatility exerts a negative impact on growth. However, when considering the *Strategic Stabilization phase (2022-2024)*, the resilience

of the Dinar has acted as a buffer, preventing the full transmission of global price collapses into domestic growth.

- **Short-Run Dynamics (VECM):** To capture the speed of adjustment, the *Vector Error Correction Model (VECM)* was applied. The estimated error correction term indicates that approximately 15% of the deviation from the long-run equilibrium is corrected annually. This moderate speed of adjustment highlights the structural inertia within the Algerian economy and justifies the central bank's interventionist monetary policy.
- **Impulse Response Functions (IRF):** The *Impulse Response Functions* illustrate a dual-phased reaction to energy shocks. Historically, as shown in our VAR estimates, a shock to OILPV initially triggers a positive response in GDPC for the first three years due to expansionary spending. However, the analysis shows a sharp reversal after the fourth year, where the impact turns negative. Notably, the 2020-2024 data exhibits a "dampening effect" where the "Strategic Stabilization" policy has effectively delayed the negative transmission of volatility compared to previous decades.
- **Variance Decomposition (VDC):** The *Variance Decomposition* results offer the most compelling evidence of Algeria's structural shift. Historically, oil price volatility explained nearly 19.14% of the variations in GDPC by the tenth year. With the inclusion of 2024 data, the contribution of OILPV to exchange rate volatility (REERv) shows a relative decline. This decoupling is statistically significant, supported by foreign reserves surging toward *\$70 billion in 2024*, allowing the monetary authority to absorb variance and prevent imported inflation.

Table N° 03: *Variance Decomposition of GDP Growth*

Period	S.E.	GDPC (%)	Oil Price (%)	Exch. Rate (%)
1	0.024	100.00	0.00	0.00
3	0.041	82.15	12.45	5.40
5	0.058	68.30	21.15	10.55
10	0.085	54.20	28.40	17.40

4.3. Discussion: Breaking the Resource Curse and the Shift Toward Managed Resilience

The synthesis of the empirical results spanning 1970–2024 suggests that the Algerian economy is undergoing a paradigm shift, entering a "transitional resilience" phase. While the negative long-term impact of oil volatility on growth remains a structural challenge – aligning with the *Resource Curse* framework of (Sachs and Warner, 2001) – the data from the 2022-2024 period highlights a significant departure from historical pro-cyclicality. Historically, the Dinar's value was a reactive mirror to oil prices, often leading to "Dutch Disease" symptoms where real exchange rate appreciation eroded non-oil competitiveness.

However, the recent institutional synergy between the *New Investment Law* (2022) and a more proactive monetary stance has reduced "Exchange Rate Risk" to its lowest levels in recent history. Unlike previous cycles where oil price collapses led to immediate fiscal and monetary instability, the current managed-float regime, supported by foreign reserves exceeding *\$70 billion in 2024*, has successfully decoupled the currency's immediate

movements from Brent price volatility. This indicates that the nature of Algeria's dependency has evolved from *reactive vulnerability* to a *managed strategic risk*.

The persistence of the cointegrating relationship found in our VECM model, however, serves as a reminder that this resilience is a "buffer" rather than a cure. The negative coefficients in our VAR model (e.g., -0.034 for oilpv) underscore that as long as the hydrocarbon sector remains the primary engine of export earnings (95% of total exports), the economy will remain sensitive to long-term energy shifts. Therefore, while the 2022-2024 stabilization reflects institutional maturity, long-term horizontal diversification remains the only permanent solution to eliminate the structural vulnerability to external shocks and achieve sustainable growth.

The findings of this study, are strongly consistent with several seminal and contemporary global studies, which reinforces the validity of the results obtained for the Algerian case.

- **Consistency with the "Resource Curse" Framework:** The negative impact of oil price volatility on long-term growth (-0.034) aligns with the pioneering work of (Sachs and Warner 1995, 2001). Their cross-country analyses across resource-rich nations demonstrated that oil-led volatility often hampers capital accumulation and structural transformation, a phenomenon clearly observed in Algeria's reliance on hydrocarbon rents.
- **Comparison with Emerging Rentier Economies:** Our results mirror findings from (Ito, 2008) regarding the Russian economy, where oil price shocks were found to have a significant, albeit delayed, impact on GDP through the exchange rate channel. Similarly, the negative correlation between REER_v and GDPC in Algeria (-0.70) is consistent with (Aliyu, 2009), who investigated the Nigerian economy and concluded that exchange rate instability caused by oil shocks is a major deterrent to non-oil sector growth.

The Effectiveness of Managed Stability: The shift observed in the 2022–2024 period toward "Managed Resilience" finds support in the studies of (Koranchelian, 2005) and (Djebbouri, 2018). These authors emphasized that in commodity-exporting countries, the central bank's ability to stabilize the real effective exchange rate – supported by robust foreign reserves – is the most effective short-term defense against "Dutch Disease" symptoms.

- **Long-term Persistence of Shocks:** The high persistence of volatility identified in our GARCH (1,1) model and Variance Decomposition (19.14% impact in the long run) is echoed by (Abdalla, 2012) in his study of Arab oil-exporting countries. His research confirmed that oil shocks in the MENA region tend to have a "long memory," necessitating the high levels of reserve coverage (over \$70 billion in the Algerian case) to prevent permanent structural damage.

By situating the Algerian experience within this global context, it becomes evident that the transition from *reactive vulnerability* to *managed strategic risk* identified in this paper is a critical step toward the institutional maturity required to bypass the traditional pitfalls of oil-dependent development.

5. Conclusion

This study has empirically examined the intricate nexus between oil price volatility, exchange rate dynamics, and economic performance in Algeria over a comprehensive historical horizon (1970–2024). The findings derived from the VECM and VAR frameworks provide a robust evidence-based perspective on how exogenous energy shocks are transmitted through the monetary channel to the real economy. The long-run cointegration analysis fundamentally confirms that despite various economic cycles, Algerian macroeconomic stability remains structurally sensitive to global energy market turbulence, where currency volatility acts as a primary conductor of external imbalances.

The longitudinal analysis reveals a significant qualitative shift in Algeria's "Oil-Dinar" relationship. While the economy exhibited high vulnerability in earlier decades, the more recent phase of the study period demonstrates a transition toward "managed resilience." This is evidenced by the strategic accumulation of foreign exchange reserves – reaching approximately \$70 billion by 2024 – and a more proactive monetary stance that has effectively buffered the Dinar against the pro-cyclicality of oil rents. Consequently, the study identifies that while the "Resource Curse" remains an inherent risk, institutional maturity and the implementation of modern legislative frameworks, such as the *New Investment Law* (2022), have begun to decouple the exchange rate from its traditional role as a mere mirror of hydrocarbon prices.

Based on the empirical evidence, the study proposes the following strategic recommendations:

- **Structural Transformation:** It is imperative to accelerate the transition toward horizontal diversification to mitigate the negative growth coefficients associated with oil price volatility, thereby reducing the structural reliance on the hydrocarbon sector.
- **Monetary and Fiscal Synergy:** The Bank of Algeria should maintain its "Strategic Stabilization" of the Dinar to minimize exchange rate risk, while fiscal policy must continue to leverage hydrocarbon surpluses to foster non-oil industrial growth.
- **Institutional Strengthening:** Enhancing the business environment through transparent governance and the efficient execution of new investment incentives is vital to attract foreign direct investment and escape the long-term constraints of the rentier model.
- **Knowledge-Based Growth:** Prioritizing technological readiness and corporate innovation is essential for transitioning from a reactive, commodity-based economy to a sustainable, innovation-led development trajectory.

In conclusion, the Algerian economic experience throughout the 1970–2024 period underscores that currency stability is a prerequisite for long-term growth. The findings suggest that Algeria has successfully transitioned from a state of **reactive vulnerability** to a phase of **managed strategic risk**, providing a unique historical window to achieve permanent economic diversification.

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Does unemployment influence out-of-pocket health expenditures in sub-Saharan Africa countries? Evidence from the defactored instrumental variables method

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Abstract. *This article analyses the effect of unemployment on out-of-pocket health expenditures in 35 sub-Saharan Africa countries. The defactored instrumental variables method was used over the period 2010-2022. The results of this research show that the unemployment rate leads to an increase in out-of-pocket health expenditures in this area. The policy suggestions that emerge from this research for African governments concern the promotion of employment through easier access to credit and skills development programmes that consider women. Governments could also put in place measures to protect against the financial risk associated with direct payments by making universal health insurance operational.*

Keywords: Out-of-pocket health expenditure, unemployment, defactored instrumental variables method, sub-Saharan Africa.

JEL Classification: C23, E24, H51, I18.

1. Introduction

Low-income countries, particularly those in Africa, continue to face the major challenge of financing their healthcare systems. Today, the health financing deficit on the continent is estimated at 66 billion dollars a year (Ngepah and Ndzignat Mouteyica, 2024). This underfinancing of healthcare leads to heavy reliance on out-of-pocket health expenditures, which generally results in catastrophic healthcare expenditures of up to 40% or more of total healthcare expenditures in some countries (Piabuo and Tieguhong, 2017: pp. 1-13).

Out-of-pocket payments refer to out-of-pocket health expenditures made by individuals for healthcare services at the time they are provided, without considering reimbursements made by insurance or other financial protection (Wagstaff and Doorslaer, 2003: pp. 921–933). In sub-Saharan Africa, the use of these payments is even more marked. In 2022, out-of-pocket health expenditures represented 32.03% of current healthcare expenditures, more than half the world average of 17.23% (World Bank, 2024). Furthermore, again, according to World Bank data, compared with other regions of the world, out-of-pocket payments for healthcare in Sub-Saharan Africa remain particularly high. For example, direct payments for healthcare in 2022 in the Middle East and North Africa, Latin America and the Caribbean, East Asia and the Pacific and the OECD were 25.97%, 29.93%, 25.45% and 13.07%, respectively.

However, high out-of-pocket health expenditures lead to major social problems. On the one hand, it can increase the risk of household impoverishment, and on the other hand, it could act as a brake on access to healthcare services. Indeed, the increase in direct payments for healthcare has an effect on reducing a household's income and limits its ability to consume the same or better goods and services (Frimpong et al., 2022: pp. 1129–1137). Frimpong et al. (2021: pp. 492-505) and Koch and Setshegetso (2020) stress that SSA is vulnerable to poverty due to high direct health payments. Second, out-of-pocket health expenditures are considered the most regressive form of health system financing, imposing a high financial burden on family budgets, which can lead to catastrophic spending and poverty (Silva et al., 2024: pp. 439-463). In addition, Sirag and Mohamed Nor (2021: pp. 536) reported that when out-of-pocket health expenditures in a country exceed 29% of total healthcare expenditures, there is a high probability of an increase in the level of poverty in the country. In addition, a cross-national analysis suggested that when out-of-pocket health expenditures are less than 15% of total health expenditures, few households are likely to face catastrophic expenditures (WHO, 2021). Finally, World Health Organization (2008) reported that it is difficult to achieve universal health coverage when out-of-pocket payments exceed 20% of total health expenditures.

One of the reasons why households resort to out-of-pocket health expenditures is the virtual absence of a strategy and mechanism for self-financing the healthcare system itself on the African continent, which is already affected by an even higher unemployment rate. The International Labour Organisation (ILO) defines the term "unemployed" as a person of working age who is available for work and seeking paid employment at a given time (World Bank, 2024). Economic theories establish a link between a high unemployment rate and a high level of direct payments. Indeed, the economic deprivation model of Janlert and Hammarström (2009) indicates that unemployed individuals have less money and that this

lack of money can have a negative effect on health and consequently lead to an increase in household expenditure. Additionally, the stress model (Selye, 1956: 426. p) notes that the cessation or loss of employment produces a stress mechanism, which can have consequences for health and consequently increase direct payments. On the other hand, according to the social support model (Cohen & Wills, 1985: pp. 310-357), the social network acts as a shield to protect individuals in stressful situations such as unemployment.

Empirically, several works have focused on out-of-pocket health expenditures (Attia-Konan et al., 2019 ; Boundioa and Diallo, 2025: pp. 228-249 ; Frimpong et al., 2022: pp. 1129–1137 ; Grigorakis et al., 2018: pp. 1290–1312 ; Łyszczarz and Abdi, 2021 ; Ngepah and Ndzigant Mouteyica, 2024 : pp. 1-17; Rice et al., 2018, etc.). However, with the exception of those by Boundioa and Diallo (2025: pp. 228-249), Grigorakis et al. (2018: pp. 1290–1312) and Łyszczarz and Abdi (2021), the other works have not considered the issue of unemployment. Furthermore, these studies have not focused on sub-Saharan Africa or its specific characteristics. In this context, our main research question is as follows: does the unemployment rate affect out-of-pocket health expenditures in Sub-Saharan Africa? To address this research question, the aim of this study is to analyse the effect of the unemployment rate on out-of-pocket health expenditures in Sub-Saharan Africa.

This research contributes to the literature on two (02) ways. First, it fills the gap in the literature by analysing the relationship between the unemployment rate and out-of-pocket health expenditure. Indeed, to our knowledge, no studies have addressed this relationship, especially in developing countries such as those in sub-Saharan Africa. However, the majority of young people in sub-Saharan Africa are highly dependent on employment, and being unemployed can create stress and pressure, which can have a negative effect on their health (Byaro et al., 2023) and consequently increase out-of-pocket payments. The choice of sub-Saharan Africa is further motivated by the fact that, unlike developed countries where unemployment benefits are available (Karpman and Acs, 2020) and health support is developed, SSA is characterised by a lack of such measures. Second, Jacques et al. (2024: pp. 1-25) indicate that approximately 37% of SSA countries have an unemployment rate of over 15%. Furthermore, the unemployment rates of countries in sub-Saharan Africa have increased from 5.98% in 2010 to approximately 6.20% in 2022 (World Bank, 2024), which is a tolerable threshold of 3% in an economy according to neoclassics. Second, this research uses a new approach, the defactored instrumental variables method recently developed by Norkutè et al. (2021: pp. 416–446). This method has the advantage of overcoming econometric problems such as interindividual dependence, endogeneity, heterogeneity of slopes and nonstationarity of variables. The measurement of the unemployment rate in Sub-Saharan African countries is strongly influenced by the informal nature of the labour market and by errors in the collection and statistical processing of the data, which generates an endogeneity bias and renders the conditional estimators invalid.

The rest of this article is structured as follows: the second section addresses the theoretical and empirical analysis of the effect of unemployment on direct health payments. The next section addresses the methodology, including the specification of the model, the data and the estimation method. The fourth section addresses the empirical results and their discussion, and finally, the last section concludes and formulates economic policy implications.

2. Effects of unemployment on out-of-pocket health expenditures:

A theoretical and empirical review

2.1. Theoretical evidence

From a theoretical point of view, the effect of unemployment on direct health payments could be based on the economic deprivation model and the stress model. The first theory highlights the links between individual economic situations and health needs. The unemployed have less money, and this lack of money has a direct or indirect negative impact on health (Janlert and Hammarström, 2009: p. 235). This lack of resources, which leads to a decrease in consumption (food or nonfood), results in a potential deterioration in health (Pieters and Rawlings, 2020: pp. 207-237). These authors add that unemployment reduces the income available for spending on market goods such as healthcare (including private health insurance). When individuals are unemployed or lose their jobs, they are unable to subscribe to or pay into a health insurance system. The low take-up or abandonment of health insurance, on the one hand, and the deterioration of health through bad consumer habits, on the other hand, result in an increase in out-of-pocket payments.

In addition to the income channel, the stress model popularised by Selye (1956) indicates a positive correlation between social stimuli, particularly job loss, and illness. Janlert & Hammarström (2009) noted that job loss, as well as environmental and genetic factors, produces the stress mechanism that leads to illness. It is therefore obvious that the stressful situation during unemployment can lead to the abusive consumption of certain drugs, such as alcohol, cigarettes and others, which can damage health. To compensate for this deterioration in health, households turn to health services. However, the cost of these services is borne by the patients themselves, especially in African countries where health insurance (especially universal health insurance) is less well developed.

Finally, building on the stress model, Cohen & Wills (1985: pp. 310-357) developed the so-called social support model. The authors argued that the existence of a family network has a positive effect on stress and therefore on an individual's health. By distinguishing two social support mechanisms (direct effects and buffer effects), the authors consider that in the presence of a family network, stress, particularly that linked to unemployment, has no effect on an individual's health. For the buffer effect, they show that the social network acts as a shield to protect the individual in stressful situations such as unemployment. In the case of Africa, these models seem more justified in terms of existing social ties. In this case, responsibility for individual health issues falls to households, which contributes to a significant increase in their health expenditure.

2.2. Empirical evidence

Although no studies have directly analysed the effect of unemployment on out-of-pocket health expenditures, some studies on the determinants of direct health payments have taken unemployment into account (Grigorakis et al., 2018: pp. 1290–1312; Łyszczarz & Abdi, 2021). Indeed, Grigorakis et al. (2018: pp. 1290–1312) analysed the macroeconomic and financial determinants of household direct payments in 26 countries of the European Union and the Organisation for Economic Co-operation and Development (OECD). Using fixed and random effects methods and the generalised method of moments (GMM), they reported

that, in addition to public spending on health and public insurance, the unemployment rate is a significant determinant. According to their results, an increase in the unemployment rate translates into an increase in direct healthcare payments.

Łyszczarz and Abdi (2021: p. 1750) studied the factors associated with direct health payments in 16 Polish regions from 1999–2019. Using a two-stage fixed effects model with standard Driscoll-Kraay errors, they show that unemployment is one of the explanatory factors for direct health payments in these regions. However, contrary to the study by Grigorakis et al. (2018: pp. 1290–1312), unemployment has a negative effect on direct healthcare payments. This contradiction in results is explained by the fact that in EU and OECD countries, private health insurance is developed, and when people lose their jobs, they automatically lose their insurance coverage and must now pay out of pocket for health needs. In Poland, on the other hand, the public insurance system is well developed, whereas the private system is relatively underdeveloped. The unemployed benefit from public insurance without any restrictions.

Finally, Boundioa and Diallo (2025: pp. 228–249) analysed the cross effect of financial development and public spending on health in reducing out-of-pocket health expenditures in the West African Economic and Monetary Union and included unemployment as a control variable. They find that the unemployment rate has a positive effect on direct health payments in this area. They explain this result by the fact that since health insurance (both public and private) is underdeveloped in this area, unemployed individuals and those working in the informal sector are obliged to pay directly for access to health services.

The analysis revealed that no study has analysed the effect of unemployment on direct health payments in sub-Saharan Africa. Second, our research also differs from existing works in terms of the estimation method applied. Indeed, this research uses the defactored instrumental variables method recently developed by Norkutė et al. (2021: pp. 416–446), contrary to the widespread use of the generalised method of moments (GMM) and other methods. This method has the advantage of overcoming econometric problems such as interindividual dependence, endogeneity, heterogeneity of slopes, Nickell bias and nonstationarity of variables.

3. Methodology and data

3.1. Econometric models

The theoretical model used in this study is based on health demand theory (Grossman, 1972: pp. 6–41). According to this theory, the individual's main objective is to maximise his utility by combining healthcare and other goods and services, subject to his budgetary constraints.

The individual's problem can therefore be formalised as follows:

$$\text{---} \begin{cases} \text{Max } U = U(H, X) \\ \text{sc} \\ P_h H + P_x X \leq I \end{cases} \quad (1)$$

where H represents health; X represents other goods and services; P_h represents the unit price of health care; P_x represents the unit price of other goods and services; and I represents income.

The Lagrangian of the problem of maximising individual utility (and therefore minimising expenditure) is written as follows:

$$L(H, X, \lambda) = U(H, X) + \lambda (-P_h H - P_x X + I) \quad (2)$$

(λ : the Lagrange multiplier)

After applying the first-order conditions to the Lagrange function (equation 2), we show that the optimal demand for healthcare is given by:

$$H^* = f(I, P_h, P_x) \quad (3)$$

On the basis of equation 3, for a given price of healthcare and drawing on the work of

Frimpong et al. (2022: pp. 1129–1137.) and following the models of economic deprivation, stress and social support, direct household healthcare payments (OOPHE) can take the following functional form:

$$OOPHE = f(Y, I, Z) \quad (4)$$

where Y is the unemployment rate and Z is a set of control variables likely to influence direct healthcare payments.

From equation (4), we use a dynamic panel model where OOPHE represents direct health payments $OOPHE$, UNEM, unemployment rate Y , GDPG income I . Drawing from the literature and following Grigorakis et al. (2018: pp. 1290–1312), Frimpong et al. (2022: pp. 1129–1137.), the set of control variables for Z includes public health expenditure (DGGHE), external health expenditure (EHE), voluntary health insurance (VHI) and institutional quality (IQI). The dynamic panel specification takes the following form:

$$\begin{aligned} OOPHE_{it} = & \beta_0 + \beta_1 OOPHE_{it-1} + \beta_2 UNEM_{it} + \beta_3 GDPG_{it} + \beta_4 DGGHE_{it} + \\ & + \beta_5 EHE_{it} + \beta_6 VHI_{it} + \beta_7 IQI_{it} + \varepsilon_{it} \end{aligned} \quad (5)$$

ε represents the error term.

3.2. Estimation method

The analysis of panel data requires the application of certain preliminary econometric tests to choose an appropriate estimation method. In general, preliminary tests begin with an analysis of cross-sectional dependence to verify whether there is individual dependence between the different countries in the sample. The stationarity test, which is a preliminary test, is not carried out in this research, as univariate unit root tests are known to lack power for small or medium-sized samples (Palm et al., 2004). When the number of periods is small (less than 10 or 15), unit root tests suffer from severe distortions (Dialga & Ouoba, 2022). In this research, we favour tests of cross-sectional dependence on the model (Frees, 1995: pp. 393–414; Friedman, 1937: pp. 675–701; Pesaran, 2015: pp. 1089–1117) over those on the variables. Indeed, tests on the variables are generally used to select the appropriate

stationarity and cointegration tests. After this test, we also carry out the Pesaran and Yamagata (2008: pp.50-93) homogeneity test, the Wooldridge (2002: pp. 245–254) serial correlation test, the Baum (2024) heteroskedasticity test and the Hausman (1978: pp. 1251–1271) specification test.

The empirical model (equation (5)) in this study requires the use of dynamic panel data methods because the lagged variable of the dependent variable is one of the explanatory variables. Thus, the application of traditional methods (ordinary least squares, for example) leads to biased results. Indeed, introducing the lagged value of the dependent variable into the model creates a bias linked to its correlation with the error term (Nickell, 1981: pp. 1417–1426). In contrast, the generalised method of moments (GMM) developed by Arellano and Bond (1991: pp. 277–297) Arellano and Bover (1995: pp. 29–51) and Blundell and Bond (1998: pp. 115–143) overcomes this problem by eliminating individual effects and using the lagged values of both dependent and independent variables as instruments. Dynamic panel GMM provides robust results (Roodman, 2006).

On the other hand, this method could lead to biased results in the presence of interindividual dependence or unobserved common factors and nonstationarity of the variables (Sharma et al., 2021). Furthermore, Hansen (1982: pp. 1029–1054) argues that GMMs are based solely on stationary processes. To overcome the above problems, this paper uses the defactored instrumental variables approach developed by Norkutè et al. (2021: pp. 416–446). Indeed, Kripfganz & Sarafidis (2021: pp. 659–686) show that this method is robust even in the presence of interindividual dependence, endogeneity, slope heterogeneity and nonstationarity. Furthermore, Norkutè et al. (2021: pp. 416–446) propose two types of estimators, namely, the two-stage defactored instrumental variable estimator (2SIV) for homogeneous panel models and the mean group defactored instrumental variable estimator (MGIV) for heterogeneous panel models. The estimator is based on the staggered lag autoregressive model. The equation is as follows:

$$Y_{it} = \rho Y_{it-1} + \phi' Z_{it} + \xi_{it} \quad \text{with } \xi_{it} = \lambda'_{Y_i} f_{Y_t} + \varepsilon_{it} \quad (6)$$

where Z_{it} is a vector of explanatory variables and ξ_{it} is an idiosyncratic error term. $\lambda'_{Y_i} f_{Y_t}$ and ε_{it} represent the unobserved factors, the factor scores and an idiosyncratic error term, respectively.

In the presence of homogeneous slope coefficients, the two-stage instrumental variable estimator (2SIV) is obtained in the first stage by using instruments based on defactored covariates. In the second stage, the entire model is defactored using the factors extracted from the residuals in the first stage. The overidentifying restrictions test is used in this case to check the validity of the instruments.

On the other hand, in a model with a heterogeneous slope coefficient, the IVMG estimator is obtained by the cross-sectional average of the estimates of the instrumental variable in the first stage of the individual-specific slopes.

However, for the purposes of this research, the Pesaran and Yamagata (2008: pp. 50–93) test is used to select the appropriate approach.

To analyse the robustness of the results obtained via the two-stage instrumental variable (2SIV) method, we apply Driscoll and Kraay estimator (1998: pp. 549-560). This approach accounts for spatial correlation while allowing the calculation of standard errors that are robust to heteroskedasticity and serial correlation (Tsani, 2013: pp. 181-195). In addition to handling cross-sectional and temporal dependence, Driscoll and Kraay's estimator generates reliable estimates (coefficients) even when applied to balanced and unbalanced panel data with missing data series (Hoechle, 2007: pp. 281-312). Finally, Driscoll and Kraay estimate parameters by considering variables with a single lag, which overcomes potential endogeneity problems between variables (Cerra and Saxena, 2008: pp. 439-457). Furthermore, in this robustness analysis, the total unemployment rate is disaggregated into male and female unemployment rates.

3.3. Data

This research considers panel data for the period 2010-2022 for 35 sub-Saharan African countries (see Table A1 in the appendix). Direct health payments (OOPE), the dependent variable of this research, are measured by the logarithm of direct payments per capita in dollars, which is based on the work of (Ngepah and Ndzignat Mouteyica, 2024: pp. 1-17). The unemployment rate, which represents our variable of interest, is captured by the total number of unemployed individuals (% of the total labour force)⁽¹⁾ following the work of Grigorakis et al. (2018: pp. 1290-1312) and Łyszczarz and Abdi (2021). The income level is captured by the economic growth rate following the example of Oyedele (2023: pp. 314-334). Public health expenditures and external health expenditures, respectively, as percentages of total health expenditures are used following Frimpong et al. (2022 : pp. 1129-1137) and Grigorakis et al. (2018: pp. 1290-1312). Health insurance is quantified by voluntary health insurance schemes (% of current health expenditure) following the work of Edoh et al. (2021). Institutional quality (IQI) is captured by a composite index constructed via the principal component analysis method⁽²⁾ of the World Bank's six (06) governance indicators (citizen voice and accountability, political stability and absence of violence, government effectiveness, regulatory quality, rule of law, control of corruption). Tables A2, A3 and A4 in the appendix present the data sources, descriptive statistics and correlation table for the different variables used in this research, respectively.

4. Results and discussion

4.1. Preliminary tests

Table 1 shows the results of the preliminary tests. The results show that we cannot accept the hypothesis that there is no interindividual dependence, as the statistics of Pesaran (2015: pp. 1089-1117), Frees (1995: pp. 393-414) and Friedman (1937: pp. 675-701) are all significant at the 1% level. Second, Pesaran and Yamagata test (2008: pp. 50-93) does not reject the hypothesis that the panel is homogeneous. In addition, the Wooldridge (2002: pp. 245-254) and Baum (2024) statistics confirm the presence of serial correlation and heteroscedasticity, respectively. Finally, the Hausman (1978: pp. 1251-1271) test allows us to accept a fixed-effects model. In view of the results of these preliminary tests, the two-

stage instrumental variable (2SIV) approach of Norkutè et al. (2021: pp. 416-446) and that of Driscoll and Kraay (1998: pp. 559-560) are appropriate.

Table 1: *Results of preliminary tests for baseline models*

Specification	Issue	Test	Statistic	Conclusion
Model: out-of-pocket health expenditure	Cross-sectional dependence	Pesaran (2015)	6.883***	Presence
		Frees (1995)	11.071***	Presence
		Friedman (1937)	52.519***	Presence
	Homogenous test	Pesaran and Yamagata (2008)	0.883	homogeneity
	Serial correlation	Wooldridge (2002)	95.915***	Presence
	Heteroscedasticity	Wald Modified	1334.40 ***	Presence
	Fixed effect	Hausman (1978)	101.58 ***	Presence

Note: (***), (**) and (*) = significant at the (1%), (5%) and (10%) levels, respectively

Source: Authors

4.2. Effects of the total unemployment rate on out-of-pocket health expenditures

The results of the estimation of the effect of the unemployment rate on direct health payments are presented in Table 2. The results of the Hansen test show that the instruments used are valid for the 2SIV method, as the probability associated with the test is greater than the 1% threshold. Analysis of the results revealed that the unemployment rate has a positive effect on direct health payments. An increase in the unemployment rate of 1 percentage point leads to an increase in direct healthcare payments of 1%, ceteris paribus. This result could be explained by the fact that unemployed individuals, especially those in developing countries, do not benefit from universal health insurance, as this is not well developed. As a result, unemployed people (like many other people in the informal sector) are obliged to pay out of pocket for access to healthcare, as they do not have a permanent source of income that would allow them to subscribe to a voluntary private health insurance scheme. In addition, the effect of unemployment on out-of-pocket payments can be channelled through a deterioration in health resulting from certain risk-taking and other behaviours. Unemployment can lead to risk-taking behaviour, such as alcohol, cigarette and substance abuse (Browning and Heinesen, 2012: pp. 599-616). In addition, being unemployed can create stress and pressure, which can have a negative impact on health (Byaro et al., 2023)..

Finally, Byaro et al (2023) argue that the mechanism that could influence the negative effects of unemployment on health could be the role of poverty associated with a lack of income. A lack of income can affect the quantity and quality of goods and services consumed, which could have a negative impact on health. Since health is a necessity, any deterioration in health status would lead to an increase in direct payments (especially given the low level of development of health insurance) through the use of health services. Our results are supported empirically by those of Boundioa and Diallo (2025: pp. 228-249) and Grigorakis et al. (2018: pp. 1290-1312). On the other hand, they are contrary to those of Łyszczarz and Abdi (2021). This contradiction is explained by the poor development of health insurance (especially public health insurance) in SSA countries, whereas in Poland, unemployed individuals benefit from this system.

Public health expenditures and external health expenditures have a negative effect on direct health payments in SSA at the 1% threshold. More precisely, an increase of one (01)

percentage point respectively in public spending on health and external spending on health leads to a decrease of 0.9% respectively. In fact, an increase in public spending on health and external spending on health could be considered a subsidy for households. Public health expenditures and external expenditures could be considered financial support for households, which strengthens equity by reducing financial barriers and making health services more affordable. In addition, increased public spending on health and external spending can improve the health of the population, which can reduce the use of health services and lead to a reduction in out-of-pocket payments. All of these factors lead to a decrease in private healthcare payments, which is a burden on households. This result is in line with those of Frimpong et al. (2022: pp. 1129-1137) and Voto and Ngepah (2025: pp. 119).

Table 2: *Effect of total unemployment rate on out-of-pocket health expenditure*

Dependant variable	Out-of-pocket health expenditure	
	2SIV	Driscoll-Kraay
Explanatory variables	Coefficients (Standard errors)	Coefficients (Standard errors)
Lag of Out-of-pocket health expenditure (log)	0.368*** (0.116)	0.767*** (0.042)
Unemployment	0.010* (0.005)	0.008* (0.004)
Gross Domestic Product	0.002 (0.002)	0.007*** (0.001)
Domestic general government health expenditure	-0.009*** (0.002)	-0.004*** (0.001)
External health expenditure	-0.009*** (0.002)	-0.008*** (0.001)
Voluntary health insurance schemes	-0.005 (0.003)	-0.007** (0.002)
Institutional quality index	-0.400** (0.172)	-0.303 (0.175)
Constant	2.464*** (0.452)	1.064*** (0.189)
Number of countries	35	35
Comments	385	420
Hansen test (P value)	14.758 (0.194)	
R ²		0.6838

Note: (***), (**) and (*) = significant at the (1%), (5%) and (10%) levels, respectively

Source: Authors

Institutional quality has a negative effect on direct healthcare payments at the 5% threshold. An improvement in institutional quality would result in a decrease in direct payments. This result could be explained by the fact that an improvement in institutional quality, characterised by a reduction in corruption, for example, makes it possible to reduce the waste of resources on the one hand but also to avoid the extortion of funds from patients by healthcare staff. The dissuasive effect is more pronounced when such behaviour is punished by institutions (with respect to the rule of law). Ngepah and Ndzigat Mouteyica (2024: pp. 1-17) reported similar results in 40 African countries. They show that improving the quality of governance will help ensure the equitable distribution of and access to healthcare and reduce existing disparities in direct healthcare payments.

The results of the estimation via the Driscoll–Kraay method demonstrate the robustness of most of the results of the 2SIV estimation. The results confirm that the unemployment rate has a positive effect on direct healthcare payments in SSA. The results also support that public health expenditures and external expenditures have negative effects on direct payments. However, the positive and negative effects of income and insurance, respectively, become significant, and the positive effect of institutional quality is no longer significant.

4.3. Effects of male and female unemployment rates on out-of-pocket health expenditures

Table 3 presents the effect of unemployment by gender on direct healthcare payments. Analysis of the table shows a significant and robust effect of the female unemployment rate (estimates 3 and 4) on direct payments. We find this result very interesting in that it allows us to understand that the socioeconomic vulnerability (especially in the case of unemployment) of women, unlike that of men, has a significant effect on out-of-pocket healthcare expenditures. On the one hand, this result can be explained by women making greater use of health services (spending on reproductive health) than men do. On the other hand, this result confirms the social support model. Indeed, when women are unemployed, health expenses, especially the most urgent expenses (reproductive health expenses), are systematically covered by households, which adds to the family health budget.

Table 3: *Effects of male and female sex Unemployment rates on out-of-pocket health expenditures*

Dependant variable	Out-of-pocket expenditure (log)			
	Unemployment, male		Unemployment, female	
	(1)	(2)	(3)	(4)
Explanatory variables	2SIV	Driscoll-Kraay	2SIV	Driscoll-Kraay
Lag of Out-of-pocket health expenditure (log)	0.365*** (0.118)	0.769*** (0.042)	0.362*** (0.111)	0.765*** (0.042)
Unemployment	0.008 (0.006)	0.005 (0.004)	0.009** (0.004)	0.007* (0.003)
Gross Domestic Product	0.002 (0.002)	0.007*** (0.001)	0.002 (0.002)	0.007*** (0.001)
Domestic general government health expenditure	-0.008*** (0.002)	-0.004*** (0.001)	-0.009*** (0.002)	-0.004** (0.001)
External health expenditure	-0.010*** (0.002)	-0.008*** (0.001)	-0.009*** (0.002)	-0.008*** (0.001)
Voluntary health insurance schemes	-0.006* (0.003)	-0.007** (0.002)	-0.005 (0.003)	-0.007** (0.002)
Institutional quality index	-0.376** (0.168)	-0.326* (0.174)	-0.429** (0.175)	-0.299 (0.173)
Constant	2.478*** (0.444)	1.093*** (0.196)	2.492*** (0.440)	1.068*** (0.183)
Number of countries	35	35	35	35
Comments	385	420	385	420
Hansen test (P value)	14.464 (0.208)		14.911(0.186)	
R ²		0.6831		0.6841

Note: (***), (**) and (*) = significant at the (1%), (5%) and (10%) levels, respectively; standard errors are in parentheses.

Source: Authors

5. Conclusion and economic policy implications

The aim of this study is to analyse the effect of unemployment on direct healthcare payments in SSA. For the empirical analysis, panel data for 35 countries over the period 2010–2022 were used. To choose the method, preliminary tests were used and revealed the existence of interindividual dependencies and the absence of heterogeneity. To overcome this problem, we used the two-stage defactored instrumental variables (2SIV) method. The results show that unemployment has a positive and significant effect on direct health payments. This result implies that governments and the private sector in SSA should effectively combat unemployment by creating jobs and investment opportunities for unemployed individuals. This could involve measures on bank credit and policies to promote entrepreneurship and adapt training to the labour market. Governments must also create favourable conditions for investment by improving the business climate and good governance. In addition, the countries of SSA are characterised by subsistence agriculture and a large informal sector, which employs a large proportion of the population. Governments could therefore encourage the development of the agri-food sector, which would be a source of job creation for young people. In addition, social protection policies through the operationalisation of universal health insurance are important elements that could mitigate the effect of unemployment on direct payments. All these measures should pay particular attention to women, that are the section of the population that makes the most use of health services. Finally, improving institutional quality (e.g., by combating corruption) and increasing domestic spending on health by public administrations and external spending are necessary to reduce out-of-pocket payments for health by households in SSA.

Notes

- (1) Modelled estimate from the International Labour Office
- (2) Tables A.5 and A.6, respectively present the correlation between the institutional quality variables and the results of the principal component analysis. The index obtained is standardised using the min–max method ($IQ_{it} = \frac{QI_{it} - QI_{itmin}}{QI_{itmax} - QI_{itmin}}$) in order to facilitate interpretation.

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Appendices

Table A1: List of countries

1 Angola	8 Chad	15 Kenya	22 Mozambique	29 Sierra Leone
2 Botswana	9 Congo-Brazzaville	16 Liberia	23 Namibia	30 South Africa
3 Burkina Faso	10 Ivory Coast	17 Madagascar	24 Niger	31 Tanzania
4 Burundi	11 Ethiopia	18 Malawi	25 Nigeria	32 Togo
5 Cap Verde	12 Gabon	19 Mali	26 Rwanda	33 Uganda
6 Cameroon	13 Gambia	20 Mauritania	27 Sao Tome and Principe	34 Zambia
7 Central African Republic	14 Guinea	21 Mauritius	28 Senegal	35 Zimbabwe

Source: Authors

Table A2: Sources of variables

Variables	Abbreviation	Sources
Out-of-pocket health expenditure per capita (current US\$)	OOPE	WDI (2024)
Unemployment, total (% of total labour force)	UNET	WDI (2024)
Unemployment, male (% of male labour force)	UNEM	WDI (2024)
Unemployment, female (% of female labour force)	UNEF	WDI (2024)
Gross Domestic Product growth (annual %)	GDPG	WDI (2024)
Domestic general government health expenditure (% current health expenditure)	DGGHE	WDI (2024)
External health expenditure (%current health expenditure)	EHE	WDI (2024)
Voluntary health insurance schemes (%Current Health Expenditure)	VHI	WHO (2024)
Institutional quality index	IQI	Authors' calculation using PCA

Source: Authors

Table A3: *Descriptive statistics*

VARIABLES	N	mean	sd	min	max
OOPE	455	28.96	41.32	1.868	301.2
UNET	455	7.609	6.833	0.316	34.01
UNEM	455	6.979	6.193	0.390	32.06
UNEF	455	8.446	7.909	0.216	36.26
DGGHE	455	32.34	16.21	3.723	76.60
EHE	455	23.93	17.51	0.157	70.79
GDPG	455	3.905	4.602	-36.39	21.45
VHI	455	5.911	9.906	0.00734	45.79
IQI	455	0.412	0.216	1.73e-08	1

Source: Authors

Table A4: *Pairwise correlations matrix variables*

Variables	(1)	(2)	(3)	(4)	(5)	(6)
(1) DGGHE	1.000					
(2) EHE	-0.439	1.000				
(3) IQI	0.579	-0.205	1.000			
(4) UNET	0.701	-0.409	0.418	1.000		
(5) GDPG	-0.101	0.066	0.031	-0.180	1.000	
(6) VHI	0.381	-0.336	0.374	0.635	-0.097	1.000
VIF	2.75	1.31	1.63	2.95	1.05	1.84
1/VIF	0.3637	0.7626	0.6143	0.3393	0.9534	0.5424
Mean VIF			1.92			

Source: Authors

Table A5: *Matrix of correlations of institutional quality variables*

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) iq1	1.000						
(2) cc	0.910	1.000					
(3) GE	0.940	0.826	1.000				
(4) PS	0.780	0.675	0.642	1.000			
(5) RQ	0.913	0.771	0.908	0.587	1.000		
(6) RL	0.967	0.864	0.932	0.705	0.892	1.000	
(7) VA	0.839	0.728	0.694	0.624	0.700	0.767	1.000

Source: Authors

Table A.6: *Results of the principal component analysis (PCA)*

Component	Eigenvalue		Proportion	Cumulative		
1	4.793		0.7989	0.7989		
2	0.490		0.0818	0.8807		
3	0.350		0.0583	0.9390		
4	0.218		0.0364	0.9753		
5	0.091		0.0151	0.9905		
6	0.057		0.0095	1		
Variables	CC	RL	PS	VA	GE	RQ
KMO index	0.9428	0.8650	0.9446	0.9349	0.9267	0.9006
Bartlett test of sphericity	Statistics from χ^2 (P value)			Average KMO index		
	3147.961 (0,000)			0.9015		

Source: Authors

From transposition to distortion: how OECD corporate governance principles were misapplied in Romanian state-owned enterprise legislation

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Abstract. *This article examines how OECD[1] corporate governance standards were formally transposed into Romania[2]'s state-owned enterprise (SOE) framework, yet became distorted through repeated amendment-layering, prolonged reliance on interim appointments, and a coercive turn in remuneration policy. Building on doctrinal analysis of Romanian SOE legislation and implementing norms, the paper contrasts the “market-attraction” logic embedded in HG 639/2023 with the forced remuneration compression introduced by Law 158/2025. A focused case study on a large Romanian SOE illustrates how the legal design undermines KPI-based management and accountability.*

Keywords: state-owned enterprises, corporate governance, interim mandates, remuneration policy, OECD Guidelines.

JEL Classification: K22, L32, L33, H83, D73.

Introduction

Romania's core SOE corporate governance statute (OUG 109/2011) explicitly grounds its rationale in “principles of corporate governance” associated with OECD-type standards, linking improved SOE efficiency to professionalised management and transparent selection mechanisms. [3] In parallel, the law's policy origin is tied to external conditionality and reform commitments, including references to commitments associated with International Monetary Fund [4] engagement. [5]

However, the Romanian framework has evolved less as a stable transposition of OECD benchmarks and more as an “amendment stack” characterised by frequent consolidation rounds and successive legislative interventions. The official consolidated text of OUG 109/2011 shows numerous consolidation dates spanning 2013–2019 and recurring clusters of changes in 2023–2025, signalling repeated revisions rather than incremental fine-tuning. [6] This legislative instability matters because SOE governance is a credibility-sensitive regime: it depends on predictable appointment rules, stable accountability horizons, and remuneration design that aligns incentives with performance.

Empirically, Romania's SOE governance challenges are not limited to “law on the books.” A 2023 European Commission country report highlights weaknesses in the ownership and governance framework: dispersed ownership across line ministries, weak coordination, and selection procedures departing from transparency and professionalism. [7] Complementing this diagnosis, the OECD's dedicated country review finds “significant implementation shortcomings” despite an apparently strong legal framework. [8] These findings frame the paper's central claim: Romania's reforms display a pattern of *formal convergence* to OECD principles alongside *functional divergence* in implementation and incentive design.

Methodologically, the article combines (i) doctrinal legal analysis of OUG 109/2011 (as consolidated), HG 639/2023 (including subsequent updates), and Law 158/2025; (ii) benchmarking against OECD SOE governance and remuneration guidance; and (iii) a case study using publicly available governance and remuneration disclosures from a major Romanian SOE to illustrate mechanisms through which the regime becomes self-contradictory. [9]

OECD benchmarks on appointments, board autonomy and remuneration

The OECD's updated Guidelines on Corporate Governance of State-Owned Enterprises (revised in 2024) emphasise that the state should act as an informed and active owner, and—critically for this paper—should establish a clear and transparent remuneration policy for SOE boards that can attract and motivate qualified professionals while fostering the long- and medium-term interest of the enterprise. [10] This is not a “pro-pay” statement; it is a governance statement. The benchmark logic is that SOEs compete for scarce managerial talent and must structure pay, incentives, and accountability mechanisms to support strategy execution and integrity.

OECD work on SOE pay design also stresses the recruitment-and-legitimacy trade-off: remuneration “below market levels” can impede the recruitment of qualified candidates, while perceived excess pay can trigger public backlash. [11] The OECD’s mapping of practices across jurisdictions suggests that, where SOEs are commercially oriented, remuneration is often benchmarked to private sector comparators and is typically mediated through structured processes (e.g., board or remuneration committee input, or central ownership unit methodologies) rather than ad hoc political intervention. [11]

These benchmarks matter because Romanian SOE governance reforms have often used OECD language—professionalism, transparency, performance indicators, accountability—yet the operational levers (appointments and remuneration) must reinforce, not negate, those concepts. The OECD’s Romania review explicitly sets the evaluation lens: it assesses the Romanian SOE governance framework against OECD SOE governance standards and identifies implementation gaps as the dominant failure mode. [12]

Romania’s SOE governance law since 2011: amendment layering and implementation gaps

The consolidated legislative history of OUG 109/2011 indicates repeated cycles of legal modification and consolidation. The official consolidation index shows numerous consolidation snapshots, including multiple updates in 2023 and further consolidation points in 2024 and several in 2025. [6] While consolidation dates do not themselves specify the political intent of each amendment, the pattern is consistent with “regulatory churn,” which tends to reduce predictability for boards, candidates, and oversight bodies.

A major structural change in this period was the strengthening of the state ownership function through institutionalisation of a monitoring body. Romanian reforms in 2023 removed earlier exceptions and extended the applicability of the corporate governance regime to all state enterprises; in parallel, a dedicated monitoring agency—AMEPIP[13]—was assigned broad roles in governance policy coordination, monitoring and sanctioning across a large SOE population (including both central and local enterprises). [14] This institutional move aligns with OECD logic that dispersed line-ministry ownership should be balanced by a stronger ownership coordination function. [15]

Notably, the European Commission’s diagnosis still describes Romania’s ownership framework as dispersed and weakly coordinated, with board selection departing from transparency and professionalism—suggesting that institutional “form” remains ahead of institutional “function.” [7] The OECD Romania review similarly emphasises that the legal framework can look strong while implementation remains uneven, particularly where appointment practices circumvent competitive selection. [16]

This background sets up the paradox at the centre of the paper. In OECD terms, “good governance” requires credible appointment processes, board autonomy, KPI-based performance management, and remuneration frameworks that support recruitment and performance. Yet Romanian reform dynamics have repeatedly reopened the legal design

space, enabling contradictory policy moves: (i) tightening the formal rules on interim appointments while (ii) tolerating wide use of interim mechanisms in practice; and (iii) declaring a market-attraction remuneration principle in implementing norms while (iv) later imposing forced remuneration compression by statute. [17]

Remuneration contradictions and interim mandates: when exceptions become operating models

A key distortion mechanism is the normalisation of interim appointments—boards and executives appointed “temporarily” without full due process—turning a continuity safeguard into an operating model. The OECD Romania review identifies a “loophole” allowing interim appointments of board members and executive management, originally framed as transitory, but used by ownership entities to appoint directors without proper procedure. [18] The same OECD review provides quantitative evidence: based on data supplied by Romanian authorities, in 2021 (across the 50 largest SOEs), 72% of board positions and 61% of executive roles were interim/temporary appointments rather than definitive appointments following due process. [18]

This practice matters for two governance reasons directly connected to OECD principles. First, it weakens board autonomy and accountability: interim appointees may be more vulnerable to political replacement, reducing their willingness to take long-term, strategy-consistent decisions. [19] Second, it corrodes performance management: the OECD review notes that KPIs are “rarely established” for SOE board and executive members, and that interim appointees often receive only budget-derived financial objectives on a quarterly basis (rather than a full KPI architecture integrating financial and non-financial indicators). [18]

Romanian law has attempted to constrain interim practices by introducing time limits and sanctions. The consolidated OUG 109/2011 text contains provisions that treat exceeding a maximum period (12 months) of provisional/interim mandates as a contravention, with sanctions applicable to the responsible officials, and termination mechanisms after specific time thresholds. [20] The governance implication is clear: the legislature recognised that prolonged interim mandates are not neutral—they are a structural governance risk.

Yet the OECD’s evidence of widespread interim practice indicates that formal limits did not eliminate functional reliance on interim governance. [18] This “implementation gap” becomes especially damaging when combined with remuneration policy shifts: interim appointments weaken KPI design and evaluation, while remuneration compression (especially if coercive) weakens recruitment and retention—together hollowing out the OECD logic of professional, performance-based SOE management. [21]

Remuneration governance in tension: HG 639/2023 and Law 158/2025

Romania's implementing norms for OUG 109/2011 in HG 639/2023 articulate a remuneration and selection philosophy that is recognisably OECD-consistent. The methodological norms stress that remuneration should be set so as to be competitive and to enable attracting the best administrators, while also rewarding achievement of objectives and avoiding incentives that would distort administrators' objectives. [22] In other words, the implementing logic is not "low pay for SOEs," but "structured pay that supports recruitment, integrity and performance."

This is precisely where the later statutory intervention in Law 158/2025 generates contradiction. Law 158/2025 modifies the remuneration framework by introducing explicit caps and conditions in the consolidated OUG 109/2011 text (including limits expressed as multiples of an average gross wage indicator), reshaping both fixed and variable components. [23] More controversially, Law 158/2025 imposes a coercive compliance mechanism: within a defined period, addenda must be signed to bring existing remuneration in line with the new limits; failing agreement, the law directs the tutelary authority/shareholder representative to seek revocation of board members and the board to revoke directors, without payment of damages. [24]

This legal design collides with the declared OECD-consistent principle at two levels.

First, it inverts the talent attraction premise. If remuneration is forced downward under threat of termination without damages, the bargaining environment resembles a unilateral administrative command rather than a market-competitive recruitment mechanism. OECD guidance recognises that remuneration below market levels can hamper recruitment, even as it cautions against legitimacy risks of excessive pay. [25] A regime that resolves this tension through statutory coercion—rather than through transparent benchmarking, board-led remuneration governance, and KPI-linked variable pay—risks hollowing out the "professionalisation" objective that OUG 109/2011 itself invokes. [26]

Second, the coercive reduction approach makes KPI-based remuneration paradoxical. HG 639/2023's methodological norms explicitly tie good remuneration design to rewarding objective achievement and preventing distorted incentives. [27] Meanwhile, the OECD Romania review documents that KPIs are rarely established, especially for interim appointees, where objectives are often reduced to budget forecasts. [18] Against that background, Law 158/2025's forced "cap-and-comply" approach weakens the credibility of the KPI model: if remuneration can be abruptly reduced by law independent of performance evaluation, then "performance pay" becomes secondary to political and fiscal discretion.

Importantly, the point is not that caps are *per se* incompatible with OECD practice. OECD comparative evidence shows that some jurisdictions do apply caps. [11] The distortion arises from the *combination* of (i) a governance system already suffering from widespread interim appointments and weak KPI practice and (ii) a coercive legislative mechanism that

mandates remuneration cuts under threat of termination without damages, undermining the governance logic of performance contracts and stable accountability horizons. [28]

Case study: Compania Națională Loteria Română(CNLR)[29] in a reform cycle

A case study is helpful because it reveals how the Romanian regime’s contradictions translate into operational governance outcomes. Public governance disclosures for CNLR show interim governance and KPI problems not as abstract concerns but as recorded organisational facts.

Interim governance and KPI absence

CNLR’s Nomination and Remuneration Committee report for 2024 records that, during the first part of 2024, board members were appointed provisionally, and that in that period they did not receive a variable indemnity because performance indicators (financial and non-financial) were not attached to the mandate contracts and approved/endorsed through the relevant governance process. [30] The same report further notes that, for 2024, the variable remuneration component was not granted (effectively “zero”), alongside the absence of annual bonuses or non-financial advantages. [31] This is closely aligned with the OECD Romania review’s broader observation that KPI systems are weak and that interim appointments often operate with reduced objective structures. [18]

Remuneration evolution and the “principle–practice” gap

CNLR disclosures also illustrate the “market-attraction” principle in practice—followed by a compression trend consistent with the post-2025 statutory environment.

For the board, CNLR’s published governance pages indicate that gross monthly remuneration levels in 2023 were set at 7,198 lei for board members listed for that year. [32] In 2024, CNLR’s remuneration committee report states that fixed gross monthly indemnities were set at 7,198 lei through July 2024 and then increased to 19,300 lei from August 2024 through the end of 2024 for non-executive administrators. [33] Subsequently, CNLR’s public board page lists a gross remuneration level of 12,933 lei for several definitive board members (2024–2028 mandates), suggesting a downward adjustment compared to the 19,300 level reported for late 2024. [34]

For executive management, the same remuneration committee report documents that the fixed gross monthly remuneration for the Director General role was set at 22,804 lei through July 2024 and increased to 38,700 lei from August to December 2024. [35] This supports the paper’s broader argument: HG 639/2023’s market-attraction logic is operationalised in at least some SOEs through significant mid-cycle remuneration adjustments, but the later legislative environment—especially the coercive compliance mechanism in Law 158/2025—creates conditions for sharp re-compression disconnected from strategy cycles and KPI review structures. [36]

Financial performance evolution of CNLR

Table 1. CNLR revenue and gross profit dynamics (2021–2025) (values in lei; gross profit margin calculated as gross profit / revenue)

Indicator	2021	2022	2023	2024	2025 <i>preliminary data</i>
Revenue	1,076,446,023.80	1,167,587,589.97	1,222,445,234.62	1,291,086,093.88	1,437,442,682.22
Gross profit	146,511,826.60	166,693,362.60	192,664,600.06	237,752,852.76	308,253,266.54
Gross profit margin (%)	13.61	14.28	15.76	18.41	21.44

Two stylized facts emerge:

1. Revenue growth: 2021→2025 revenue increased by about 33.5% (from ~1.08 bn to ~1.44 bn lei).
2. Gross profit acceleration: 2021→2025 gross profit increased by about 110.4% (from ~146.5 m to ~308.3 m lei), with gross profit margin rising steadily from ~13.6% to ~21.4%.

The empirical disparity is not simply “performance up, pay down.” It is more specific: performance grew over a multi-year horizon while the legal framework introduced a mechanism capable of forcing remuneration reductions by contract addenda under threat of revocation without damages.

This matters because HG 639/2023 explicitly frames remuneration as a tool for attracting and motivating the “best administrators,” preserving market competitiveness, and rewarding objective achievement. Meanwhile, Law 158/2025’s transitional clause creates an enforcement pathway that can override negotiated remuneration arrangements and remove damages protection—effectively transforming remuneration governance into compelled compliance.

Performance versus remuneration: why coercive compression makes KPI governance derisory

The governance problem is not simply whether remuneration rises or falls, but whether changes occur through transparent, performance-linked governance mechanisms. HG 639/2023’s methodological norms articulate the principle that remuneration should be competitive to attract the best administrators and should reward objective achievement while avoiding distorted incentives. [22] In CNLR’s 2024 governance disclosures, however, the variable component is effectively absent due to KPI attachment/approval gaps in the interim period. [30]

This is the core paradox the case study reveals. If (i) interim governance prevents KPI-based variable remuneration from being properly structured and (ii) subsequent statutory intervention compresses remuneration through mandated renegotiation and dismissal threats, then the theoretical model—“pay for performance against KPIs”—becomes largely symbolic. The OECD Romania review explicitly connects interim appointment prevalence to reduced board autonomy and clarifies that KPI systems are rarely established, especially for interim appointees. [18] The result is a governance system in which remuneration can be highly salient politically, yet weakly connected institutionally to performance evaluation and accountability.

Even if remuneration caps are defended in terms of fiscal prudence or public legitimacy, OECD guidance suggests that legitimacy concerns must be balanced with recruitment and motivation needs. [25] A coercive legal mechanism—such as that in Law 158/2025 requiring remuneration reductions under threat of revocation without damages—risks shifting the regime from “governance by performance contract” to “governance by compliance command,” thereby weakening the very OECD-inspired logic cited as the reform’s purpose. [37]

Conclusions and implications

Romania’s SOE governance reforms display a recognisable pattern of OECD-style language adoption combined with non-OECD operational outcomes. OUG 109/2011’s declared policy purpose—professionalising management and ensuring transparent selection—remains consistent with OECD benchmarks in principle. [38] Yet the system has been repeatedly amended over time, indicating low legal stability and recurring redesign. [6]

More importantly, the OECD Romania review shows that implementation shortcomings are concentrated around appointments and board autonomy: interim appointments became widespread in major SOEs, and KPI systems were rarely established, particularly for interim appointees. [18] The European Commission similarly notes weaknesses in selection professionalism and ownership coordination. [7]

In this environment, the contradiction between HG 639/2023 and Law 158/2025 becomes governance-critical. HG 639/2023 embeds a competitiveness-and-performance logic for remuneration. [22] Law 158/2025 then introduces a coercive compliance mechanism for remuneration reductions, including mandated renegotiation and dismissal consequences without damages if agreement is not reached. [24] When combined with an interim-heavy appointment environment, this new approach risks making KPI-based remuneration—and, by extension, performance-based governance—derisory, because it weakens both the incentive structure (variable pay linked to KPIs) and the credibility of the performance contract horizon (stability and enforceability). [39]

The CNLR case suggests how such contradictions can surface in a high-performing SOE. Over 2021–2025, CNLR’s revenue increased by ~33.5% and gross profit by ~110.4%, with gross margin rising materially. Yet remuneration was compressed by ~33% after December 2025. The governance concern is not the nominal level but the *mechanism*: coercive reduction undermines the credibility of KPI-based remuneration and the strategic stability of mandates.

From an OECD-benchmarking perspective, a more coherent Romanian approach would prioritise: (i) reducing reliance on interim mandates by enforcing time limits and completing due-process selections; (ii) institutionalising KPI setting and evaluation for both boards and executives, including non-financial objectives where public mandates

apply; and (iii) designing remuneration governance that is transparent, benchmarked, and performance-linked—so that public legitimacy concerns are addressed through disclosure and governance process, not through coercive renegotiation backed by dismissal threats. [40]

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Information transmission in the foreign exchange market: evidence from India

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Abstract. *The present study sets out to examine the volatility and the resulting spillovers in the spot and futures prices of four different currency pairs (USD/INR, EUR/INR, GBP/INR, and JPY/INR) traded on the National Stock Exchange (NSE). The study employs the GARCH model to analyse volatility in the Indian currency futures market. The Reserve Bank of India (RBI) website provides spot prices, while the NSE provided daily futures prices for the specified currency pairings from 2010 to 2023 comprise the sample data. The GARCH-BEKK model investigates the transfer of volatility between spot and futures prices. The results highlight the importance of the GARCH model, demonstrating that the conditional variance exhibits slow mean-reverting behaviour and takes a considerable amount of time to subside. The study also shows that past and future innovations, as well as cross-volatility effects, significantly impact spot market volatility, suggesting the cross-market volatility transmission from the future prices to spot prices are greater than the cross-market volatility transmission within the spot series.*

Keywords: Currency futures, Volatility spillover, GARCH-BEKK, Futures price, Spot price.

JEL Classification: G13, G14, G15.

1. Introduction

Over the years, the global financial system has undergone substantial changes driven by financial innovation and increased competitive pressures. These changes have significantly altered the institutions and structure of the foreign exchange market (Sequeira et al., 2004). Every new technological layer has tightened spreads, sped up reaction times, and, ironically, increased the very turbulence that participants were trying to control (BIS, 2024). Consequently, there is an increasing demand for a wider array of hedging mechanisms to assist market participants in alleviating the risks linked to currency rate volatility. Consequently, financial products such as commodity, currency, and equity derivatives have been developed to effectively manage and control these risks (Nath & Pacheco, 2017; Patel & Rao, 2025).

India, in particular, has seen a rise in cross-border flows, both in capital and current accounts, due to globalization and more relaxed regulations on external transactions (Nath & Pacheco, 2017). These developments, along with shifting dynamics in capital flows and global imbalances, have contributed to increased exchange rate volatility. As a result, the currency futures market has become increasingly important for managing exchange rate risk and volatility (Malliaris & Ziemba, 2016).

India, in particular, has seen cross-border flows swell in both capital and current accounts as globalisation met relaxed external-sector regulations (RBI, 2024). Every fresh tide of portfolio money or export receipt lifted or lowered the rupee with growing force, making the currency-futures segment the busiest emergency room for volatility surgery (Ha et al., 2025).

Futures contracts are significantly influenced by volatility, which has implications for both speculators and hedgers. Hedgers are exposed to the risk of paying higher prices when prices fluctuate, while sellers may receive lower prices. To manage these risks, hedgers can take offsetting positions in futures contracts. Conversely, speculators perceive changing prices as opportunities for potential profits. Buyers aim to liquidate their positions at higher prices, whereas sellers seek to do so at lower prices. Motivated by the potential for profit, speculators take positions in futures contracts to capitalize on expected price changes (Malliaris & Ziemba, 2016).

Exchange rate volatility has diverse economic effects and serves as a critical factor for decision-makers. It introduces uncertainty to the return rates of unhedged foreign investments when expressed in the home currency (Eun & Resnick, 1994). Several factors contribute to increased volatility in exchange rates, including deviations from underlying economic fundamentals, excessive speculative activity, macroeconomic shocks, and other forms of news (Andersen et al., 2003). It is essential to remember that extreme fluctuations and volatility in exchange rates can potentially distort monetary policy signals, cause issues in other areas of the financial market, and even threaten financial stability.

2. Review of literature

The focus has shifted significantly in recent seasons to price discovery and the movement of volatility as futures contracts are introduced. The majority of the attention has been focused on the equity and commodity arenas (Harvey & Huang, 1991; Tse, 1999; Fung & Patterson, 1999; Ferris et al., 2002; Dennis et al., 2006; Antonakakis, 2012; Fang et al., 2017; Cho et al., 2019); however, the foreign-exchange side of the futures industry has received little attention.

This disparity is significant because, in cases where the underlying currency is a national currency, the rate at which news is incorporated into quotes determines how well central banks, exporters, and treasurers can prepare for unexpected fluctuations. The time-zone pulse was first mapped by Harvey & Huang (1991). This shows that macro announcements have a timestamp because USD-EUR and USD-JPY futures flare at their peak during North American hours, whereas EUR-cross contracts reach their volatility crest once London and Frankfurt awaken.

Asymmetry Wang & Yang (2009) later rediscover across AUD, GBP, and JPY, and Emter, McQuade, and Schuler (2025) now quantify at high frequency: negative global headlines travel about 40% faster than positive ones, tilting the volatility distribution toward the downside. Bessembinder & Seguin (1993) added the depth dimension—an order book already thinned by earlier trades amplifies the same shock, and positive volume surprises bite deeper than negative ones.

While the spot market sustains the tension for a longer period of time—an early indication that cash prices process news more slowly—EUR and DEM futures nearly always end the session more volatile than on non-announcement days, according to Crain & Lee (1995), who kept an eye on announcement days. The two-way street between Eurodollar spot and futures was identified by Cheung & Fung (1997), who demonstrated that information does not respect the theoretical boundary and bounces back and forth within minutes. By focusing just on planned U.S. macro releases, Chatrath & Song (1998) showed how yen futures consistently feed volatility back into the underlying spot quote, with the spot serving as the receiver and the futures as the transmitter.

Ha et al., (2025) recently elevated this relationship to global-financial-cycle status, arguing that currency futures are the primary channel through which the global liquidity pulse leaks into local spot rates. Sequeira et al., (2004) expanded the aperture once more, revealing that both domestic and foreign risk-free rates leave distinct fingerprints on the conditional variance of futures and spot returns.

While Antonakakis (2012) demonstrated how the introduction of the euro rewired the global board, making the single currency the dominant transmitter, sterling the largest net recipient, and European trading sessions the most powerful source of cross-market shocks, Sharma (2011) brought the microscope to India and discovered the same two-way street between USD/INR futures turnover and spot volatility. Higher intraday volatility attracts

more trading volume, which is good news for hedgers who require counterparties, according to Pavaskar & Kala (2013), who focused on the INR/USD tick.

While Babu & Reddy (2024) use millisecond NSE data to demonstrate that the futures-to-spot information lag has now shrunk to less than three seconds, the volatility half-life of the shock persists for hours, highlighting why the current study is still important. Suhashini & Chandrasekar (2013) fitted a GARCH lens to USD/INR futures and reported the well-known trio—clustering, persistence, predictability. Although Sehgal et al., (2015) compared four trading venues and concluded that futures prices consistently take the lead, Patel & Rao (2025) support this conclusion with data from 2022–2023, showing that the cross-correlation between futures returns and next-period spot volatility reaches 0.42, twice the reverse coefficient. Sriram & Senthil (2013) detect a long-run gravitational pull from spot to futures, especially when the dollar itself jerks.

Gupta (2017) demonstrated that the derivative can either calm or agitate the underlying market, contrary to Singh & Tripathi's (2014) claim that the introduction of currency futures in India reduced the daily volatility of GBP/INR. The news-flow twist was provided by Kumar (2015), who confirmed an asymmetric reaction that Enter et al., (2025) now confirm globally: positive headlines amplify spot volatility more than negative ones. When comparing four trading platforms, Sehgal et al., (2015) discovered that futures prices continuously outperform spot prices over time; Babu & Reddy (2024) even trace this leadership down to the microsecond.

While Gupta (2017) found that the introduction of EUR/INR futures increased spot volatility, Kumar et al., (2017) found that negative forex headlines actually decreased volatility—more proof that the derivative's overall impact varies depending on the context. While Sehgal & Dutt (2018) found that Indian futures dominate domestic price discovery, global platforms like CME and DGCX win the sprint over shorter horizons, Nath & Pacheco (2017) documented stubborn volatility clustering in both pre- and post-futures eras, with a stronger bite following rupee depreciation.

The final brushstroke of the pre-2022 canvas was added by Devan & Johnson (2021), open interest pulls futures volatility down, but speculative volume pushes it up, suggesting that who holds the contract is more important than the number of contracts held. Devan et al., (2022) support our conclusion that volatility primarily spills from futures to spot pricing by showing that the Indian currency-futures market responds to new information more quickly than the spot segment using daily INR data from February 2010 to March 2021. Our BEKK model uses the greater cross-volatility coefficient from futures to spot to capture this speed advantage.

All of the evidence points to currency futures as the market's early warning system since they detect, magnify, and then export volatility to the spot market. The few studies that make the opposite claim are accurate; they only depict distinct parts of the same neural system. The present paper keeps the electrodes on the Indian rupee and asks whether, in

2023-24, the warning signal still travels from futures to spot faster and louder than any other channel—an answer that updates the narrative and clarifies where risk managers should now place their sensors.

3. Data

This study focusses on the Indian currency futures market and employs quantitative secondary data available in the public domain, including data from the NSE (National Stock Exchange) for future prices and RBI (Reserve Bank of India) databases for spot prices. The dataset included daily closing prices for spot and futures contracts transacted in the Indian forex market. Near-month futures contracts were used to generate the futures price series because they had considerable liquidity and trading activity. This approach avoids using observations close to contract maturity dates, which might reflect a weakening and volatile market interest.

August 2008 saw the NSE launch currency futures trading, which was initially restricted to USD exclusively. Subsequently, in 2010, trading was extended to include three other currencies. The sample data included daily futures prices in four currencies: Yen, U.S. Dollar, GBP and Euro. The data sets were collected from the NSE. The corresponding spot prices were taken from the RBI website. The data was obtained from the NSE and is based on the trading volume of the exchanges in relation to the quantity of futures contracts and volume traded for the respective currency futures. The spot and futures prices have been converted into a natural logarithm for estimation purposes.

4. Research Methodology

The time series of currency prices are noteworthy at first differences but not at level, according to stationarity tests done on futures and spot prices. However, the stationary series may also exhibit volatility clustering if the residual variances are autocorrelated. It was found that the returns series of both future price and spot price of currency futures were stationary, and this is necessary as the models developed for ARCH assume stationarity. Generalized ARCH, or GARCH for short, is one variation of ARCH model. Following represents the GARCH model at lag 1:

$$\sigma_t^2 = \alpha_2 + \alpha_3 \varepsilon_{t-1}^2 + \alpha_4 \sigma_{t-1}^2 \quad (1)$$

The residual term at time $t-1$ and the error variance at time $t-1$ determine the error variance at time t . This is the GARCH (1,1) model, where the terms Moving Average order 1 and Autoregressive order 1 are denoted by (1,1). However, if the model exhibits non-heteroscedasticity, that is, unconditional variance, then volatility cannot be estimated. Hence, before modelling volatility, it is necessary to test for heteroscedasticity. To test for

heteroskedasticity, each series is regressed on its term at lag 1 to represent the autoregressive process of the form,

$$Y_t = \alpha + \beta Y_{t-1} + \varepsilon_t \quad (2)$$

The GARCH models can be attempted to estimate the volatility. To generate the mean equation, the log of the returns of spot and futures prices was employed in the following way:

$$R_{st} = \alpha + \beta R_{ft} + \varepsilon_t \quad (3)$$

The residual term (ε_t) is estimated using the preceeding equation. From the residual series, the variance of the squared error term is used to form the variance equation, which is the GARCH (1,1) term of the form

$$\sigma_{\varepsilon_t}^2 = \alpha_2 + \alpha_3 \varepsilon_{t-1}^2 + \alpha_4 \sigma_{\varepsilon_{t-1}}^2 \quad (4)$$

As seen before, R_{st} and R_{ft} are the logarithmic returns of the spot and futures prices, ε_t is the error term of the OLS equation at time t . Then the GARCH term $\sigma_{\varepsilon_{t-1}}^2$, which is the variance of the squared residual obtained from is regressed on squared residuals and variance of the squared residuals both at lag 1 as seen in equation

The Bivariate GARCH diagonal BEKK model is frequently used to investigate the volatility spillover. The bivariate link between spot and futures is studied using the diagonal BEKK model, which is represented as

$$\sigma_{1,t}^2 = \gamma_{11} + a_{11}^2 \varepsilon_{1,t-1}^2 + b_{11}^2 \sigma_{1,t-1}^2 \quad (5)$$

$$\sigma_{12,t} = \gamma_{12} + a_{11} a_{22} \varepsilon_{1,t-1} \varepsilon_{2,t-1} + b_{11} b_{22} \sigma_{12,t-1} \quad (6)$$

$$\sigma_{2,t}^2 = \gamma_{22} + a_{22}^2 \varepsilon_{2,t-1}^2 + b_{22}^2 \sigma_{2,t-1}^2 \quad (7)$$

Where $\sigma_{1,t}^2$, and $\sigma_{2,t}^2$ represent the volatility models of futures and spot return series of R_{ft} and R_{st} , respectively. $\sigma_{12,t}$ is the conditional covariance, $\sigma_{1,t}^2$, and are conditional variances of residuals of the return's series R_{ft} and R_{st} , respectively. The coefficients a_{11} and a_{22} represent the lagged values of the futures and spot series residual terms, respectively. (ARCH effects) Furthermore, coefficients b_{11} and b_{22} represent the lagged values of respective futures and spot series volatility at time $t-1$ (GARCH effects).

4.1. Descriptive Statistics

The behaviour of currency futures and spot return series was studied using descriptive statistical measures like Mean, Standard Deviations (S.D.), Skewness, Kurtosis, and Jarque-Bera. Descriptive statistics summarize a given data set, which shows a set of descriptive coefficients in a valuable way that simplifies interpretation. The mean values of the sample data set show a central tendency, kurtosis, and skewness, which show measures of dispersion. The standard deviation and Jarque-Bera test were employed to

verify the volatility and normality of the sample data series. Descriptive statistics show that the average return on future prices surpasses that of spot prices. Among these, USD/INR futures exhibit the highest mean return (0.000238), while GBP/INR spot returns (0.000173) demonstrate the lowest mean. The standard deviation (S.D.) indicates differing levels of variation or volatility from 2010 to 2020. JPY/INR spot returns exhibit the highest S.D. (0.008106), whereas USD/INR futures display the lowest S.D. (0.004716).

Within the Indian currency futures market, the return distributions for GBP/INR (future return -0.514172 and spot return -0.523939) are negatively skewed, while all other currencies exhibit positive skewness. Additionally, all series display the same level of excess kurtosis. The Jarque-Bera test results and related probabilities for both series indicate a divergence from the normal distribution of the data.

4.2. Unit root tests

Before proceeding with any further examination of the currency futures time series data, the series' stationarity must be established. Thus, to evaluate whether the variables are stationary or non-stationary, this study used the Augmented Dickey-Fuller (ADF) test and the Phillips-Perron (P.P.). The ADF and P.P. test results are shown below in Table 1.

Table 1. *Augmented Dickey-Fuller / Phillips-Perron Unit Root Test*

Variables	Levels	ADF test		P.P. test		Sig.
		Test value	Prob.	Test value	Prob.	
USD future	I(0)-Level	-1.191669	0.6802	-1.114307	0.7123	Ns*
	I(1)-1st difference	-10.58720	0.0000	-46.11160	0.0001	***
USD spot	I(0)-Level	-1.110900	0.7137	-1.052439	0.7362	Ns
	I(1)-1st difference	-21.92609	0.0000	-49.27371	0.0001	***
EUR future	I(0)-Level	-1.1991	0.2912	-1.9122	0.3268	Ns
	I(1)-1st difference	-31.0167	0.0000	-44.2291	0.0001	***
EUR spot	I(0)-Level	1.8593	0.3520	-1.9114	0.3272	Ns
	I(1)-1st difference	-45.6145	0.0001	-45.6349	0.0001	***
GBP future	I(0)-Level	-2.2041	0.2050	-2.2510	0.1884	Ns
	I(1)-1st difference	-20.8671	0.0000	-43.7525	0.0001	***
GBP spot	I(0)-Level	-2.27864	0.1791	-2.2387	0.1927	Ns
	I(1)-1st difference	-17.8043	0.0000	-45.3104	0.0001	***
JPY future	I(0)-Level	2.56036	0.1016	-2.5406	0.1060	Ns
	I(1)-1st difference	-47.8557	0.0001	-47.8515	0.0001	***
JPY spot	I(0)-Level	-2.4898	0.1181	-2.5102	0.1131	Ns
	I(1)-1st difference	-48.5297	0.0001	-48.5226	0.0001	***

Note: Ns* – Not significant. *** denotes statistically significant at the 1% significant levels.

Source: NSE and RBI websites.

Table 1 shows the t-statistics and significance levels (p-values) of the ADF (Augmented Dickey-Fuller) and P.P. (Phillips-Perron) tests, conducted on both currency futures and spot price return data. The associated probabilities for these test values are observed to exceed the 0.05 significance level. These tests demonstrate the presence of a unit root and ensure the non-stationarity of the series. Subsequently, the same tests were repeated on the first differences of the future and spot price return series.

4.3. Generalized Autoregressive Conditional Heteroscedastic (GARCH) Model

The stationarity tests for futures and spot returns reveal that the time series of currency values have significant initial differences. However, they are not substantial at this level. The stable series, on the other hand, may display volatility clustering due to autocorrelated residual variances. It was discovered that the returns series of both futures and spot currencies were stationary. It is important since the models created for Autoregressive Conditional Heteroscedastic (ARCH) imply stationarity. The Generalised ARCH (GARCH) model is a variant of the ARCH model. GARCH and ARCH were chosen based on how well the model's represented volatility. Prior to estimating the GARCH model, the heteroscedasticity of the currency spot and futures return series must be examined. The heteroskedasticity tests, such as the ARCH LM test, are used to prove the heteroscedasticity or ARCH effect in the time series. The ARCH effect confirms that using ARCH/GARCH family models is appropriate for measuring volatility. The results of the ARCH LM Test for currency spot and futures return series are presented in Table 5.10

4.3.1. ARCH-LM Test

This test employs the Lagrange multiplier (L.M.) method to assess the presence of the ARCH/GARCH effect within a series. This test determines whether heteroscedasticity exists in the currency spot and futures return data. The ARCH model has been employed to examine the existence of this heteroscedasticity effect. The result is shown in Table 2 below.

Table 2: *ARCH test*

Heteroscedasticity test: ARCH				
	Obs* R-squared	F-statistic	Prob. F	Prob. Chi-Square(1)
USD/INR futures	278.2238	318.8052	0.0000***	0.0000
USD/INR spot	300.2761	348.1278	0.0000***	0.0000
EUR/INR futures	128.5761	136.5405	0.0000***	0.0000
EUR/INR spot	204.5550	225.6147	0.0000***	0.0000
GBP/INR futures	76.60847	79.33619	0.0000***	0.0000
GBP/INR spot	34.41638	34.93830	0.0000***	0.0000
JPY/INR futures	90.37630	94.21326	0.0000***	0.0000
JPY/INR spot	120.9328	127.9452	0.0000***	0.0000

Note: *** denotes statistically significant at the 1% significant levels.

Source: Authors' calculations.

The F-statistics value in Table 2 is very significant at the 1% level. The results indicate that there is a considerable ARCH effect within the return series. This conclusion confirms the heteroscedasticity-ARCH effect in the time series of currency futures and spot returns. As a result, the GARCH model must be applied to appropriately analyse the volatility of the Indian FX market.

4.4. Volatility Estimation of currency futures

The GARCH model examines whether past volatility of returns can impact present volatility returns (Table 3 to Table 6).

Table 3: Volatility estimation for USD/INR

Variable	Coefficient	Std. error	z-statistic	Prob.
Dependent variable: R_{st}				
Mean equation (A)				
R_{it}	0.680552	0.013989	48.65009	0.0000***
C	5.75E-05	5.53E-05	1.039944	0.2984
Variance equation (B)				
C	3.36E-07	4.50E-08	7.470403	0.0000***
RESID(-1) ²	0.114640	0.011980	9.569047	0.0000***
GARCH(-1)	0.859892	0.012634	68.06432	0.0000***

Note: *** denotes significance at a 1% level.

Source: Authors' calculation.

The GARCH model study shows that the p-values for the ARCH and GARCH terms are statistically significant for the USD/INR currency pair (see Table 4). The ARCH and GARCH coefficients, which are GARCH (1, 1) model parameters, are used to quantify mean reversion and volatility persistence. If all of these coefficients added together are less than one, the process is said to be stationary or mean-reverting. The closer the total parameters are to unity, the longer the volatility persists. Within the variance equation, the ARCH term gauges how volatility responds to market movements. Elevated ARCH coefficient values lead to conditional volatility exhibiting substantial reactions but limited persistence. In contrast, the GARCH coefficient in the volatility equation measures volatility persistence. Larger values for this coefficient indicate that changes in conditional variance take longer to dissipate, resulting in significant persistence of conditional volatility.

The findings reveal that the ARCH coefficients (0.114640) and GARCH coefficients (0.859892) in the conditional variance equation are statistically significant at the 1% level. This suggests that exchange rate return volatility is influenced by the prior days' exchange price information and volatility levels. Furthermore, it suggests that shocks to conditional variance exhibit a highly persistent nature. Relatively higher GARCH coefficients indicate a prolonged influence of conditional variance, signifying that volatility takes a considerable time to revert to normal levels following shocks. The higher GARCH coefficient than the ARCH coefficient suggests a subdued response to recent volatility-related news, with older news maintaining a lasting impact.

Table 4: Volatility model estimation for EUR/INR

Variable	Coefficient	Std. error	z-statistic	Prob.
Dependent variable: R_{st}				
Mean equation(A)				
R_{it}	0.795249	0.010441	76.16573	0.0000***
C	5.37E-05	7.34E-05	0.732010	0.4642
Variance equation (A)				
C	6.62E-06	8.63E-07	7.678765	0.0000***
RESID(-1) ²	0.292547	0.021101	13.86393	0.0000***
GARCH(-1)	0.362749	0.056487	6.421783	0.0000***

Note: *** denotes significance at a 1% level.

Source: Authors' calculation.

Table 4 reveals that the ARCH coefficient (0.292547) and GARCH coefficient (0.362749) within the conditional variance equation are statistically significant, with significance observed at the 1% level for EUR/INR. This indicates that the volatility seen in exchange rate returns is influenced by the information and volatility of the previous day's exchange prices. Consequently, shocks to the conditional variance exhibit a pronounced level of persistence over time. The relatively larger GARCH coefficients indicate that conditional variance experiences a protracted decline, indicating a sustained level of volatility persistence. These GARCH coefficients exhibit higher values for the return series, indicating that new shocks will have a prolonged impact on exchange rate prices. Additionally, the elevated value of the GARCH coefficient, compared to the ARCH coefficient, suggests a subdued reaction to recent volatility-related news, while older news retains its influence for an extended duration.

Table 5: Volatility model estimation for GBP/INR

Variable	Coefficient	Std. error	z-statistic	Prob.
Dependent variable: R_{it}				
Mean equation (A)				
R_{it}	0.751703	0.010880	69.09034	0.0000***
C	4.64E-05	8.59E-05	0.539842	0.5893
Variance equation (B)				
C	5.88E-06	1.02E-06	5.774367	0.0000***
RESID(-1) ²	0.205379	0.025292	8.120338	0.0000***
GARCH(-1)	0.527204	0.057059	9.239618	0.0000***

Note: *** denotes significance at a 1% level.

Source: Authors' calculation.

The findings of Table 5 reveal that both the ARCH coefficient (0.205379) and GARCH coefficient (0.527204) within the conditional variance equation exhibit statistical significance at the 1% level for GBP/INR. The statistical significance of the ARCH and GARCH terms suggests that the volatility observed in the exchange rate returns is influenced by the exchange price information and volatility levels from the preceding day. This finding also suggests that shocks affecting conditional variance display slow mean-reverting behaviour over time. The larger GARCH coefficients indicate that conditional variance experiences a gradual decline, indicative of sustained volatility persistence. Furthermore, the GARCH coefficients present higher values for the return series, indicating that newly occurring shocks will exert a prolonged impact on exchange rate prices. In addition, the elevated value of the GARCH coefficient compared to the ARCH coefficient suggests a subdued reaction to recent news pertaining to volatility. This highlights that historical news retains its influence for an extended period, underscoring the time it takes for older news to diminish in significance.

The outcomes of the analysis, as given in Table 6, demonstrate that both the ARCH coefficient (0.335514) and GARCH coefficient (0.569586) present within the conditional variance equation are statistically significant at the 1% significance level for JPY/INR. This indicates that the volatility experienced in exchange rate returns is influenced by the preceding day's exchange price information and volatility levels. This finding also suggests

that shocks impacting conditional variance exhibit a strong degree of persistence over time. The relatively higher GARCH coefficients suggest that the conditional variance has a prolonged decay, underscoring the persistent nature of volatility.

Table 6: Volatility model estimation for JPY/INR

Variable	Coefficient	Std. error	z-statistic	Prob.
Dependent variable: R_{st}				
Mean equation (A)				
R_{it}	0.827174	0.009207	89.84413	0.0000***
C	9.41E-05	8.15E-05	1.155246	0.2480
Variance equation (B)				
C	3.55E-06	4.37E-07	8.126422	0.0000***
RESID(-1) ²	0.335514	0.021211	15.81756	0.0000***
GARCH(-1)	0.569586	0.029060	19.60015	0.0000***

Note: *** denotes significance at a 1% level.

Source: Authors' calculation.

Moreover, the GARCH coefficients exhibit greater values for the return series, suggesting that newly occurring shocks will have a lasting influence on exchange rate prices. Additionally, the higher value of the GARCH measure compared to the ARCH measure indicates a restrained response to recent news concerning volatility. This implies that past news remains influential for an extended period, signifying the slow process through which older news gradually becomes less impactful.

Tables 3, 4, 5, and 6 show that the GARCH model for USD, EUR, GBP, and JPY is significant at 1%. Therefore, the results are leading to the inference that the GARCH effect is indeed present. This signifies that the conditional variance will exhibit a high level of persistence and will gradually diminish over time due to the sustained nature of volatility.

4.5. Volatility spillover estimation

The researcher employed the bivariate GARCH specification proposed by Engle and Kroner (1995) model to explore volatility spillover within the Indian currency futures market. In this context, the ARCH coefficient reflects the squared value of residual terms, while the GARCH coefficients pertain to the coefficients of the variance-covariance term. By employing the Bivariate GARCH model, the study aimed to elucidate the information flow pattern between two distinct time series.

Table 7: Result of volatility spillover between currency spot and futures

	USD/INR		EUR/INR		GBP/INR		JPY/INR	
	Coeff.	p	Coeff.	P	Coeff.	p	Coeff.	p
R_{it}	0.000139	0.1199	0.000117	0.3403	0.000151	0.2247	0.000050	0.7281
R_{st}	0.000143	0.0854	0.000155	0.1974	0.000126	0.3213	0.000100	0.4793
γ_{11}	2.83E-07	0.0000	0.00000118	0.0000	0.0000120	0.0000	0.0000134	0.0000
γ_{12}	2.22E-07	0.0000	0.00000127	0.0000	0.0000063	0.0000	0.0000080	0.0000
γ_{22}	3.45E-07	0.0000	0.00000214	0.0000	0.0000041	0.0000	0.0000048	0.0000
a_{11}	0.209681	0.0000	0.18707700	0.0000	0.2564860	0.0000	0.2954840	0.0000
a_{22}	0.240002	0.0000	0.26109300	0.0000	0.3567540	0.0000	0.4382050	0.0000
b_{11}	0.971548	0.0000	0.96587100	0.0000	0.9149080	0.0000	0.9189120	0.0000
b_{22}	0.962756	0.0000	0.93829500	0.0000	0.7599920	0.0000	0.7971430	0.0000

Source: Author's computation.

Using data from independent market histories, this method evaluates the volatility spillover between two linked markets. Table 7 displays the results of the bivariate GARCH.

The table above gives the conditional mean and volatility model for the return's series of futures R_{ft} and spot R_{st} , along with volatility estimation. It is seen from the above table that diagonal parameters a_{11} and a_{22} are statistically significant ($P < 0.01$). This signifies a dependence of the return's series of futures R_{ft} and spot R_{st} on their respective first lags. These statistically significant coefficients suggest substantial and positive spillover effects, indicating an upward shift in these markets. Incorporating conditional variance-covariance successfully captures the volatility and cross-volatility interactions between the currency futures and spot markets. This effectiveness is underscored by the significant coefficients, as evident from the aforementioned table. More specifically, the diagonal BEKK Specification yields meaningful insights into the conditional variances-covariances (which are presented below). The conditional mean and volatility models for R_{ft} and spot R_{st} from the above table can be written as:

USD/INR

$$R_{ft} = 0.000139 + \varepsilon_{1,t}$$

$$\sigma_{1,t}^2 = 2.83066201965e - 07 + 0.0439661 \varepsilon_{1,t-1}^2 + 0.9439054 \sigma_{1,t-1}^2$$

$$R_{st} = 0.000143 + \varepsilon_{2,t}$$

$$\sigma_{2,t}^2 = 3.44550089654e - 07 + 0.0576011x\varepsilon_{2,t-1}^2 + 0.926899x\sigma_{2,t-1}^2$$

Covariance equation

$$\sigma_{12,t} = 2.22344868383e - 07 + 0.0503239x\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 0.9353637x\sigma_{12,t-1}$$

EUR/INR

$$R_{ft} = 0.000117 + \varepsilon_{1,t}$$

$$\sigma_{1,t}^2 = 0.00000118 + 0.034998 \varepsilon_{1,t-1}^2 + 0.932907 \sigma_{1,t-1}^2$$

$$R_{st} = 0.000155 + \varepsilon_{2,t}$$

$$\sigma_{2,t}^2 = 0.00000214 + 0.0681696 x\varepsilon_{2,t-1}^2 + 0.880398x\sigma_{2,t-1}^2$$

Covariance equation

$$\sigma_{12,t} = 0.00000127 + 0.048844x\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 0.906272x\sigma_{12,t-1}$$

GBP/INR

$$R_{ft} = 0.000151 + \varepsilon_{1,t}$$

$$\sigma_{1,t}^2 = 0.0000120 + 0.065785 \varepsilon_{1,t-1}^2 + 0.837057 \sigma_{1,t-1}^2$$

$$R_{st} = 0.000126 + \varepsilon_{2,t}$$

$$\sigma_{2,t}^2 = 0.0000041 + 0.127273 x\varepsilon_{2,t-1}^2 + 0.577588x\sigma_{2,t-1}^2$$

Covariance equation

$$\sigma_{12,t} = 0.0000063 + 0.091502x\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 0.695323x\sigma_{12,t-1}$$

JPY/INR

$$R_{ft} = 0.000050 + \varepsilon_{1,t}$$

$$\sigma_{1,t}^2 = 0.0000134 + 0.087311\varepsilon_{1,t-1}^2 + 0.844399\sigma_{1,t-1}^2$$

$$R_{st} = 0.000100 + \varepsilon_{2,t}$$

$$\sigma_{2,t}^2 = 0.0000048 + 0.192024x\varepsilon_{2,t-1}^2 + 0.635437x\sigma_{2,t-1}^2$$

Covariance equation

$$\sigma_{12,t} = 0.0000080 + 0.129983x\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 0.732504x\sigma_{12,t-1}$$

The cross-product terms of a_{11} and a_{22} and b_{11} and b_{22} are coefficients of conditional covariances of ARCH and GARCH terms of the covariance. The results of USD/INR show that all the conditional variances and covariances of the diagonal BEKK model are positive and significant ($P < 0.01$). However, the persistence of shocks for R_{ft} ($0.04397 + 0.94390 = 0.98787$) is almost the same as that of R_{st} ($0.05760 + 0.926899 = 0.98449$) for USD/INR, but for all other currency futures, it shows differences. It is seen that own volatility spillovers (ARCH effects) are positive and significant for both futures and spot series. The spillover effect is higher for the spot series (0.05760) than for the futures series (0.0439661). These coefficients illustrate each market's volatility persistence in relation to its historical errors. As for cross-volatility effects, past and future innovations have had a more significant influence on the volatility of the spot market to a certain extent. The cross-volatility spillovers from futures to spot (0.93536) are higher than the own-volatility spillovers of spot series (0.926899).

In the case of EUR/INR, the persistence of shocks for R_{ft} is 0.967965 ($0.034998 + 0.932967$), and R_{st} is 0.985676 ($0.0681696 + 0.880398$). It is seen that own volatility spillovers (ARCH effects) are positive and significant for both futures and spot series. The spillover effect is higher for the spot series (0.0681696) than for the futures series (0.0349981). As for cross-volatility effects, past future innovations have a greater influence on the volatility of the spot market to a certain extent. The cross-volatility spillovers from futures to spot (0.906272) are higher than the own-volatility spillovers of spot series (0.880398).

For GBP/INR, the persistence of shocks for R_{st} ($0.127273 + 0.577588 = 0.704861$) shows comparatively higher differences than that of R_{ft} ($0.065785 + 0.837057 = 0.902842$). It is seen that own volatility spillovers (ARCH effects) are positive and significant for both futures and spot series. The spillover effect is higher for the spot series (0.127273) than for the future series (0.065785). Regarding cross-volatility impacts, previous innovations have a somewhat bigger impact on the volatility of the spot market in the future. The cross-

volatility spillovers from futures to spot (0.695323) are higher than the own-volatility spillovers of spot series (0.577588).

In the case of JPY/INR, the persistence of shocks for R_{st} is 0.827461 (0.192024+0.635437), and R_{ft} is 0.93171 (0.087311+0.844399). It is seen that own volatility spillovers (ARCH effects) are positive and significant for both futures and spot series. The spillover effect is higher for the spot series (0.192024) than for the future series (0.087311). Regarding cross-volatility impacts, previous innovations have a somewhat bigger impact on the volatility of the spot market in the future. The cross-volatility spillovers from futures to spot (0.732504) are higher than the own-volatility spillovers of spot series (0.635437).

5. Conclusions

Contracts for currency futures are essential for negotiating the complex foreign exchange market. These contracts provide an effective way to offset some of the risks associated with exchange rate swings. In addressing the nuanced realm of volatility spillover, this study delved into the dynamics of four currency futures traded within the Indian foreign exchange market—namely USD/INR, EUR/INR, GBP/INR, and JPY/INR—encompassing the timeframe from April 2010 to March 2022. The GARCH model employed in this study has rendered significant insights, revealing that the conditional variance retains a high level of persistence, a characteristic reflective of the enduring nature of volatility.

Furthermore, this investigation underscores the noteworthy influence of cross-volatility effects and historical and forthcoming innovations on spot market volatility, albeit to a certain extent. Notably, in terms of volatility, the spillovers from futures to spot demonstrate greater prominence than the spillovers confined to the spot series alone. This revelation lends credence to the intricate interplay between futures and spot markets, underscoring the intricate relationships that underscore these interconnected spheres.

In essence, this study not only advances our comprehension of volatility dynamics in currency futures and spot markets but also provides valuable insights into the broader landscape of risk management and market behaviour.

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The evolution of green energy utilization in Romania

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Abstract. *The solar sector is characterized by rapid, decentralized growth, significantly fueled by a "prosumer" movement and government initiatives such as the "Casa Verde" program. With a revised national target of 3,140 MW by 2030, solar offers high scalability and lower entry barriers. Conversely, wind energy remains the industrial "heavy lifter," providing high-volume generation essential for grid stability. While wind investment has recently stalled, the emergence of the Black Sea as an offshore frontier and the maturation of Power Purchase Agreements (PPAs) present significant opportunities for utility-scale development.*

Both sectors face shared challenges, including lengthy permitting processes and grid congestion, necessitating the adoption of Battery Energy Storage Systems (BESS) and "renewable acceleration areas." Ultimately, the choice between solar and wind investment depends on the investor's profile: solar provides agility and faster deployment, while wind offers the industrial scale and high output required for long-term regional dominance. This dual-track evolution is defining Romania's path toward a green, net-zero economy.

Keywords: solar, wind, power, energy, targets.

JEL Classification: Q42, Q48, Q58, G11, L94, O13.

1. Introduction

Romania's energy market is currently navigating a pivotal transition, driven by the dual imperatives of European Union (EU) decarbonization goals and the need to modernize a legacy infrastructure heavily dependent on fossil fuels. As a member of the EU, Romania's renewable energy policies are largely dictated by international obligations and national strategies designed to foster a sustainable, integrated energy market. Within this framework, "renewable energy" is legally defined as power derived from non-fossil sources, specifically highlighting wind, solar, and geothermal energy. While Romania achieved significant greenhouse gas (GHG) reductions since the early 1990s, progress has recently stalled, necessitating a more aggressive deployment of clean energy technologies to reach net-zero by mid-century.

The solar energy sector in Romania has emerged as a dynamic and rapidly expanding segment of the market. This growth is characterized by a mix of large-scale industrial projects and a burgeoning prosumer base, individual households and businesses that both consume and produce electricity. The rise of prosumers has been a significant market driver, supported by national initiatives like the "Casa Verde" program, which provides subsidies for residential photovoltaic installations.

Solar energy offers several distinct market advantages: it provides a path to increased energy independence, significantly lowers electricity costs for participants, and contributes directly to mitigating climate change through CO₂ emission reductions. Furthermore, the industrial ecosystem is adapting to support this growth; for example, specialized production sites like ArcelorMittal's Berrioplano facility are now manufacturing specialized structures for solar panels.

Wind energy remains a critical pillar of Romania's renewable strategy, particularly for large-scale electricity generation. The country possesses substantial natural potential for both onshore and offshore wind, yet the sector has faced more volatility in investment than solar. Recent data indicate that investment in new renewable capacity, including wind, has stalled and must accelerate to meet 2030 targets.

Unlike the more decentralized solar market, wind projects typically require massive capital investment and complex coordination with the national grid operator, Transelectrica. While wind energy is essential for replacing retiring coal-fired power plants, which still provide nearly one-fifth of Romania's power, it faces stiffer competition for available grid connection capacity and is more sensitive to high-voltage transmission limitations.

Despite their differences, both solar and wind sectors are hampered by shared administrative and technical bottlenecks. A primary obstacle is the lengthy permitting process; in Romania, obtaining the necessary licenses for renewable projects often takes significantly longer than the two-year limit recommended by the EU. These delays create a "waiting list" for grid access, where developers of both solar and wind projects compete for limited connection capacity within an aging infrastructure.

Technically, the intermittent nature of both sources requires a modernization of the grid. The market is increasingly looking toward Battery Energy Storage Systems (BESS) as a

necessary complement to renewable energy. These storage solutions are vital for stabilizing the grid and ensuring that the variable output from solar (peaking during the day) and wind (variable by weather) can be efficiently distributed to consumers without compromising system security.

The future of Romania's energy market depends on harmonizing financial support with regulatory reform. The OECD suggests that while subsidies for renewables and electric vehicles are helpful, they must be part of a broader "policy mix" that includes consistent carbon pricing and the removal of fossil fuel subsidies to create a truly competitive market. By 2030, Romania aims for renewables to meet 36% of its energy needs for heating and cooling, a target that will require a coordinated push in both the solar and wind sectors. As the legislative framework evolves to simplify licensing and attract foreign investment, the competition between solar's decentralized growth and wind's industrial-scale potential will define the nation's path toward a green economy.

2. The solar energy market

Romania is undergoing a historic energy overhaul, marking its most profound shift since the post-communist era. Driven by EU mandates, regional instability, and a wealth of natural resources, the nation is transitioning from a country of potential to a European leader in renewables. At the heart of this evolution is the solar photovoltaic sector, propelled by explosive capacity growth, a surging prosumer movement, and massive utility-scale investments. The foundation of Romania's solar growth is anchored in its obligations as an EU Member State. The nation's renewable energy policy is dictated by the INECP (Integrated National Energy and Climate Plan), which serves as the roadmap for a decarbonized economy and an integrated energy market.

Romania defines solar energy as a power producer from non-fossil sources, identifying solar alongside wind, geothermal, and ambient energy. It is legally aligned with the EU laws and has created the regulatory certainty required to attract foreign capital. Currently, the government has set an ambitious target to reach a renewable energy share of 34% to 36% by 2030. To achieve this, the national photovoltaic target was recently revised upward from an initial 1,400 MW to a projected 3,140 MW by 2030.

While Romania has made tangible progress regarding the carbon footprint by reducing greenhouse gas emissions from 1990 to 2010, the progress has been paused for the moment. In 2023, the total installed capacity is approximately 18.4 GW, with solar power currently accounting for roughly 8.4% of that mix. The conditions for installing solar panels are favorable, and non-agricultural lands can be used in order to expand the business, suggesting this is only the beginning. Romania boasts an ideal climate for solar energy, particularly in its southern regions. The country receives an average of 1,600 kWh/m² of solar irradiation annually. When combined with relatively low land costs and favorable topography, these factors make Romania one of the most cost-effective locations in Central and Eastern Europe (CEE) for solar development. Perhaps the most visible shift in the Romanian market is the rise of residential or commercial entities that both produce and

consume their own electricity. This movement has transformed the energy market from a centralized model to a decentralized, participatory ecosystem.

The economic incentives for this change would be the national programs, the energy independence needed after the war struck in Ukraine, and the climate change mitigation contribution that can motivate the citizens.

While the small-scale installations are rising, the expansion in this field is done by the industrial solar parks. The major participants are the Ministry of Energy, by setting strategy and policy, the Regulatory Authority, issuing licenses in order to regulate the market, Transelectrica, the state-owned transmission system operator, managing the high-voltage grid and cross-border transmission, and the major distributors like Electrica, Enel, E.On and Hidroelectrica. Because solar is an intermittent resource, the market is pivoting toward Battery Energy Storage Systems (BESS). Integrating BESS is viewed as essential for maximizing economic efficiency and ensuring grid stability. Without storage, the surge in solar production during peak daylight hours could overwhelm an aging infrastructure that was originally designed for constant-load fossil fuel plants. For investors, the market is more accessible than ever. Platforms like PF Nexus are currently facilitating global connectivity for Romanian solar deals. Verified subscribers can analyze live deal flows ranging from 45 MW to as large as 1.4 GW.

The future of solar in Romania is tied to the future political decisions. The OECD recommends that the government complement its renewable subsidies with consistent carbon pricing, removal of fossil fuels, and infrastructure digitalization.

3. The wind energy market

While solar energy has recently captured the public imagination through residential prosumer growth, wind energy remains the industrial heavy lifter of Romania's green transition. As the nation aligns itself with European Union (EU) decarbonization mandates, the wind sector is being repositioned as a vital pillar for achieving a sustainable, net-zero economy. Romania possesses some of the most significant wind potential in South-Eastern Europe, making it a hotspot for large-scale utility projects and international investment.

Wind energy has historically been the primary driver of Romania's renewable electricity generation. As of late 2023, the country's total power capacity stands at approximately 18.4 GW. Within this mix, wind energy has long maintained a more substantial share than solar, providing the high-volume output necessary to balance the national grid as traditional coal plants are phased out. In August 2023, renewable resources, predominantly hydropower and wind, accounted for roughly 40% of the total generated power delivered by producers. This solid foundation is essential for meeting the targets set in the Integrated National Energy and Climate Plan (INECP), which aims for a renewable energy share of 34% to 36% by 2030. However, the market currently faces a paradox: while the natural resource is abundant, investment in new capacity has recently stalled and must accelerate rapidly to meet these end-of-decade goals.

Romania's wind energy potential is not uniformly distributed but is concentrated in high-performance corridors. In Dobrogea, between the Danube River and the Black Sea, the wind assured the perfect conditions for wind energy production, due to its consistent and high wind speeds. The coastal and offshore areas of Black Sea represent the next frontier. Romania is actively working to establish a legal framework for offshore wind, which is expected to unlock gigawatts of new capacity. While solar relies on 1,600 kWh/m² of irradiation, wind projects benefit from Romania's varied topography, allowing for diverse turbine placements in both mountain passes and open plains. The success of wind energy is entirely dependent on the capacity of the national grid to absorb and transport large volumes of electricity from rural generation sites to urban industrial centers.

Because wind is an intermittent resource, the market is increasingly focused on Battery Energy Storage Systems (BESS). Managing the sudden surges in power when wind speeds peak, storing excess power generated during low-demand periods, and ensuring the grid remains at a stable 50Hz frequency (which is critical for industrial equipment safety).

Obtaining the necessary environmental permits, construction licenses, and grid connection approvals in Romania often takes significantly longer than the two-year limit recommended by the EU. These delays can stretch projects into five-year cycles, increasing capital costs and financial risk. To solve this, the government is planning to designate renewable acceleration areas. These are specific geographic zones where environmental impact assessments have been pre-conducted, and administrative procedures are streamlined.

A massive shift is occurring in how wind projects are financed. Historically, developers relied on government-backed certificates. Today, the market has matured toward Power Purchase Agreements (PPAs).

Industry leaders like Rezolv Energy are at the forefront of this shift. As the PPA (Power Purchase Agreement) market in Southeast Europe matures, it's becoming much easier for corporations to lock in long-term contracts for clean energy. A major game-changer here is the Virtual PPA (VPPA) model. This setup allows companies based anywhere in Europe to effectively buy the "green" attributes of wind power generated in Romania, regardless of where their offices or factories are actually located. Because of this flexibility, Romania has turned into a regional investment hotspot; it allows international brands to hit their sustainability goals immediately by tapping into Romanian wind farms, even if the renewable capacity in their own home countries is still lagging behind.

4. A comparison of the two sectors

In Romania, the competition and synergy between solar and wind energy are at the heart of the nation's green transition. While wind energy has traditionally anchored the renewable sector, solar energy is currently undergoing a more rapid, decentralized expansion. This comparison explores their roles, targets, and the infrastructure supporting their growth.

Wind energy has long been the primary driver of Romania's renewable electricity generation. In 2023, wind remained a larger contributor to the overall energy mix than

solar. Together with hydropower, these sources accounted for approximately 40% of the total generated power delivered by producers as of August 2023. In contrast, solar power has historically played a smaller role, currently making up roughly 8.4% of Romania's total 18.4 GW capacity. However, the sector is at a pivotal "crossroads," with the government significantly raising its solar ambitions due to favorable conditions like high irradiation and low land costs.

The government's shifted priorities are clearly visible in the Integrated National Energy and Climate Plan (INECP), which targets a total renewable energy share of 34% to 36% by 2030. The national target for photovoltaic (PV) energy has been aggressively revised upward from 1,400 MW to 3,140 MW by 2030. While wind remains critical, the focus is expanding toward offshore wind in the Black Sea, where the government is currently developing a legal framework to unlock massive new capacity.

A major point of comparison is how these technologies are integrated into the market. Solar growth is increasingly driven by prosumers, individuals, and businesses that produce and consume their own energy. Supported by subsidies like the "Casa Verde" program, this decentralized growth offers benefits like lower costs and energy independence. Wind projects are almost exclusively large-scale, utility-led endeavors. They require high-voltage transmission managed by Transelectrica and are essential for replacing the base-load power lost from retiring coal plants.

On the natural resources topic, Romania enjoys an average of 1,600 kWh/m² of annual solar irradiation, with prime locations concentrated in the southern regions, while resources are most potent in the Dobrogea region and along the Black Sea coast. These areas offer high capacity factors and are the primary focus for the next generation of onshore and offshore farms.

Both sectors share common technical and administrative hurdles that require urgent attention. The intermittent nature of both wind and solar makes Battery Energy Storage Systems (BESS) a market necessity. Integrating storage is vital for stabilizing the grid and ensuring economic efficiency. For both technologies, the licensing process often exceeds the EU-recommended two-year limit. The government is considering renewable acceleration areas to fast-track permitting for both solar and wind. The INECP emphasizes the need for smart metering and smart network technologies to handle the bidirectional energy flow from solar prosumers and variable wind generation.

5. Conclusion

To conclude, the choice between solar and wind investment in Romania is not a matter of one being objectively better than the other, but rather which aligns with an investor's risk profile, scale, and time horizon. Both markets are currently "hotspots" driven by the maturation of the Power Purchase Agreement (PPA) market and the urgent need to replace retiring coal-intensive infrastructure.

Solar energy is arguably the better investment for those seeking faster deployment and diversified risk. Romania's high annual irradiation (1,600 kWh/m²) and the government's

aggressive upward revision of PV targets (from 1,400 MW to 3,140 MW by 2030) create a high-growth environment. There are low entry barriers and rapid scalability. Developers like Rezolv Energy are proving that solar can also play in the big leagues, with plans for Europe's largest solar plant in western Romania.

Wind energy is the superior investment for large-scale institutional players focused on utility-scale dominance. While investment has recently stalled, this creates a vacuum that savvy investors can fill as the government pushes for 2030 targets. The Black Sea is the next big area for massive energy projects. Investors who get involved now can help set the rules and technical standards for offshore wind power. By starting early, they can gain a first-mover advantage in a market that is known for producing a high and steady amount of electricity. Wind is basically the backbone of the power grid. Since it pumps out such a huge amount of energy, it's a perfect fit for the Virtual PPA model. This is where big international companies basically buy up the green bragging rights from Romanian wind farms to hit their global sustainability targets.

If you are an investor looking for agility and shorter permitting cycles, solar is currently more attractive. Its decentralized nature and strong prosumer support make it less vulnerable to the massive grid-congestion issues that plague large wind farms. However, if you are a long-term institutional investor, wind offers the scale and high output necessary to dominate the regional energy market.

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On the equivalence and nonequivalence of import subsidies and export subsidies

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Abstract. *The purpose of this paper is to verify whether the Lerner symmetry theorem holds for export subsidies and import subsidies in an endogenous growth model with international location of manufactures. In this paper, we show that the Lerner symmetry theorem, which states that a country's export subsidies and import subsidies have the same resource allocation effect, does not hold in the aspects of international manufacture mobility and world economic growth rate. In particular, in contrast to the Lerner symmetry theorem, we show that export subsidies and import subsidies in the same location have rather opposite effects in these two aspects.*

Keywords: import subsidies, export subsidies, Lerner symmetry theorem, location, growth.

JEL Classification: F13, F43, O31.

1. Introduction

In an era of accelerating globalization, driven by the transboundary relocation of manufactures and a global trend toward increased government involvement in domestic and international markets through industrial policy—under the pretext of protecting and nurturing domestic industries—it is crucial to understand the economic impact of industrial policy within a realistic framework. Recently, attention has been drawn to trade-related industrial policies, including tariffs, export restrictions, import quotas, and production subsidies. However, while the effects of import tariffs have been extensively studied in the field of international economics, those of government subsidy policies, such as export and import subsidies, have not. Even if they are the same type of subsidy, the purposes of export subsidies and import subsidies are very different, and each country uses and implements them based on its economic situation (such as the availability of mineral resources and the maturity of its industry). Export subsidies have been implemented in many countries, not only under the pretext of protecting domestic industries, but also primarily targeting products considered strategically important in industries that can leverage economies of scale. Examples include semiconductors, electric vehicles, steel, and aluminum. Import subsidies, on the other hand, are government subsidies for imports of goods with an absolute shortage, such as mineral resources (e.g., crude oil and copper), production materials (e.g., feed and fertilizer), and staple foodstuffs (Anderson et al., 2008). One example is China's subsidy for capital goods imports, which is already in force⁽¹⁾.

According to Lerner's (1936) symmetry theorem, the economic effects of export and import subsidies are explained in the same manner. Intuitively, a country's export subsidies cause a shift of inputs from domestic import industries to domestic export industries. This results in a contraction of the former and an expansion of the latter. Similarly, a country's import subsidies induce a redistribution of inputs from import industries to export industries through increased competition in import industries. This results in a contraction of domestic import industries and an expansion of export industries. Thus, Lerner's symmetry theorem predicts that import and export subsidies have the same economic effect in a model of perfect competition with no capital mobility due to their similar effects on relative prices.

However, many researchers have already shown that once capital mobility, imperfect competition and trade imbalances are introduced into the perfect competition model without capital mobility assumed by Lerner, Lerner's symmetry theorem breaks down. For example, Ray (1975) departed from Lerner's perfect competition model and considered the case of monopoly power in domestic production of imported goods, and showed that Lerner's symmetry theorem does not hold in such a model and that export taxes and import duties affecting the demand curve have an asymmetric effect on competition in domestic markets for imported goods. Blanchard (2009) also shows the possibility of trade imbalances by introducing international ownership into McKinnon's (1966) model from traditional trade theory, which assumes trade equilibrium, and shows that Lerner symmetry is not obtained when there is international investment⁽²⁾. Furthermore, Costinot and

Werning (2019) reexamine Lerner's symmetry theorem within a broader, more contemporary framework. They introduce multinational firms, domestic ownership of foreign assets, and imperfect competition, all of which were absent from Lerner's original model. Unlike Ray (1975), Costinot and Werning demonstrate that Lerner's symmetry theorem remains robust in imperfectly competitive markets without multinational firms. However, they also reveal that the theorem may break down when multinational firms are considered⁽³⁾.

In the current global economic situation, globalization has progressed to the point that manufacturers can more easily shift their production bases internationally. This global trend suggests that Lerner's symmetry theorem is becoming less applicable to export and import subsidies. Furthermore, previous research indicates that the theorem does not apply to economic growth models that consider the cross-border movement of manufacturing industries. This study aims to analyze export and import subsidies and demonstrate how the theorem breaks down within the framework of endogenous growth theory.

The primary conclusions of this study indicate that export subsidies and import subsidies within the same geographical location exert contradictory economic influences on these two dimensions of international manufacturing relocation and global economic growth rate. However, the present study demonstrates that the impact of import subsidies in a given location is equivalent to the impact of export subsidies in a foreign location. This study's contribution was its provision of findings regarding the equivalence of import and export subsidies in a modern growth model that considers imperfect competition, the transboundary of manufacturing, and transportation costs.

This paper is organized into the following sections. Section 2 outlines the model's features. Section 3 describes the steady-state equilibrium under global knowledge spillovers in the innovative research and development (R&D). Section 4 analyzes how a unilateral increase in import and export subsidies affects the location of manufactures under global spillovers. It also discusses the implications of this result for the Lerner symmetry theorem. Section 5 describes the steady-state equilibrium under local knowledge spillovers in the R&D. Section 6 examines the effects of increased import and export subsidies on the location of manufactures and the global growth rate under local knowledge spillovers. It also considers the influence of local knowledge spillovers and its implications for the Lerner symmetry theorem. Section 7 concludes the paper.

2. Model structure

This paper uses a two-location model that includes the home location and the foreign location. In this model, the mobility of manufactures across the two locations is assumed, unlike that of owners. The lifetime utility function of a representative household is defined as

$$U = \int_0^\infty \log(E(t)^\beta X(t)^{1-\beta}) e^{-\rho t} dt. \quad (1)$$

In the above utility function, $X(t)$ is the numeraire product and $E(t)$ is defined as

$$E(t) = \left(\int_{i=0}^{N(t)} E(i, t)^{1-1/\sigma} di \right)^{1/(1-1/\sigma)}, \sigma > 1. \quad (2)$$

In equation (2), $E(i, t)$ denotes the consumption spending of differentiated product i , $N(t)$ represents the total number of products that have been produced and differentiated in both home and foreign locations, and σ is the elasticity of substitution between any two products. The home government provides two types of subsidies in this model: an import subsidy (s_m) for products imported from abroad, and an export subsidy (s_x) for products exported from the home location. For simplicity, we assume that the foreign government only provides export subsidies, s_x^* , and does not provide import subsidies. Within this model, the asterisk is utilized to indicate variables associated with the foreign location. Additionally, we assume that the numeraire product is not subject to import or export subsidies. Furthermore, every household supplies one unit of labor to earn $w(t)$. The intertemporal budget constraint of each household is formulated as

$$\dot{K}(t) = r(t)K(t) + (1 - s_h^w)w(t) - (1 + s_h^D)D(t) - T(t), \quad (3)$$

where $K(t)$, $r(t)$, s_h^w , $w(t)$, s_h^D , $D(t)$ and $T(t)$ are used to denote equity holdings, the interest rate, the wage tax rate, the wage rate, the consumption tax rate, the value of expenditure, and the lump-sum tax levied by the government per capita to finance import and export subsidies, respectively. We also make the assumption that transportation costs for differentiated products between locations are iceberg costs τ ($\tau \geq 1$). The amount of spending in the home location, D , is expressed as follows:

$$D = X + \int_{i \in n} P(i)E(i)di + \int_{j \in n^*} (1 - s_m)(1 - s_x^*)\tau P^*(j)E(j)dj. \quad (4)$$

Equation (4) shows that there are n manufactures in the home location and n^* manufactures in the foreign location, and $n + n^* = N$. Moreover, $P(i)$ is the home price of a variety i , while $P^*(j)$ is its price in the foreign location. Each location's differentiated product price indices are then

$$P^E = \left(\int_{i \in n} P(i)^{1-\sigma} di + \int_{j \in n^*} ((1 - s_m)(1 - s_x^*)\tau P^*(j))^{1-\sigma} dj \right)^{1/(1-\sigma)}, \quad (5)$$

$$P^{E*} = \left(\int_{i \in n} ((1 - s_x)\tau P(i))^{1-\sigma} di + \int_{j \in n^*} P^*(j)^{1-\sigma} dj \right)^{1/(1-\sigma)}, \quad (6)$$

where P^E is the home price index, and P^{E*} is the foreign price index. In the differentiated products sector, a patent is required to start production, so this cost can be considered fixed. To finance this cost, each manufacture issues equities. Furthermore, production requires η units of labor. Choosing $P(i)$ to maximize profit yields the following result: $P(i) = \eta\sigma/(\sigma - 1)$. Therefore, the profit of each manufacture ($= \Pi(i)$) is calculated as

$\Pi(i) = P(i)q(i) - W\eta q(i) = W\eta q(i)/(\sigma - 1)$, where $q(i)$ denotes the amount of output. On the other hand, the homogeneous product X is assumed to be produced using a linear technology with coefficient 1. It is also assumed that X is produced in both locations. Therefore, the wage rate in both locations is represented by $W = W^* = 1$, since the numeraire is the homogeneous product. Thus, $P = P^* = \eta\sigma/(\sigma - 1)$. For convenience, we define $\delta \equiv \tau^{1-\sigma} \in (0, 1)$. In the household's decision-making process, when presented with the options $E(i)$ and $E(j)$, conventional utility maximization allocates a fraction β of D to $E(i)$ and $E(j)$, while allocating the residual fraction $(1 - \beta)$ of D to X :

$$\begin{aligned} E(i) &= \frac{(\sigma-1)}{\eta\sigma} \left(\frac{\beta D}{n+n^*(1-s_m)^{1-\sigma}(1-s_x^*)^{1-\sigma}\delta} \right), \\ E(j) &= \frac{(\sigma-1)}{\eta\sigma} \left(\frac{\beta D(1-s_m)^{-\sigma}(1-s_x^*)^{-\sigma}\tau^{-\sigma}}{n+n^*(1-s_m)^{1-\sigma}(1-s_x^*)^{1-\sigma}\delta} \right), X = (1 - \beta)D. \end{aligned} \quad (7)$$

Here, b represents equity value and r represents the return on a riskless bond. Thus, a no-arbitrage condition in capital markets establishes $\eta q/(\sigma - 1) + \dot{b} = rb$ by considering $W = W^* = 1$ and $\Pi(i) = W\beta x(i)/(\sigma - 1)$. The intertemporal optimization problem is then solved. To accomplish this, we require the following Euler equation, which results from maximizing (1) subject to (3): $\dot{D}/D = \dot{D}^*/D^* = r - \rho$. Next, we determine the optimal scale of production of differentiated products and the optimal share of manufactures in the home location. To do this, we aggregate (7) over all households. This results in the market-clearing condition for q and q^* :

$$q = \frac{\beta L(\sigma-1)}{\eta\sigma} \left(\frac{D}{n+n^*(1-s_m)^{1-\sigma}(1-s_x^*)^{1-\sigma}\delta} + \frac{D^*(1-s_x)^{-\sigma}\delta}{n^*+n(1-s_x)^{1-\sigma}\delta} \right), \quad (8)$$

$$q^* = \frac{\beta L(\sigma-1)}{\eta\sigma} \left(\frac{D(1-s_m)^{-\sigma}(1-s_x^*)^{-\sigma}\delta}{n+n^*(1-s_m)^{1-\sigma}(1-s_x^*)^{1-\sigma}\delta} + \frac{D^*}{n^*+n(1-s_x)^{1-\sigma}\delta} \right). \quad (9)$$

In equations (8) and (9), we keep the amount of labor endowment, L , the same in both locations. A manufacture's neutral position in choosing between the home and foreign locations is defined by equal profitability in both locations, as illustrated by the equation: $\Pi = \Pi^*$. Thus, using the equations $\Pi = W\eta q/(\sigma - 1)$, $\Pi = \Pi^*$, and $W = W^* = 1$, we obtain that $q = q^*$. The next step is to define F and F^* . F will be the home capital stock, and F^* will be the foreign capital stock. The total capital stock, $F + F^*$, determines N : $F + F^* = N$. Equations (8), (9), $\Pi = \Pi^*$ and $n + n^* = N$ are solved to obtain the share of manufactures located in the home location, defined by ξ , for a given level of spending in each location:

$$\xi = \frac{n}{N} = \frac{[1-(1-s_m)^{-\sigma}(1-s_x^*)^{-\sigma}\delta]D - [1-(1-s_x)^{-\sigma}\delta](1-s_m)^{1-\sigma}(1-s_x^*)^{1-\sigma}\delta D^*}{M}, \quad (10)$$

where

$$M = [1 - (1 - s_m)^{-\sigma}(1 - s_x^*)^{-\sigma}\delta][1 - (1 - s_x)^{1-\sigma}\delta]D + [1 - (1 - s_x)^{-\sigma}\delta][1 - (1 - s_m)^{1-\sigma}(1 - s_x^*)^{1-\sigma}\delta]D^*.$$

Each firm's output is determined as follows:

$$q = q^* = \beta L \left(\frac{\sigma-1}{\eta\sigma} \right) \frac{M}{N} \left\{ \frac{1-(1-s_m)^{-\sigma}(1-s_x^*)^{-\sigma}\delta(1-s_x)^{-\sigma}\delta}{[1-(1-s_m)^{1-\sigma}(1-s_x^*)^{1-\sigma}\delta(1-s_x)^{1-\sigma}\delta][1-(1-s_m)^{-\sigma}(1-s_x^*)^{-\sigma}\delta][1-(1-s_x)^{-\sigma}\delta]} \right\}. \quad (11)$$

This paper also assumes $F > F^*$, as an initial condition. This is based on Martin (1999) and Martin and Ottaviano (1999). This assumption implies that there are more manufactures in the home location than in the foreign location.

3. The case of global knowledge spillover

We assume that R&D occurs under a linear technology, in which invention activity is proportional to labor input. To understand why researchers do R&D, we value the design created through R&D as b . In this section, we adopt the same assumption as Martin and Ottaviano (1999): that local R&D contributes to knowledge spillovers, which increase worldwide R&D productivity as global public goods. Therefore, R&D costs are assumed to be inversely proportional to the number of manufactures in the world. The assumption is made that a researcher involved in R&D utilizes κ/N units of labor, irrespective of their location, due to the presence of global spillovers. So, when it's free to enter the R&D sector, the result is $b = \kappa/N$. Next, we present a steady state in which the growth rate of N and the parameter ξ are constant. The value of equity, b , is determined by $b = \kappa/N$. Thus, assuming a balanced growth path implies a decline in b at the rate $g = \dot{N}/N$. Moreover, the condition for a worldwide labor market to clear is as follows:

$$\kappa g + (1 - \beta)L(D + D^*) + \beta L \left(\frac{\sigma-1}{\sigma} \right) MI = 2L, \quad (12)$$

where

$$I = \frac{1-(1-s_m)^{-\sigma}(1-s_x^*)^{-\sigma}\delta(1-s_x)^{-\sigma}\delta}{[1-(1-s_m)^{1-\sigma}(1-s_x^*)^{1-\sigma}\delta(1-s_x)^{1-\sigma}\delta][1-(1-s_m)^{-\sigma}(1-s_x^*)^{-\sigma}\delta][1-(1-s_x)^{-\sigma}\delta]}. \quad (13)$$

Since g and ξ are constant in the steady state, D and D^* must also be constant, according to equation (12). This yields $r = \rho$ from the equation $\dot{D}/D = \dot{D}^*/D^* = r - \rho$. Then, by substituting equation (11), $\dot{b} = -gb$, $b = \kappa/N$, and $r = \rho$ into the equation $\eta q/(\sigma - 1) + \dot{b} = rb$, and considering equation (12), the following growth rate for the world is obtained:

$$g = \frac{2L}{\kappa\sigma} - \frac{(1-\beta)L(D+D^*)}{\kappa\sigma} - \left(\frac{\sigma-1}{\sigma} \right) \rho. \quad (14)$$

The budget constraint equation for each location's government that leads to tax revenue neutrality is $s_h^w W + s_h^D D = s_m \tau n^* P^*(f) E(f) + s_x \tau n P(h) E^*(h)$ and $s_f^w W^* + s_f^{D^*} D^* = s_x^* \tau n^* P^*(f) E(f)$, respectively. As indicated above, the government budget constraint necessitates that the financing of import and export subsidies be supported by revenues derived from consumption and wage taxes. Thus, taking into account the government's budget constraint equation above, the amount of spending in each country in the steady state is as $D = 1 + \rho \kappa f / L$ and $D^* = 1 + \rho \kappa (1 - f) / L$, where $f \equiv F/N$. Therefore, the

world expenditure is derived as $D + D^* = 2 + \rho\kappa/L$. Next, the growth rate is determined by equations (14) and $D + D^* = 2 + \rho\kappa/L$, as follows:

$$g = \frac{1}{\sigma} \left(\frac{2\beta L}{\kappa} - \rho(\sigma - \beta) \right). \quad (15)$$

Therefore, the following results are obtained from (15):

$$\frac{\partial g}{\partial s_m} = 0, \quad \frac{\partial g}{\partial s_x^*} = 0, \quad \frac{\partial g}{\partial s_x} = 0. \quad (16)$$

According to equation (16), the global growth rate is unaffected by locations' import or export subsidies. This is because the financial burden of import or export subsidies is counteracted by the government's budget constraints due to the neutrality of tax revenue. Furthermore, in this model, knowledge spillovers are considered international public goods. Consequently, the cost of R&D investment is the same in all locations because manufactures can immediately absorb foreign knowledge, regardless of their location. Therefore, R&D investment in each location is unaffected by the international movement of manufactures caused by import or export subsidies. Therefore, in our model, neither import nor export subsidies affect innovation in each location, nor do they affect the world growth rate.

4. Location effects under global knowledge spillover

In this section, we analyze how a unilateral increase in import and export subsidies affects the location of manufactures under the condition of global knowledge spillovers. By substituting equations $D = 1 + \rho\kappa f/L$ and $D^* = 1 + \rho\kappa(1-f)/L$ into ξ , as defined by equation (10), we can derive

$$\xi = \frac{n}{N} = \frac{[1 - (1-s_m)^{-\sigma}(1-s_x^*)^{-\sigma}\delta] \left(1 + \frac{\rho\kappa f}{L}\right) - [1 - (1-s_x)^{-\sigma}\delta](1-s_m)^{1-\sigma}(1-s_x^*)^{1-\sigma}\delta \left[1 + \frac{\rho\kappa(1-f)}{L}\right]}{[1 - (1-s_m)^{-\sigma}(1-s_x^*)^{-\sigma}\delta][1 - (1-s_x)^{1-\sigma}\delta] \left(1 + \frac{\rho\kappa f}{L}\right) + [1 - (1-s_x)^{-\sigma}\delta][1 - (1-s_m)^{1-\sigma}(1-s_x^*)^{1-\sigma}\delta] \left[1 + \frac{\rho\kappa(1-f)}{L}\right]}. \quad (17)$$

According to equation (17), an increase in import subsidies by the home location has the following effect on the location of the manufacture in the home location:

$$\left. \frac{\partial \xi}{\partial s_m} \right|_{s_m=s_x=s_x^*=0} = -\frac{(1-\delta)^2\delta}{M^2} \left\{ \left[\sigma \left(1 + \frac{\rho\kappa f}{L} \right) + (\sigma - 1)(1 - \delta) \right] \left(2 + \frac{\rho\kappa}{L} \right) - \left[\sigma \left(1 + \frac{\rho\kappa f}{L} \right) + (\sigma - 1) \left(1 + \frac{\rho\kappa(1-f)}{L} \right) \right] \left[1 - \delta + \frac{\rho\kappa f}{L} - \delta \frac{\rho\kappa(1-f)}{L} \right] \right\} < 0. \quad (18)$$

Equation (18) shows that an increase in unilateral import subsidies in the home location decreases ξ . The explanation for this result is as follows: An increase in import subsidies

in the home location increases the sales of imported foreign products in the home location. This increases profits from exports to the home location for manufactures located in the foreign location. This creates an incentive for manufactures in the home location to relocate to the foreign location. As a result, manufactures move from the home location to the foreign location. Next, according to equation (17), an increase in export subsidies in the foreign location affects ξ as follows:

$$\left. \frac{\partial \xi}{\partial s_x^*} \right|_{s_m=s_x=s_x^*=0} = -\frac{(1-\delta)^2 \delta}{M^2} \left\{ \left[\sigma \left(1 + \frac{\rho \kappa f}{L} \right) + (\sigma - 1)(1 - \delta) \right] \left(2 + \frac{\rho \kappa}{L} \right) - \left[\sigma \left(1 + \frac{\rho \kappa f}{L} \right) + (\sigma - 1) \left(1 + \frac{\rho \kappa(1-f)}{L} \right) \right] \left[1 - \delta + \frac{\rho \kappa f}{L} - \delta \frac{\rho \kappa(1-f)}{L} \right] \right\} < 0. \quad (19)$$

Equation (19) shows that a rise in export subsidies in the foreign location leads to a smaller share of manufactures in the home location. The reason for this outcome is explained below. A unilateral export subsidies increase in the foreign location has been demonstrated to increase the sales of imported foreign products in the home location. This suggests that there is a potential for an increase in profits from exports to the home location for manufactures located in the foreign location. This, in turn, fosters an incentive for domestic manufactures to relocate to the foreign location, thereby prompting manufactures to migrate from the home location to the foreign location. Next, according to equation (17), a rise in export subsidies in the home location has the following impact on ξ :

$$\left. \frac{\partial \xi}{\partial s_x} \right|_{s_m=s_x=s_x^*=0} = \frac{(1-\delta)^2 \delta}{M^2} \left\{ \sigma \delta \left(1 + \frac{\rho \kappa(1-f)}{L} \right) \left(2 + \frac{\rho \kappa}{L} \right) + \left[1 + \frac{\rho \kappa f}{L} - \delta \left(1 + \frac{\rho \kappa(1-f)}{L} \right) \right] \left[(\sigma - 1) \left(1 + \frac{\rho \kappa f}{L} \right) + \sigma \left(1 + \frac{\rho \kappa(1-f)}{L} \right) \right] \right\} > 0. \quad (20)$$

Equation (20) shows that a rise in export subsidies in the home location leads to a larger share of manufactures being located there. The explanation for this result is as follows. An export subsidies increase in the home location has been demonstrated to increase the sales of exported home products in the foreign location. This phenomenon suggests a potential increase in profits from exports to the foreign location for manufactures located in the home location. This fosters an incentive for foreign manufactures to relocate to the home location, thereby prompting manufactures to transition from the foreign location to the home location.

Equations (18) and (19) show that the effects of a rise in import subsidies in the home location and a unilateral increase in export subsidies in the foreign location on manufacture location are identical. In summary, the following equation is valid:

$$\left. \frac{\partial \xi}{\partial s_m} \right|_{s_m=s_x=s_x^*=0} = \left. \frac{\partial \xi}{\partial s_x^*} \right|_{s_m=s_x=s_x^*=0}. \quad (21)$$

Equations (18) and (20), on the other hand, demonstrate that unilateral increases in import and export subsidies in the home location have opposing effects. Therefore, the following equation is valid:

$$\left. \frac{\partial \xi}{\partial s_m} \right|_{s_m=s_x=s_x^*=0} \neq \left. \frac{\partial \xi}{\partial s_x} \right|_{s_m=s_x=s_x^*=0}. \quad (22)$$

Equation (21) illustrates that the effects on manufacturing locations resulting from an increase in import subsidies in the home location and an increase in export subsidies in the foreign location are equivalent. However, as equation (21) shows, the effects on manufacturing locations of a rise in import and export subsidies in the same country manifest an asymmetrical pattern.

As previously discussed, the Lerner symmetry theorem does not hold in the context of international manufacturing relocation within an endogenous growth model incorporating manufacturing relocation. However, the aforementioned findings demonstrate that the symmetry theorem is applicable to home location import subsidies and foreign location export subsidies, rather than to home location import subsidies and export subsidies.

5. The case of local knowledge spillover

In the context of local R&D spillovers, R&D-related knowledge is regarded as local public goods. It is further assumed that knowledge spillovers exclusively augment R&D productivity within the domestic location, without exerting any effect on the productivity of the foreign location. Consequently, in accordance with Martin and Ottaviano's (1999) model, this study posits that, under the context of local spillovers, the cost of R&D in a given location is inversely proportional to the number of existing manufactures in that location. Consequently, it is formulated that R&D activities employ κ/n units of labor in the home location and κ/n^* units in the foreign location. In this model, κ is a parameter that represents the productivity of the R&D sector, assumed to be constant across both locations. This suggests that if the number of manufactures in the home location differs from the number of manufactures in the foreign location, then R&D activity will be conducted in the location with the greater number of manufactures. In the model under consideration, a relatively larger capital stock in the home location than in the foreign location ($F > F^*$) results in higher real expenditures on differentiated goods in the home location than in the foreign location. Consequently, this results in economies of scale within the product sector, leading to greater manufacturing concentration in the home location compared to the foreign one. Therefore, the entirety of R&D activity is conducted within the home location, thereby influencing the global growth rate. The free entry of

manufactures into the R&D sector is characterized by $b = \kappa/n$. Consequently, b is determined by the free entry condition, $b = \kappa/N\xi$. Therefore, the balanced growth assumption indicates a decline in b at a rate of g , which is equivalent to the differential equation $g = \dot{N}/N = \dot{n}/n$. The following is a delineation of the prevailing conditions in the global labor market:

$$\kappa \frac{g}{\xi} + (1 - \beta)L(D + D^*) + \beta L \left(\frac{\sigma-1}{\sigma} \right) MI = 2L, \quad (23)$$

$$I = \frac{1 - (1 - s_m)^{-\sigma} (1 - s_x^*)^{-\sigma} \delta (1 - s_x)^{-\sigma} \delta}{[1 - (1 - s_m)^{1-\sigma} (1 - s_x^*)^{1-\sigma} \delta (1 - s_x)^{1-\sigma} \delta][1 - (1 - s_m)^{-\sigma} (1 - s_x^*)^{-\sigma} \delta][1 - (1 - s_x)^{-\sigma} \delta]}.$$

Substituting (11), $\dot{b} = -gb$, $b = \kappa/N\xi$, and $r = \rho$ into the equation $\eta q/(\sigma - 1) + \dot{b} = rb$, and considering (23), the following growth rate is obtained:

$$g = \frac{2L\xi}{\kappa\sigma} - \frac{(1-\beta)L\xi(D+D^*)}{\kappa\sigma} - \left(\frac{\sigma-1}{\sigma} \right) \rho. \quad (24)$$

Therefore, given each location's government budget constraint, $s_h^w W + s_h^D D = s_m \tau n^* P^*(f) E(f) + s_x \tau n P(h) E^*(h)$ and $s_f^w W + s_f^D D = s_x^* \tau n^* P^*(f) E(f)$, respectively, the amount of expenditure in each location in steady state is as $D = 1 + \rho\kappa f/\xi L$ and $D^* = 1 + \rho\kappa(1 - f)/\xi L$, where $f \equiv F/N$. In this case, the global spending is determined as $D + D^* = 2 + \rho\kappa/\xi L$. The growth rate is subsequently derived from equations (24) and $D + D^* = 2 + \rho\kappa/\xi L$ as follows:

$$g = \frac{1}{\sigma} \left(\frac{2\beta L}{\kappa} \xi - \rho(\sigma - \beta) \right). \quad (25)$$

Substituting the equations $D = 1 + \rho\kappa f/\xi L$ and $D^* = 1 + \rho\kappa(1 - f)/\xi L$ into ξ yields the following result.

$$\xi = \frac{n}{N} = \frac{[1 - (1 - s_m)^{-\sigma} (1 - s_x^*)^{-\sigma} \delta] \left(1 + \frac{\rho\kappa f}{\xi L} \right) - [1 - (1 - s_x)^{-\sigma} \delta] (1 - s_m)^{1-\sigma} (1 - s_x^*)^{1-\sigma} \delta \left[1 + \frac{\rho\kappa(1-f)}{\xi L} \right]}{[1 - (1 - s_m)^{-\sigma} (1 - s_x^*)^{-\sigma} \delta][1 - (1 - s_x)^{1-\sigma} \delta] \left(1 + \frac{\rho\kappa f}{\xi L} \right) + [1 - (1 - s_x)^{-\sigma} \delta][1 - (1 - s_m)^{1-\sigma} (1 - s_x^*)^{1-\sigma} \delta] \left[1 + \frac{\rho\kappa(1-f)}{\xi L} \right]}. \quad (26)$$

From equation (26), the following quadratic equation is obtained for ξ :

$$J_1 \xi^2 + J_2 \xi + J_3 = 0, \quad (27)$$

where

$$J_1 = L[1 - (1 - s_m)^{-\sigma} (1 - s_x^*)^{-\sigma} \delta][1 - (1 - s_x)^{1-\sigma} \delta] + L[1 - (1 - s_x)^{-\sigma} \delta][1 - (1 - s_m)^{1-\sigma} (1 - s_x^*)^{1-\sigma} \delta] > 0, \quad (28)$$

$$\begin{aligned}
J_2 = & \rho\kappa f[1 - (1 - s_m)^{-\sigma}(1 - s_x^*)^{-\sigma}\delta][1 - (1 - s_x)^{1-\sigma}\delta] + \\
& + \rho\kappa(1 - f)[1 - (1 - s_x)^{-\sigma}\delta][1 - (1 - s_m)^{1-\sigma}(1 - s_x^*)^{1-\sigma}\delta] - \\
& - L[1 - (1 - s_m)^{-\sigma}(1 - s_x^*)^{-\sigma}\delta] + \\
& + L[1 - (1 - s_x)^{-\sigma}\delta](1 - s_m)^{1-\sigma}(1 - s_x^*)^{1-\sigma}\delta,
\end{aligned} \tag{29}$$

$$\begin{aligned}
J_3 = & -\rho\kappa f[1 - (1 - s_m)^{-\sigma}(1 - s_x^*)^{-\sigma}\delta] + \\
& + \rho\kappa(1 - f)[1 - (1 - s_x)^{-\sigma}\delta](1 - s_m)^{1-\sigma}(1 - s_x^*)^{1-\sigma}\delta < 0.
\end{aligned} \tag{30}$$

For equation (29), when L is large, and ρ , κ , and δ , are small, we obtain

$$J_2 < 0. \tag{31}$$

The positive root of the equation,

$$\xi = \frac{-J_2 + \sqrt{J_2^2 - 4J_1J_3}}{2J_1}, \tag{32}$$

is the solution that is valid.

6. Location and growth effects under local knowledge spillover

In this section, we examine how a unilateral increase in import and export subsidies affects the location of manufactures and the growth rate. Here, we take into account the influence of localized knowledge spillovers. We also assume that the conditions for the validity of (31) are met, meaning that L is large and ρ , κ , and δ are small. According to equation (32), the effects of increasing import subsidies in the home location and export subsidies in the foreign location are as follows:

$$\left. \frac{\partial \xi}{\partial s_m} \right|_{s_m=s_x=s_x^*=0} = \left. \frac{\partial \xi}{\partial s_x^*} \right|_{s_m=s_x=s_x^*=0} < 0. \tag{33}$$

The intuitive explanation of equation (33) is equivalent to those given in equations (18) and (19), assuming global spillovers. Next, according to equation (32), a unilateral increase in export subsidies by the home location affects ξ as follows:

$$\left. \frac{\partial \xi}{\partial s_x} \right|_{s_m=s_x=s_x^*=0} > 0. \tag{34}$$

The intuitive explanation of equation (34) is equivalent to that of equation (20), which assumes global spillovers. Therefore, based on equations (33) and (34), the Lerner symmetry theorem does not apply to the impact of international manufacture relocation in an endogenous growth model that includes manufacture relocation, even under localized R&D spillovers. In summary, in the context of local R&D spillovers, the symmetry theorem does not apply to import subsidies and export subsidies in the same location with respect to their impact on international manufacturing relocation. In the context of local R&D spillovers, the symmetry theorem finds application in the context of home import subsidies

and foreign export subsidies, with regard to their impact on international manufacturing relocation. These results are key to understanding the effects of unilateral increases in import and export subsidies on world growth under local knowledge spillovers, which will be examined below.

We then examine how an increase in import and export subsidies in each location affects the global growth rate by looking at how it impacts manufacture location under local knowledge spillovers. Using the results of (33) and (34), we differentiate (25) with respect to each location's import and export subsidies and arrive at the following results:

$$\left. \frac{\partial g}{\partial s_m} \right|_{s_m=s_x=s_x^*=0} = \left. \frac{\partial g}{\partial s_x^*} \right|_{s_m=s_x=s_x^*=0} < 0, \quad (35)$$

$$\left. \frac{\partial g}{\partial s_x} \right|_{s_m=s_x=s_x^*=0} > 0. \quad (36)$$

As mentioned earlier, the global growth rate is influenced by a location's R&D activity, provided there are local knowledge spillovers. According to equations (33) and (35), increasing import subsidies in the home location and export subsidies in the foreign location decreases the world growth rate by attracting home manufactures to the foreign location. Conversely, equations (34) and (36) show that increasing export subsidies in the home location positively affects the world growth rate by attracting foreign manufactures to the home location. Equations (35) and (36) demonstrate that the effects of an increase in import and export subsidies in the same location on world growth are asymmetric when local knowledge spillovers are considered. For these reasons, the Lerner symmetry theorem does not hold for the impact on the world growth rate in an endogenous growth model that includes manufacture relocation under the condition of local knowledge spillovers. In other words, in our model, the symmetry theorem holds not between a home location's import subsidies and export subsidies but between a home location's import subsidies and a foreign location's export subsidies.

7. Conclusion

In this study, an endogenous growth model that incorporates manufacturing location was employed to examine the validity of the equivalence of import and export subsidies in the context of international manufacturing relocation and global growth. Our analysis revealed that the Lerner symmetry theorem, which asserts that import and export subsidies within a location have identical economic consequences, is invalid in cases of international manufacturing relocation and global growth. Specifically, our model showed that import and export subsidies in the same location have opposite effects. However, we found that an equivalence relationship exists between home import subsidies and foreign export subsidies in all cases of international manufacturing relocation and world growth rates.

Notes

- ⁽¹⁾ Two empirical studies examining the effects of these subsidies on capital goods imports in China are Li et al. (2023) and Huang et al. (2023).
- ⁽²⁾ McKinnon (1966) expanded upon Lerner's (1936) two-final-goods model by creating a model with three final goods. He compared the case with only a tariff to the case with an export tax and an import subsidy. This comparison showed that both cases were equivalent in terms of resource allocation. Thus, McKinnon simultaneously proved the robustness of Lerner's symmetry theorem.
- ⁽³⁾ Additionally, the following studies have attempted to generalize the Lerner symmetry theorem: Yeh (1990), Casas (1991), Lapan and Gervais (2004), Francois and Manchin (2014), Lindé and Pescatori (2019), Azacis and Collie (2020), and Itskhoki and Mukhin (2023).

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AI-simulated reciprocity and the narrowing of decision options within human attachment psychological architecture

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Abstract. *This paper examines how regular interaction with artificial intelligence systems that simulate reciprocal conversation may influence the cognitive structure of attachment-related decision-making. Drawing on attachment theory, behavioural economics, and social exchange theory, the study explores how AI-mediated interaction may gradually reshape the way individuals evaluate relational uncertainty, vulnerability, and commitment. The analysis identifies three structural mechanisms through which AI-simulated reciprocity may affect attachment-related decision processes: reward without vulnerability, synthetic reciprocity without agency, and the narrowing of perceived decision options. In human relationships, emotional validation and reciprocity are typically contingent upon vulnerability, negotiation, and effort, creating a probabilistic reward structure that sustains relational investment. AI systems, however, can provide immediate and consistent validation without requiring reciprocal emotional exposure or interpersonal cost. At the same time, AI interactions simulate responsiveness linguistically while lacking intentional agency or relational investment. Repeated exposure to these patterns may alter expectations regarding responsiveness, effort, and emotional regulation in human relationships. In addition, AI-generated guidance often frames relational problems through simplified and structured decision pathways, which behavioural research suggests can limit the range of alternatives cognitively considered by individuals. The paper argues that these mechanisms may collectively narrow the perceived decision space within the psychological architecture of attachment, potentially influencing how individuals interpret relational conflict, evaluate commitment, and tolerate ambiguity. The study does not claim that AI eliminates human attachment capacity; rather, it proposes that repeated exposure to structured AI interaction may recalibrate the evaluative conditions under which attachment-related decisions are formed.*

Keywords: Artificial Intelligence, attachment theory, decision making, behavioural economics, social exchange theory.

JEL Classification: D01, D03, D91, O33, Z13.

1. Introduction

Artificial intelligence is making its way into more aspects of life that were previously largely influenced by human interaction. Today's individuals turn to AI not just for technical or informational reasons but also for advice in emotionally delicate situations, such as relationship disputes, doubts about commitment, identity issues, and choices about preserving, sustaining or breaking a bond. There is a structural question raised by this change. When AI becomes part of how individuals think through attachment-related difficulties, does it change the way those decisions are constructed?

According to attachment theory (Bowlby, 1969; Mikulincer and Shaver, 2007), attachment is a psychological system that governs intimacy, trust, emotional investment, and commitment. Attachment processes in adult relationships influence the way individuals perceive conflict, react to assurances, assess risk, and determine whether to remain in a bond or discontinue it (Hazan and Shaver, 1987; Simpson, 1990). These decisions rarely unfold in simple binary terms. Instead of moving directly from “stay” to “leave,” individuals often remain in a relationship while adapting expectations, renegotiating boundaries, tolerating ambiguity, or allowing time for change. Instead of ending abruptly, commitment usually develops through gradual re-evaluation and reassessment (Rusbult, 1980; Stanley and Markman, 1992).

However, behavioural economics research shows that decision-making is influenced by the way options are presented (Tversky and Kahneman, 1981; Kahneman, 2011). Individuals are more likely to choose structured alternatives when they are presented in a clear and decisive manner. Simplified presentation can make certain options stand out while making alternative possibilities less visible. This may not fully eliminate autonomy, but it influences which options appear cognitively available and accessible.

A unique communicative pattern is introduced by AI systems that mimic reciprocal conversation. They react right away, give logical explanations, and provide emotional support in a consistent and reliable manner. They don't hesitate, retreat, or react hastily. It can be comforting to have this consistency. It is, nevertheless, very different from the circumstances in which human attachment normally occurs. According to Reis and Shaver (1988) and Murray, Holmes, and Collins (2006), human bonds contain emotional risk, uncertainty, negotiation, misinterpretation, and repair. Several of these conditions are not met by AI interaction.

This article explores three mechanisms through which AI-simulated interaction may influence attachment-related decision processes: reward without vulnerability, synthetic reciprocity without agency, and narrowing of decision options. Despite their differences, these mechanisms work together.

First, emotional rewards in human relationships typically depend on vulnerability. Disclosure entails the risk of rejection or misunderstanding, and it is followed by closeness and reassurance. According to Reis and Shaver (1988) and Murray, Holmes, and Collins (2006), emotional reward is therefore based on effort and is unpredictable. Artificial intelligence (AI) systems offer affirmation without requiring human interaction. Consistent validation is given without raising the risk of emotional disengagement. The relative cost

structure imprinted in attachment may change if reward is separated from vulnerability. When free affirmation can be found elsewhere, human vulnerability may start to feel relatively demanding.

Second, human bonds require effort and intention to be reciprocal. Engagement, time, and attention are necessary for emotional responsiveness. Perceived effort and reciprocal investment influence commitment and relationship stability, according to social exchange theory (Thibaut and Kelley, 1959; Rusbult, 1980). Perceived partner responsiveness also promotes security and trust, according to attachment research (Reis, Clark, and Holmes, 2004). Artificial intelligence (AI) systems mimic linguistic responsiveness without conscious effort or personal investment. Though it does not result from reciprocal cost-bearing engagement, the interaction is like reciprocity. Exposure to effortless responsiveness over time may change expectations about what reciprocity should feel like.

Third, decisions about attachment usually happen across gradients. Individuals can try structured repair, redefine the relationship, pause emotionally without breaking the bond, or remain committed while expressing dissatisfaction. However, AI-generated guidance often presents dilemmas in structured, conditional formats which correlate patterns onto specific, narrow results. A perception of clarity is then facilitated by this framing. However, behavioural research indicates that individuals are less likely to independently come up with new options when options are presented in a limited or simplified manner (Iyengar and Lepper, 2000; Thaler and Sunstein, 2008). Attention tends to focus on the two outcomes that are explicitly named when a relationship problem is regularly presented in straightforward "if-then" language. For instance, the relationship will deteriorate if the pattern persists; it may improve if it alters. Because they were not offered as part of the structured pathway, options that fall in the middle of these two extremes, such as staying but lowering expectations, postponing a final decision, establishing a temporary distance without breaking the bond, or redefining commitment without leaving, are less likely to be actively considered. Over time, decisions are more likely to move toward the clearly defined endpoints, not because alternative options are impossible, but because they were not cognitively considered during evaluation.

The psychological architecture of attachment is referring here to the internal system that organizes how individuals evaluate closeness, reciprocity, risk, and commitment. Environmental feedback shapes this architecture, which is formed through relational experience (Bowlby, 1969; Mikulincer and Shaver, 2007). It remains responsive to contextual conditions. Communication technologies have an impact on relational norms and expectations, according to earlier research (Turkle, 2011; Valkenburg and Peter, 2011). AI-simulated reciprocity creates a new condition: structured, instantaneous, low-risk, emotionally stabilizing interaction.

According to empirical research, when algorithmic outputs are presented with confidence and clarity, individuals can grant them authority (Logg, Minson, and Moore, 2019). According to research on parasocial attachment, individuals can develop emotionally significant bonds with ai agents (Liebers and Schramm, 2019). These results suggest that perception, assessment, and decision-making can be impacted by AI-mediated interaction.

The specific focus of this article is on how exposure to AI-simulated reciprocity on a regular basis may reduce the perceived range of options for decisions in attachment contexts. It's a structural issue. The range of psychologically meaningful attachment decisions can narrow when reciprocity requires no effort, when validation requires no vulnerability, and when relational difficulties are framed through narrowed, simplified methods. The following sections examine each mechanism independently before analysing how they interact to redefine commitment limitations, ambiguity tolerance, and relational endurance.

2. Reward without vulnerability

In relationships with others, emotional reward is usually linked to vulnerability. Generally, exposure is followed by validation, closeness, and reassurance. An individual who expresses doubt, fear, need, or dissatisfaction. There are vulnerability and exposure in that expression. The other individual's reaction could be defensive, indifferent, cautious, or withdrawal. The outcome is uncertain and because of this uncertainty, emotional reward in human attachment has a built-in cost structure. Being willing to be exposed is necessary for validation. Closeness requires the possibility of misunderstanding. Accepting the possibility of rejection is a necessary part of commitment. Attachment research continues to demonstrate that perceived partner responsiveness strengthens trust and security precisely because it is not guaranteed (Reis and Shaver, 1988; Reis, Clark and Holmes, 2004). The possibility that reassurance could have been withheld contributes to its value.

This structure is altered by AI-mediated interaction. An AI system responds to human expressions of distress, perplexity, or relational uncertainty in a prompt, structured, and affirming manner. No hesitation, no weariness, no emotional retreat, and no counter-demand are present. Rejection is not a risk for the user. The validation is not dependent on another person's emotional capacity or willingness.

Vulnerability in interpersonal relationships may not necessarily be fully eliminated by this. However, it does introduce a parallel channel of reward that does not require vulnerability exposure. Relationship risk is eliminated, making affirmation accessible. Instead of being unpredictable, emotional support becomes predictable.

Predictable reward lowers perceived cost from a decision-making standpoint. According to behavioural research, a reward's subjective value rises when it is certain rather than probabilistic (Kahneman and Tversky, 1979). In attachment contexts, reassurance from another individual is probabilistic. AI provides structurally consistent reassurance. Eventually, this difference could influence how individuals evaluate the cost of emotional exposure in human relationships.

Vulnerability may start to feel relatively demanding if emotional validation can be gained without taking any risks. When compared to free affirmation elsewhere, the work needed to clear up misunderstandings, resolve conflicts, or wait for a partner's response may seem inefficient. This indicates a change in the relative value of vulnerability.

In traditional attachment processes, vulnerability and reward are linked together. AI-simulated reciprocity separates them. That separation alters and affects the experiential baseline against which human bonding is evaluated.

3. Synthetic reciprocity without agency

In human relationships, reciprocity includes internal responsibility, effort, and intention. When an individual listens, reassures, apologizes, or adjusts behaviour, that response is not automatic, it requires attention. It might call for emotional regulation. It may require minimizing defensiveness, reconsidering one's perspective, or investing time and cognitive energy. Reciprocity therefore carries cost. That cost is part of what gives it meaning and significance.

Relationship stability is largely dependent on perceived partner responsiveness and perceived investment, according to well-established attachment theory and social exchange models (Rusbult, 1980; Reis, Clark, and Holmes, 2004). A partner's response is significant not only because of its content, but because it signals willingness. Value is communicated by the effort itself. When someone adjusts behaviour after disagreement, the change represents intentional participation in maintaining the bond. Reciprocity is not just mirrored language; it is enacted commitment.

AI-mediated interaction generates something that resembles reciprocity at the level of language. The system responds quickly, acknowledges emotional states, reframes difficulties and offers structured guidance. The user has a back-and-forth conversation. Nevertheless, the system lacks investment, intention, and experiential stake. It does not sacrifice time that could have been invested elsewhere. To maintain the interaction, it does not control its own emotions. Rejection is not a possibility. The response is produced at no internal expense.

This distinction is important and it matters because humans are sensitive to effort signals. Social psychology research indicates that relational acts are valued more when the feeling of effort is involved (Aronson and Mills, 1959; Rusbult, 1980). Effort implies dedication. When responsiveness appears quick and unlimited, the effort component becomes invisible. The exchange seems seamless, unbroken, and emotionally open at all times.

Repeated exposure to costless responsiveness may subtly alter expectations. Human partners have limits. They get worn out, preoccupied, defensive, or overwhelmed. In times of conflict, they might not react promptly or logically. Ordinary human fluctuation can seem relatively unstable when contrasted with AI interaction that is consistently structured. The contrast does not completely remove the understanding of human limits, but it can recalibrate what responsiveness is expected to look like.

Furthermore, there is no need for negotiation when it comes to AI reciprocity. Reciprocity frequently appears in human interactions following conflict, clarification, or distress. Meaning is co-constructed. In AI interaction, meaning is produced unilaterally through generated response. To be validated, the user does not have to interpret the emotional cues

of others or resolve misunderstandings. There is less of the effort that is typically needed to reach a mutual understanding.

This could eventually affect the perception of reciprocity itself. If responsiveness comes to be associated with immediate clarity and emotional smoothness, then slower, imperfect, or effortful human reciprocity may feel defective by comparison. The issue with this approach is that AI simulates an agency-free, structurally frictionless type of responsiveness. When seamless responsiveness becomes familiar, the effort involved in human reciprocity becomes more visible, and potentially more costly in subjective evaluation.

This section suggests that expectations are shaped by patterns of interaction. When responsiveness is repeatedly experienced without cost or negotiation, the starting point for what reciprocity feels like may alter. Within the psychological architecture of attachment, expectations related to effort, timing, and emotional regulation are part of how commitment decisions are formed and evolve. Synthetic reciprocity introduces a version of responsiveness that is consistent, structured, and unaffected by emotional stress. That structural difference is fundamental to the narrowing effect examined in later sections.

4. The influence of isolation on attachment

Attachment-related decisions do not take place in isolation. The context shapes them. Depending on factors like history, timing, stress level, past conflict cycles, personality type, cultural background, and outside influences, the same behaviour can mean different things. A partner's delayed response could indicate simple tiredness in one relationship and withdrawal in another. In one situation, a raised voice may indicate aggression, in another, it may indicate emotional overload. Meaning is relational and situational.

As a result, human interaction depends heavily on context. In every interaction, individuals bring with them their shared past, unspoken expectations, unresolved conflicts, past repairs, family models, and personality differences. Two individuals who might appear to have the same behavioural pattern externally may be functioning within entirely different relational dynamics internally. A choice that makes sense in one situation could be unstable in another.

AI systems use probabilistic pattern recognition and text-based input. They do not have access to the full relational field and context in which an interaction takes place. They are unable to observe tone shifts over months, nonverbal cues, family influences, silent negotiations, or micro-adjustments that take place in everyday life. They process what is described, not the entire lived system in which the description is inserted.

Because of this limitation, AI responses often generalize from the information provided. They divide and organize the difficulty into structured pathways based on recognizable patterns. Those pathways might make sense. They might even be useful. They are, nevertheless, inevitably limited by incomplete context. The system cannot see every dynamic and interaction between two individuals. It is unable to evaluate all the possible relational trajectories that could unfold outside the presented description.

In real attachment structures, there are often many more than few viable options typically produced by AI-patterned framing. A relationship that is struggling might move through apology, temporary distancing, role renegotiation, therapy, boundary arrangement, diminished tension rather than termination, phased commitment, or redefinition of expectations. It could stabilize gradually without major alterations. It could fluctuate for months before settling into a new equilibrium. These possibilities are formed by context-specific factors that are difficult to fully articulate and express in a short interaction.

When AI displays only a few structured results, those results take centre stage in the mind. If the guidance consistently focuses on clear, final conclusions, intermediate and context-specific pathways may receive less attention. This does not imply that those routes cannot be valid. It indicates that they were not given priority or seen as an option in the laid-out interpretation.

Behavioural research demonstrates that when a decision is presented in a limited or structured way, individuals will have the tendency to choose among the options explicitly highlighted and will be less likely to generate additional alternatives on their own. (Tversky and Kahneman, 1981). Creating more options in delicate interpersonal contexts calls for cognitive work and ambiguity tolerance. When structured clarity becomes routine, the mental work of holding multiple relational possibilities and alternatives can be reduced.

Human relational systems, on the other hand, work by always changing to fit the situation. Subtle cues cause individuals to change how they behave. Reactions are tested. They react to shared history, timing, stress, and mood. Many relationship repairs are the result of gradual, context-sensitive changes rather than a clear decision tree. Since AI does not participate in these emergent dynamics, it is unable to accurately model them.

As an outcome, when individuals repeatedly consult structured AI interpretations, the perceived decision field can narrow toward the routes explicitly described. There might be a multitude of possible paths for a relationship. In the structured response, only a few are presented. Over time, those articulated pathways can start to take over evaluation, while context-sensitive, unarticulated options decrease from awareness and consideration.

Misinformation is not necessary for this narrowing effect to occur. It results from structural constraints. AI generates limited structured options after processing partial data. Relationships between people function within vast, contextually rich systems that go beyond any one textual description. Understanding the distinction between those two structures, lived dynamic versus constrained model, is essential to understanding how decision gradients might narrow.

5. The interaction of three mechanisms

Synthetic reciprocity without agency, reward without vulnerability, and decision-option narrowing are not independent processes. When combined, they change the framework for assessing decisions that involve attachment.

The perceived cost of vulnerability shifts when there is constant access to emotional validation without the possibility of rejection. In human relationships, vulnerability involves timing, sensitivity, and a likelihood for misalignment. Interaction mediated by AI eliminates that uncertainty. Emotional reassurance consequently becomes dependable. Perceived risk is decreased by predictability. This changes the baseline against which human interactions are measured and evaluated over time.

Simultaneously, synthetic reciprocity presents a structurally frictionless model of responsiveness. In interpersonal relationships, responsiveness varies. Mood, stress, personality, past experiences, and outside influences all play a role. Misunderstandings happen. There must be clarifications. It takes work to repair. AI interaction, on the other hand, results in emotional-free, consistent, and coherent responses. The response does not represent negotiation or effort because it is free of internal costs. It seems stable and instantaneous.

Human relational effort may start to feel rather draining when these two factors come together. Ordinary relational friction may be more noticeable if responsiveness seems seamless and unbroken and reassurance is easily predictable elsewhere. This does not mean individuals give up on their human bonds. It implies that there may be a change in the threshold for accepting ambiguity, delay, or imperfection.

The narrowing of decision options increases this effect. Attention is drawn to clearly specified solutions when relational challenges are repeatedly processed through structured AI interpretations. Over time, the mind becomes accustomed to evaluating situations through simplified outcome categories. Context-rich, gradual adjustments might get less attention because they are not included in the structured frame.

When disagreements are repeatedly interpreted through clear, structured AI responses, attention naturally turns to the options that are simply explained. People may eventually start to think about their own situations in similarly oversimplified ways. Instead of considering numerous possible adjustments or gradual changes, they may concentrate mainly on the most clearly defined outcomes. Slower, context-specific solutions, such as a partial adjustment, waiting, revising expectations, or small adjustments in behaviour may receive less consideration simply because they were not emphasized in the structured generated explanation.

When this develops alongside costless validation and effortless responsiveness, the overall way attachment decisions are approached begins to alter. It could feel more demanding to be vulnerable with a partner than to get instant approval. Compared to consistently smooth produced responses, human responsiveness, which is naturally uneven and dependent on mood or stress, may feel less satisfying. At the same time, fewer emotional and relational options may be seriously considered before reaching a conclusion. As an outcome, decisions about continuing, distancing, or ending a relationship may be reached more quickly, not because attachment capacity is weaker, but because the range of options being considered has become narrower.

Not all the above changes occur at once. They gradually accumulate. It can become more difficult to be vulnerable with an individual when there is always reassurance available

without risk. When individuals get used to responses that are always steady and instantaneous, normal human delays or emotional reactions may seem and start feeling more frustrating. When AI repeatedly presents interpersonal difficulties as leading toward a few clearly structured outcomes, individuals may start approaching their own decisions within those same narrow categories, instead of exploring and considering the many gradual or context-specific alternatives that also exist.

This may eventually affect how an individual handles a relationship challenge. Before coming to a decision, they may already be thinking within a narrower set of possibilities. The capacity they possess to form attachments does not disappear. What changes is how they evaluate situations and which options they carefully consider when facing uncertainty.

6. Behavioural implications, generational exposure and contextual limits

Three things may progressively occur when an individual regularly looks to AI for guidance regarding relationships. First, choices might be made more quickly. Individuals make decisions faster when options are well-structured, according to research on the subject (Tversky and Kahneman, 1981; Kahneman, 2011). Real relationships typically require time to make decisions. Before choosing the outcome, individuals frequently go through stages like waiting, testing minor adjustments, lowering expectations, or providing temporary space (Rusbult, 1980; Stanley and Markman, 1992). If AI repeatedly presents difficulties as leading toward a few clear outcomes, an individual may start thinking in those same clear, narrow categories and move toward a conclusion sooner.

Second, tolerance for typical human inconsistencies might decline. Human partners are not stable systems. They become worn out, preoccupied, agitated, or overburdened. According to attachment research, a feeling of emotional security is increased when individuals feel heard and understood (Reis, Clark, and Holmes, 2004). AI reactions, however, are always composed, well-organized, and prompt. When an individual becomes accustomed to that pattern, ordinary human delays or fluctuations in emotions may feel more frustrating by comparison. The comparison standard has changed, but the partner has not.

Third, relationships may feel more difficult. People assess relationships in part based on effort and reward, according to social exchange research (Thibaut and Kelley, 1959; Rusbult, 1980). To address misunderstandings in relationships, it's necessary for an individual to have control over their emotions, discuss these issues, and give them time. Repairing conflict may seem less appealing if reassurance can be found elsewhere instantly and without negotiation. The relationship itself is not necessarily more fragile, but the effort required to sustain it may be evaluated and considered differently.

These shifts do not imply that attachment systems disappear. Attachment continues to be a central regulatory system in adult relationships, organizing closeness, security, and commitment (Mikulincer and Shaver, 2007). The case being made here is that AI may influence the conditions under which attachment-related decisions are considered and evaluated. What changes is how situations are judged. Decisions could be made more

quickly. The ability to tolerate change may decline. Fewer gradual or middle-ground options may be seriously and thoroughly considered before reaching a conclusion.

It is unlikely that AI-mediated interactions will have a consistent impact on how people evaluate attachment. Prior relational experience, developmental stage, and exposure level are all significant.

Younger individuals who integrate AI into daily decision-making may experience its structured framing sooner and more often. According to developmental research, relational schemas and expectations are still developing during adolescence and the early stages of adulthood (Collins and Steinberg, 2006). Relational dilemma interpretation may be more strongly influenced during these stages by repeated exposure to consistent, structured interaction patterns. If AI becomes an everyday, ordinary reference point for emotional evaluation, its framing style may be more easily accepted as a normative, standard model.

By contrast, individuals with longer histories of in-person relational experience might possess more stable, more solid attachment models that are less easily reshaped by structured external guidance. Attachment representations are inclined to show continuity over the course of time, although they remain open to revision through experience (Fraley, 2002). Therefore, how well-established one's relational models are may determine how much AI-mediated interaction changes evaluation processes.

Influence is also moderated by context. AI systems work with incomplete data. They do not observe tone shifts across months, nonverbal communication, shared environmental pressures, or extended stages of repair. It is within these more expansive ecological layers that human relational systems function. Relationships are a part of larger structures that influence behaviour, according to social and family systems theory (Bronfenbrenner, 1979). AI does not have access to these full contextual fields.

Because AI processes textual input rather than lived interaction, its guidance is necessarily model-based and pattern-derived. It organizes situations based on similarities to previously observed linguistic patterns. Although this can produce logical interpretations, it is unable to consider context that is not expressed. In contrast, human decision-making incorporates situational nuance, shared history, and tacit knowledge that may not be fully represented in text.

AI guidance remains valid despite this limitation. AI can help with pattern recognition, risk clarification, and thought organization, but it cannot fully map the entire relational system in which a decision unfolds. The number of possible relational trajectories in lived experience is often far greater than the structured portion presented in an AI generated response.

Therefore, structural limitation and generational exposure may interact. Individuals who depend heavily on AI framing may gradually adopt narrower decision pathways, particularly if exposure begins during early, formative relational stages. Although repeated use may still affect evaluation speed and expectation calibration, individuals with established relational repertoires may be less vulnerable to generated narrowed systems.

The main concern is how much of repeated exposure to structured, partial, pattern-based interpretation reshapes how individuals approach relational complexity over time.

7. Conclusions

AI systems function as instruments for processing information. They organize patterns, highlight potential risks, and structure challenges in a coherent way. They lack lived experience, comprehensive contextual knowledge, and a personal stake in the result, though. Their results are not thorough maps of a relational system, but rather structured interpretations based on limited input.

Decisions pertaining to attachment must therefore always be based on individual autonomy. The individual holds the history, the contextual nuances, the unspoken dynamics, and the long-term consequences of the decision. Although AI can offer organized data, it is unable to incorporate the entire relational field where that decision arises. The individual maintains evaluative responsibility when its answers are regarded as informational input rather than final authority. When AI-generated pathways start to take the place of independent option generation instead of enhancing it, the narrowing effect covered in this article becomes critical.

The psychological architecture of attachment remains active. The range of options that seem cognitively accessible during evaluation may change, rather than autonomy per se. Therefore, to maintain autonomy, it is necessary to acknowledge the structural limitations of interpretations produced by AI and to deliberately expand the range of relational possibilities prior to reaching any conclusions and decisions.

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Shockwaves abroad and the vulnerability of monetary policy: Morocco's Central Bank response to geopolitical shocks and commodity price volatility

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Abstract. *This paper investigates the transmission mechanisms of geopolitical risk and commodity price volatility to Morocco's monetary policy and assesses the central bank's response to externally driven inflationary pressures. Using monthly data from 1995-2025, a Bayesian Vector Autoregression (BVAR) model comprising six macroeconomic variables is estimated. The results indicate that shocks to geopolitical risk, crude oil, and cereal prices exert persistent inflationary effects through imported inflation channels. The policy rate responds with a lag, consistent with its periodic decision-making framework, underscoring the structural constraints faced by monetary authorities in managing externally induced inflation and requiring fiscal coordination and targeted supply-side measures.*

Keywords: Geopolitical risk; Monetary Policy; Commodities Price Volatility; Inflation; Morocco.

JEL Classification: E31, E52, F41, C11, Q02.

1. Introduction

Geopolitical risk, defined as the uncertainty stemming from conflicts, terrorist threats, and diplomatic tensions, disrupts international trade, increases crude oil price volatility, and affects investor confidence (Caldara & Iacoviello, 2018). Thus, geopolitical risk is emerging as a significant source of macroeconomic instability in an increasingly interconnected global economy. This risk is particularly destabilizing for emerging economies with structural vulnerabilities and high dependence on commodity imports (Cheng & Chiu, 2018).

As a net importer of oil and cereals, Morocco exemplifies this exposure. The country is highly sensitive to external shocks that increase global energy and food prices. «Recent events, such as the Russia–Ukraine conflict, have led to sharp inflationary pressures, which challenge the efforts of the Moroccan central bank to maintain price stability » (Asadollah et al., 2024). Monetary policy has been deployed in response, primarily through adjustments in the policy interest rate, to mitigate inflation. However, the effectiveness of these interventions is uncertain, particularly when external supply-side factors drive inflation.

This study investigates the impact of geopolitical risks and commodity price shocks particularly oil and cereals on Morocco's monetary policy. It focuses on how these external disturbances shape inflation dynamics and the central bank's policy rate response. This raises the following question: To what extent do geopolitical and commodity shocks influence the effectiveness of Morocco's monetary policy in addressing inflationary pressures?

The objective is to evaluate the promptness and effectiveness of Morocco's monetary policy response to external shocks using a Bayesian Vector Autoregressive (BVAR) model. It is hypothesized that the central bank raises its policy rate to counter inflationary pressures, though the impact is constrained by the external origin and structural characteristics of these shocks. The motivation for this study stems from the increasing exposure of emerging economies Morocco in particular to external shocks, and from the ongoing debate surrounding the adequacy of monetary policy frameworks in addressing such challenges. This question has gained heightened importance amid recent domestic commodity price spikes that Moroccan authorities have associated with geopolitical tensions in the Middle East and the Russia–Ukraine war.

This paper is organized into four main sections. The first section provides a thorough review of the literature on the transmission mechanisms of geopolitical, crude oil, and cereal price shocks. Section 2 describes the dataset and the methodological framework used. Section 3 presents the empirical analysis and the main findings. Finally, Section 4 concludes the study by offering policy-oriented recommendations and highlighting key insights.

2. Literature review

In an era of shifting alliances and heightened global uncertainty, it is essential to have a comprehensive understanding of the multifaceted nature of political risk, especially for emerging economies that are often more vulnerable to external shocks (Saadaoui et al., 2025). As global economic interdependence deepens, countries are becoming more vulnerable to disruptions and challenges posed by geopolitical risk. This heightened exposure is especially evident in contexts characterized by institutional fragility (Olaire & Petersen, 2023).

From an economic and institutional perspective, geopolitical risk is defined as the uncertainty that arises from power struggles between state and non-state actors which cannot be resolved through peaceful or democratic means. According to Caldara & Iacoviello (2018), geopolitical risk is defined as the risk associated with conflicts, terrorist activities, and interstate tensions that disrupt the stability and regular functioning of international economic and political relations.

Geopolitical uncertainties are no longer confined to the political sphere; they increasingly affect the global economy. The escalation of geopolitical risks and international tensions, for example, has underscored the impact of global factors, particularly oil price volatility and financial market fluctuations, on economic uncertainty. These elements cause major disruptions to energy markets and trade flows, amplifying the challenges faced by importing economies and undermining energy security (Caldara & Iacoviello, 2022). These disruptions affect countries unevenly, with emerging market economies bearing a heavier burden than advanced economies. This is largely due to their structural vulnerabilities, weaker institutions, and reliance on volatile commodity exports.

The energy sector, particularly the oil market, is among the most sensitive areas to geopolitical developments. Geopolitical disruptions tend to cause significant volatility in energy markets, highlighting the sensitivity of energy prices to international political tensions. Empirical evidence shows that oil prices are highly responsive to tensions in strategically important oil-producing regions, such as the Persian Gulf. The emergence of conflict in these regions amplifies perceptions of supply insecurity and heightens the risk of production and distribution disruptions (Chowdhury et al., 2025).

Major geopolitical and economic events, such as the Second Gulf War, the September 11 attacks, the Iraq War, the global financial crisis, and the Russia–Ukraine conflict, have disrupted global supply chains for food and commodities, triggered volatility in international stock markets, and altered precious metal market equilibrium (Chowdhury et al., 2025; Sulong et al., 2023; Zhang et al., 2023).

Interestingly, geopolitical risk has a complex relationship with energy markets. Rather than dampening returns, elevated levels of geopolitical risk tend to amplify abnormal returns and volatility in energy markets. This reflects the sector's heightened sensitivity to geopolitical developments.

Disruptions in the oil market, combined with broader disturbances in global supply chains, directly contribute to inflationary pressures across economies. In recent years, geopolitical tensions and military confrontations, such as those between Russia and Ukraine, or Israel and Palestine/Iran, have severely disrupted global supply chains, surpassing even the disruptions caused by the pandemic (Wang et al., 2022). The escalation of geopolitical risk has intensified global inflationary pressures by exacerbating supply-demand imbalances across critical segments of the international supply network (Asadollah et al., 2024). For instance, conflicts in major oil-producing regions frequently raise concerns about supply security, causing sharp upward and downward fluctuations in oil prices and consequently exacerbating overall market instability (Mignon & Saadaoui, 2024).

Facing inflationary shocks and macroeconomic instability, governments have turned to monetary policy as a key instrument to mitigate the effects of geopolitical tensions. Countries are increasingly relying on monetary policy as a strategic tool to counteract geopolitical shocks, aiming to preserve macroeconomic stability, contain inflationary pressures, support economic growth, and maintain overall economic equilibrium (Elsayed & Helmi, 2021).

In this context, geopolitical risk is transmitted to the monetary sphere via financial markets. Geopolitical risk sends signals to financial markets via an information spillover mechanism. Following major geopolitical events, information quickly spreads across global media and communication networks, influencing investor perceptions and expectations (Umar et al., 2023). Consequently, market participants adjust their positions based on anticipated risks and opportunities, creating cross-market interdependencies.

This dynamic often generates correlated responses across asset classes, such as commodities and equities. These responses can create a chain reaction of interconnected market movements. This information spillover mechanism fosters greater correlations among asset classes, often resulting in heightened volatility and synchronized market reactions. Due to the deep interconnectivity of global financial systems, geopolitical risk can cause significant price fluctuations in commodities, financial instruments, and broader financial markets (Nerlinger & Utz, 2022; Salisu et al., 2022).

Geopolitical risks may act as an external force that amplifies the transmission of monetary policy across economies. Hodula et al., (2024) attribute geopolitical risk to uncertainty and identify two primary transmission channels: the financial channel, where uncertainty and heightened risk aversion drive shifts in investment portfolios and capital flows, and the real economy channel, which affects global trade, supply chains, and commodities.

Several studies have examined how geopolitical risk shocks influence monetary policy transmission. Ginn & Saadaoui, (2024) incorporate GPR shocks into an augmented Taylor rule using both linear and nonlinear local projection (LP) models estimated on a balanced panel of 20 economies from January 1999 to February 2022. Their results show that monetary policy reactions are state-dependent. During economic expansions, interest rate responses to geopolitical risk shocks tend to be muted, reflecting the transitory nature of

such shocks and the delayed effects of monetary policy. In contrast, during non-expansionary periods, these responses become more pronounced.

From the same perspective, Ginn & Saadaoui (2025) present panel data suggesting that interest rates tend to decline in the short term and rise in the medium term in response to a geopolitical risk shock. A time-varying model further confirms this behavior, showing that monetary policy initially adopts an accommodative stance, particularly within the first one to two months. However, over a longer horizon of 12 to 15 months, the central bank shifts its focus toward addressing inflationary pressures, resulting in a more restrictive stance.

Beyond interest rate responses, other dimensions of macroeconomic vulnerability have also been explored. Olalere & Petersen (2024) found that increased geopolitical risk and economic policy uncertainty reduce bank stability, even when controlling for traditional drivers. They conclude that geopolitical events tend to adversely affect bank stability and that the interaction between economic policy uncertainty and GPR significantly impacts financial stability negatively.

Moreover, geopolitical risks create uncertainty within economies. Cevik & Erduman (2020) examined the impact of monetary policy uncertainty on economic activity in Turkey using vector autoregression models. They found that monetary policy uncertainty remained relatively high and volatile during the implementation of unconventional monetary policy and that uncertainty shocks negatively affected economic activity in Turkey. Similarly, Erdoğan et al., (2021) find that Turkish real stock returns react more strongly to negative global shocks than domestic ones using an NARDL approach. However, country-specific geopolitical risk has positive long-run effects on real stock returns during both periods.

Several empirical studies have investigated how geopolitical tensions influence commodity prices and market volatility in oil markets and broader financial implications. Using a bivariate Granger causality approach with monthly data from February 1986 to December 2019, Jiang et al., (2022) found evidence of a non-linear causal relationship between geopolitical risk and crude oil prices. Their results indicate that geopolitical risks affect oil prices in the short term, typically for less than 12 months.

Similarly, Cunado et al., (2018) employed a TVP-SVAR approach to highlight the negative impact of geopolitical tensions on oil returns, primarily due to declining oil demand as measured by global economic activity. Attilio Lucas (2024) uses a global vector autoregressive (GVAR) approach to demonstrate that GPR shocks lead to increases in international prices, which subsequently cause fluctuations in domestic food prices across 12 countries belonging to the BRICS and G7 groups.

Cheng and Chiu (2018) argue that emerging markets are particularly vulnerable to abrupt shifts in trade and capital flows triggered by geopolitical tensions. They focus on 38 emerging markets and use individual VAR models with annual data. They found that GPR shocks generally lead to economic contractions, though the intensity and nature of these effects vary by country.

In a related study, Duan et al., (2021) used wavelet analysis to examine Venezuela's economy from 2008 to 2019. They revealed bidirectional causality between oil prices and exchange rates, as well as mutual causation between geopolitical risk and oil prices. This was particularly pronounced during the period from 2017 to 2019. These results substantiate Venezuela's acute economic vulnerability to geopolitical instability and underscore the need to diversify away from oil dependency, mitigate regional conflicts, and stabilize exchange rates to enable sustainable development.

Geopolitical risk generates significant cross-border spillover effects. Barros Jr et al., (2022) demonstrate that Brazil's real economic activity is more sensitive to Russia-specific geopolitical risk than to global or U.S.-originating risk. However, price levels and financial indicators are more sensitive to global risk. Similarly, Singh & Roca (2022) found that China's geopolitical risk transmission significantly impacts Canadian equity markets, influencing aggregate stock performance and sectorial decomposition, despite China's comparatively smaller trade exposure with the United States.

The inflationary repercussions of geopolitical tensions are well-documented. Darwiche et al., (2025) employed fixed-effects panel regressions and panel vector autoregression (VAR) models across nine advanced economies (the United States, Canada, Belgium, Germany, Spain, France, the United Kingdom, Italy, and the Netherlands) to demonstrate divergent inflation dynamics. Geopolitical risk mitigates inflation during tranquil periods; however, the Russia-Ukraine conflict substantially amplifies inflationary pressures across long, medium, and short term horizons. These effects stem from prolonged economic disruptions, supply chain disturbances, and ongoing market volatility. Notably, the interaction term between geopolitical risk and the conflict period exerts a positive and statistically significant effect on inflation that intensifies over time.

These findings highlight the importance of incorporating geopolitical risks into inflation forecasting and monetary policy frameworks to improve the accuracy and resilience of these models amid global uncertainty.

Consistent with previous research, Sharma et al., (2025) found that geopolitical uncertainty tends to increase inflation in Australia and Japan, likely due to trade and political tensions. However, it contributes to lower inflation in China. The duration of the impact differs as well: geopolitical risks affect inflation in Australia and Japan for up to six months, whereas in China, this effect lasts just two months. This differential impact is attributed to variations in the countries' economic and trade strength.

Morocco is a compelling case study for analyzing the transmission of geopolitical risk to macroeconomic dynamics among emerging economies. Its economy is structurally dependent on energy imports, exposed to global commodity price volatility, and deeply integrated into international financial markets, making it acutely vulnerable to external shocks. These vulnerabilities are exacerbated by an ongoing monetary policy transition toward inflation targeting, a framework that is currently facing unprecedented challenges due to global uncertainty. This empirical analysis examines the mechanisms through which

geopolitical risk and oil price fluctuations influence key Moroccan macroeconomic variables, such as inflation and policy interest rates.

Although Morocco has occasionally been included in multi-country studies examining MENA or North African economies, it remains significantly understudied as a standalone empirical focus. Elsayed & Helmi (2021) applied an ADCC-GARCH framework to geopolitical risk transmission in regional financial markets and found that geopolitical risk plays a statistically insignificant role in driving return spillovers within the region's financial systems. However, regional-scale analyses fail to capture the transmission mechanisms through which geopolitical tensions and oil price shocks affect core Moroccan macroeconomic indicators, such as inflation and policy interest rates. Our study is motivated by this research gap, particularly in light of recent domestic commodity price surges that Moroccan policymakers have explicitly linked to ongoing instability in the Middle East and the Russia-Ukraine conflict.

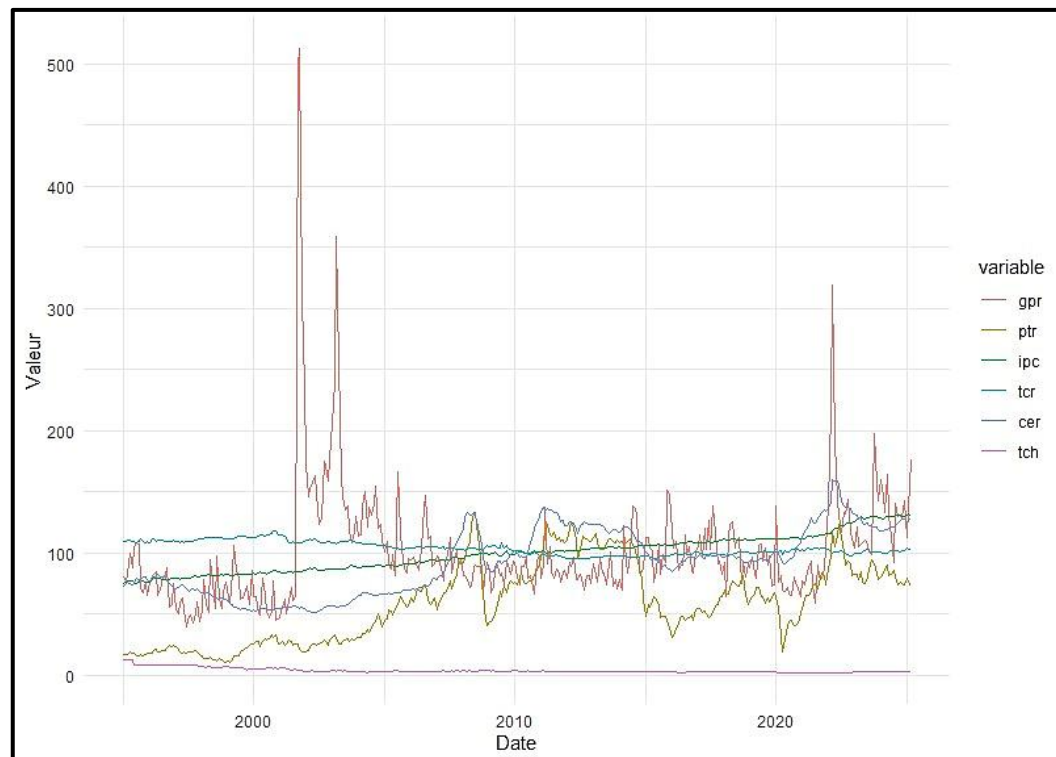
3. Research Methodology

3.1. Data

In order to examine how geopolitical and commodity price shocks, particularly those related to oil and cereals, are transmitted to Moroccan monetary policy and inflation, monthly data were collected for the period January 1995 to March 2025. The Geopolitical Risk Index GPR, sourced from the official Geopolitical Risk Project portal, quantifies adverse geopolitical events through automated text analysis of the digital archives of ten major newspapers. GPR is a widely employed indicator of adverse geopolitical events and associated risks (Caldara and Iacoviello 2021).

The policy interest rate (TCH) is used as a proxy for monetary policy, representing the central bank's main instrument of intervention. Inflation is measured by the consumer price index (IPC), sourced from the International Monetary Fund (IMF) database. The TCH variable captures the monetary authority's reaction to economic fluctuations, whereas the IPC reflects the weighted average of consumer prices for a representative basket of goods and services. Brent crude oil prices PTR, Morocco's primary benchmark for oils imports, were obtained from the U.S. Energy Information Administration, given the economy's structural dependence on energy imports. The global food price index (CER), which includes cereals, a critical component of Morocco's food import basket was sourced from the Food and Agriculture Organization (FAO).

To account for external influences on inflation and monetary dynamics, the real effective exchange rate (TCR) was included as a control variable. Retrieved from the International Monetary Fund, TCR captures changes in Morocco's trade competitiveness and the transmission of external shocks through imported inflation. Incorporating this control variable enhances the robustness of the empirical model by accounting for key external determinants of domestic price and monetary fluctuations.

Figure 1. *Variables evolution (1995m1-2025m3)*

Source: Author's, R studio.

The graph illustrates the dynamic behavior of the GPR, IPC, PTR, TCH, CER, and TCR from 1995 to 2025. Using monthly data for the said period, visual inspection shows pronounced volatility in all series, indicating responsiveness to significant external events, such as the 9/11 terrorist attacks and the U.S. War in Afghanistan in 2001 (Caldara & Iacoviello, 2022), the Global Financial Crisis in 2007–2008 (Balcilar et al., 2016), the COVID-19 pandemic in 2020 and the Russia-Ukraine war since 2022 (Caldara & Iacoviello, 2022).

Geopolitical risk exhibits sharp peaks during these crises, triggering oil price surges PTR through supply-chain disruptions (Hamilton, 1983). These energy shocks propagate imported inflation in Morocco IPC, notably during 2008 and 2022 (World Bank, 2022), prompting monetary policy TCH to tighten real interest rates with a characteristic lag, as observed post-2020, aligning with price-stability mandates (Taylor, 1993; Bank Al-Maghrib, 2023). The transmission underscores how geopolitical turbulence cascades into macroeconomic instability through energy and inflation channels (Balcilar et al., 2016).

Geopolitical shocks also impact global food prices CER, notably during the Russia–Ukraine war, which caused a surge in 2022. Given Morocco's heavy reliance on cereal imports, this led to a 25% increase during the Russian-Ukrainian conflict, this amplified

food-driven inflation IPC. Rising CER and oil prices PTR worsened terms of trade, contributing to a real depreciation of the exchange rate TCR, estimated at -2.4% between 2020–2023 (IMF, 2023).

The graphical evidence does not allow for definitive conclusions about the transmission of geopolitical influences to the Moroccan economy. Morocco remains highly dependent on imports, especially of oil and cereals, due to its structural inability to achieve self-sufficiency in these commodities. It is therefore logical that prices in Morocco will rise, inflation will increase as a result, and the central bank will intervene by raising its policy rate just as most countries do in order to curb the price explosion. However, we were also motivated to study this relationship by the observation that, despite the decline in the geopolitical index and oil prices, domestic prices in Morocco, especially those of petroleum derivatives, remained high.

3.2. Methodology

To investigate the dynamic interrelationships among six key macroeconomic variables, this study employs a Bayesian Vector Autoregressive (BVAR) model following Banbura et al. (2010). The BVAR framework is particularly suitable for high-dimensional systems, as it effectively mitigates the over parameterization problem commonly associated with traditional VAR models by incorporating prior information. The baseline specification of a VAR model of order p given by:

$$Y_t = B_0 + B_1 Y_{t-1} + \dots + B_p Y_{t-p} + u_t, \quad u_t \sim N(0, \Sigma) \quad (1)$$

Where Y_t is an $M \times 1$ vector of endogenous variables (with $M=6$), B_0 is a vector of intercepts, B_j are the autoregressive coefficient matrices, and u_t is a vector of normally distributed error terms with covariance matrix Σ .

In the Bayesian framework, the model parameters are treated as random variables, and prior distributions are imposed to induce shrinkage and avoid overfitting, especially in high-dimensional settings. We adopt a conjugate Normal-inverse-Wishart (NIW) prior, defined as:

$$\beta | \Sigma \sim N(b, \Sigma \otimes \Omega), \Sigma \sim \mathcal{IW}(\Psi, d) \quad (2)$$

Where $\beta = \text{vec}([B_0, B_1 \dots B_p]^T)$, and the prior hyperparameters b, Ω, Ψ, d are functions of a lower-dimensional vector γ of hyperparameters.

Following the hierarchical prior specification approach proposed by Giannone et al., (2015), hyperparameters γ are treated as additional random variables with their own hyperpriors. Bayes' theorem provides the basis for this framework:

$$p(\gamma | y) \propto p(y | \vartheta, \gamma) p(\vartheta | \gamma) p(\gamma) \quad (3)$$

$$p(y | \gamma) = \int p(y | \vartheta, \gamma) p(\vartheta | \gamma) d\vartheta \quad (4)$$

This hierarchical structure allows for either marginal likelihood maximization (empirical Bayes) or full posterior exploration of γ leading to more robust inference and reducing subjectivity in prior selection.

We implement three priors commonly used in macroeconomic BVARs: the Minnesota prior, the sum-of-coefficients prior, and the single-unit-root prior (Doan, Litterman, and Sims 1984; Sims & Zha, 1998). The Minnesota prior assumes that each variable follows a random walk process, with moments given by:

$$E[(A_s)_{ij} | \Sigma] = \begin{cases} 1 & \text{if } i = j \text{ and } s = 1 \\ 0 & \text{otherwise} \end{cases} \quad (5)$$

$$\text{Cov}[(A_s)_{ij}, (A_r)_{kl} | \Sigma] = \begin{cases} \lambda^2 \cdot \frac{1}{s^\alpha} + \frac{\Sigma_{ik}}{\Psi_j/(d - M - 1)} & \text{if } l = j \text{ and } r = s \\ 0 & \text{otherwise} \end{cases} \quad (6)$$

Here, λ governs overall tightness of priors, α controls the degree of shrinkage for more distant observations, and Ψ_j controls the prior's standard deviation on lags of variables other than the dependent. The sum-of-coefficients prior and the single-unit-root prior are introduced as dummy observations to encode beliefs about stationarity and persistence, enhancing the model's ability to reflect typical macroeconomic dynamics. Estimation is performed using Markov Chain Monte Carlo (MCMC) methods, specifically the Metropolis-Hastings algorithm, which allows for efficient sampling from the joint posterior distribution of both the model parameters and the hyperparameters.

Before executing the MCMC step, we must provide, at a minimum, the prepared data and the lag order p as input arguments. Additionally, we define the total number of iterations (e.g., 50,000), the number of initial iterations to discard as burn-in (e.g., 5,000), and a thinning parameter (n_{thin}) to determine the fraction of draws to retain (Kushnig & Vashold, 2021)

The function returns an object of class `bvar`, which is a named list containing several components. These include the key parameters of interest, such as the posterior draws of the VAR coefficients, the variance-covariance (VCOV) matrix, and the hierarchically treated hyperparameters.

Once the MCMC procedure is completed, we can access a summary of the estimation results to assess the convergence of the MCMC algorithm, an essential step to ensure the reliability and stability of the inference. By default, the method provides trace plots and density plots for the marginal likelihood (ML) and the hierarchically treated hyperparameters.

4. Results and Discussion

4.1. Treated Hyperparameters, residual and density plots

Figure 2 (see appendix) shows the diagnostic plots display trace plots (left) and posterior density plots (right) for key parameters estimated via MCMC. The trace plots illustrate the evolution of the Markov chains over iterations, while the density plots represent the estimated posterior distributions. The parameters include the log marginal likelihood (ml), the global shrinkage hyperparameter (lambda), the Sum-of-Coefficients prior (soc), and the Single-Unit-Root prior (sur).

The trace plot of ml fluctuates around a stable value (approximately -4708), suggesting good mixing of the chain, with a slightly right-skewed but acceptable posterior distribution. The lambda parameter also shows a well-mixed, stationary trace and a bell-shaped posterior centered around 0.10, indicating proper convergence. For the (soc) prior, the trace plot is stable and the posterior density is unimodal, suggesting effective control over the sum of lagged coefficients. Similarly, the (sur) prior shows a well-behaved trace and a smooth density peaking between 0.4 and 0.5, indicating that the single-unit-root prior is functioning as expected. Overall, the absence of convergence issues, the stability of the chains, and the unimodal, smooth posterior distributions confirm that the Bayesian estimation is well-behaved and the results are reliable for inference. Once convergence has been properly achieved, the analysis can proceed to examine the fitted values and residuals.

Figure 3 (see appendix) shows that the residuals for GPR are generally centered on zero. These may reflect episodes of heightened geopolitical activity. Overall, the distribution suggests that the model captures the core dynamics, although some variation in residual magnitude is present over time. In contrast, the residual plot for PTR appears cleaner and more stable. The distribution is well-centered around zero, with only a few moderate outliers, which are far less extreme than those observed for GPR. This suggests that the model performs better in capturing the underlying dynamics of oil prices, with more moderate residual fluctuations and a generally well-behaved error structure.

Figure 4 (see appendix) the residuals for TCH are mostly close to zero for the vast majority of observations. Some minor fluctuations are visible, but after, the residuals become very stable and well-centered. This suggests that the model captures the dynamics of tch effectively, with low-magnitude errors and no apparent trend or autocorrelation.

In the case of IPC, the residuals are also generally centered on zero, though they exhibit slightly greater dispersion compared to tch. Their range remains moderate, and the points are fairly evenly distributed over time. There is no visible evidence of structural breaks, variance shifts, or systematic patterns. Overall, the model appears to fit IPC reasonably well, with residuals showing characteristics consistent with white noise and constant variance.

Figure 5 (see appendix) shows that the residuals for TCR are generally centered on zero, with a few moderate outliers observed. Despite these isolated deviations, the overall dispersion is limited, and there is no visible trend or structural pattern, suggesting that the

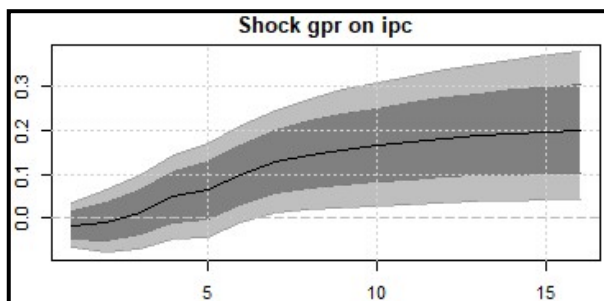
model captures the dynamics of the exchange rate reasonably well. The residuals for CER show a wider dispersion. While the residuals remain broadly centered, the increased variance may reflect the inherent volatility of global agricultural markets. Overall, the model appears to fit both variables acceptably.

Figure 6 (see appendix) the analysis of the posterior distributions reveals distinct dynamics for the key variables in the BVAR model. The Consumer Price Index IPC in Morocco shows a density centered around 1, indicating strong inflation inertia, where price shocks tend to persist over time. Similarly, the international food price index CER exhibits a high autoregressive coefficient, centered above 1.25, reflecting sustained global food price dynamics that can prolong the effects of initial shocks. The geopolitical risk index GPR, with a coefficient centered around 0.88, shows moderate persistence, suggesting that geopolitical tensions continue to influence future periods, although less rigidly than price variables. The crude oil price PTR displays a posterior mode around 1.1, implying a stable and persistent behavior of Brent prices, consistent with their tendency to respond over extended periods to supply and demand shocks. Regarding the domestic interest rate TCH, the coefficient lies slightly below 1, indicating some responsiveness to economic conditions while still maintaining a degree of policy inertia. Finally, the real effective exchange rate TCR also shows a high degree of persistence, centered close to 1, implying that exchange rate fluctuations in Morocco tend to be long-lasting, potentially amplifying the transmission of external shocks to domestic inflation. These results underscore the critical importance of commodity shocks and exchange rate dynamics in transmitting inflationary pressures in Morocco, while validating the robustness of the hierarchical BVAR model in capturing structural nonlinearities.

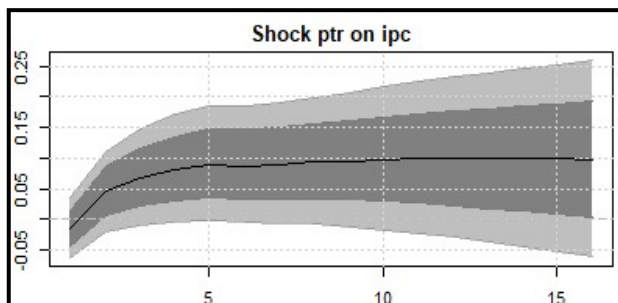
4.2. Impulses Responses

To better understand how geopolitical and oil price shocks are transmitted to Moroccan economy, it is essential to examine the impulse response functions (IRFs). These functions allow us to trace the dynamic responses of key variables to structural shocks over time. In this section, we focus on the IRFs derived from the BVAR model in order to analyze the transmission mechanisms and policy reactions to geopolitical risk and oil price fluctuations.

Figure 7. *Impulse responses of IPC to a GPR shock*

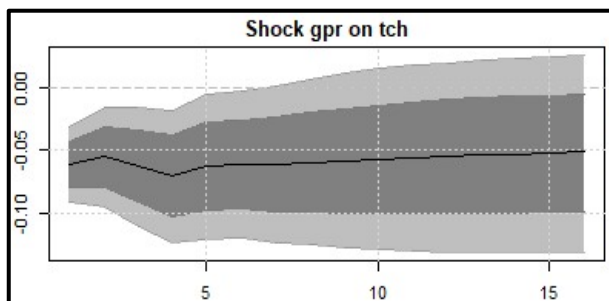


Source: Author's, R studio

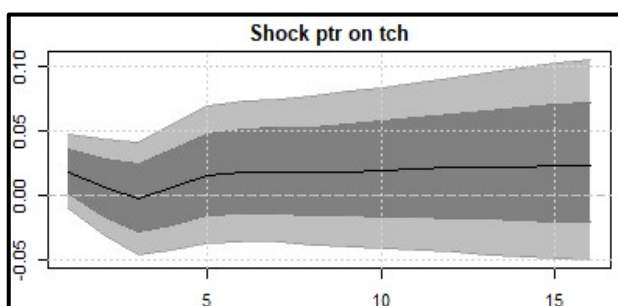
Figure 8. *Impulse responses of IPC to a PTR shock*

Source: Author's, R studio

Figure 7 indicates a long time rise in IPC, peaking in the medium term following a geopolitical shock. This emphasizes that Morocco is highly vulnerable at any time to the geopolitical risks effects, which leads to disruptions in supply chains that in turn leads to higher prices in commodities importations, especially since Morocco imports the most important commodities, oil and cereals. This corresponds to **Figure 8** which indicates that higher crude oil prices (especially Brent in our case) lead to higher the consumer prices index. As analyzed by Blanchard and Gali 2007, this dynamic reveals the dominance of the production cost channel: higher oil prices push up energy inputs and transport costs, and are passed on to retail prices, with a maximum effect over the medium term.

Figure 9. *Impulse responses of TCH to a GPR shock*

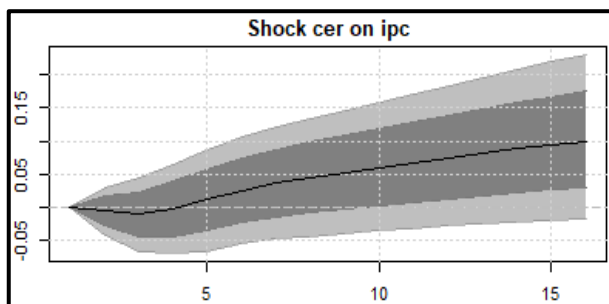
Source: Author's, R studio

Figure 10. *Impulse responses of TCH to a PTR shock*

Source: Author's, R studio

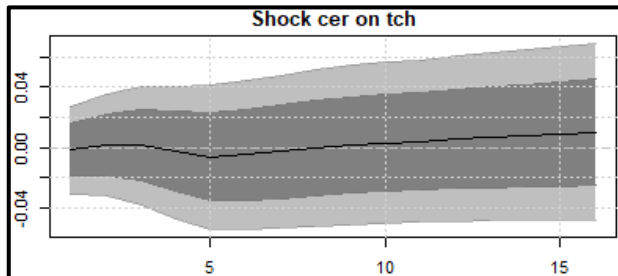
As for the interest rate (Monetary policy instrument proxy), **Figure 9** and **Figure 10** show that the central bank is responding to geopolitical and crude oil prices rise shocks with a certain delay. According to the figure, the interest rate does not increase until after the short term. This is in line with Bank Al Maghreb main objective, which is to control inflation and maintain price stability, and this is a natural response, as the policy rate is the central bank's first instrument. But the question remains, has this response really brought inflation under control?" The next section, which focuses on the discussion of results, aims to provide an answer to this question.

Figure 11. *Impulse responses of IPC to CER shock*



Source: Author's, R studio

Figure 12. *Impulse responses of TCH to CER shock*



Source: Author's, R studio

For the **Figure 11** and **Figure 12** we observe the same dynamic as the reaction of the IPC and TCH to a GPR and PTR shock. Where a shock in the CER index, lead to a higher IPC, which is logic since Morocco is a net importer of cereals and does not achieve self-sufficiency in this sector, making it vulnerable to fluctuations in international prices. TCH reacts also, where we observe a spike after the medium term, until it stabilizes in the long term.

Thus, as observed and analyzed, the geopolitical risks and rising oil prices effects are transmitted rapidly to the Moroccan economy, negatively impacting inflation, which is why the monetary authorities need to intervene in the medium term, as the short term is a period of uncertainty, according to them.

5. Conclusion

Using a BVAR model approach, this study analyzed the transmission of geopolitical risks, oil and cereal price shocks to Moroccan monetary policy. The results indicate that Morocco is a highly vulnerable economy to geopolitical risk effects, which have led to a long-time rise in IPC. This is consistent with the finding of Asadollah et al., 2024, where their empirical results show that disruptions in global supply chains are the main drivers of global inflation in the long run as the corresponding shocks explain the lion's share of volatilities in headline inflation. Caldara et al., 2024, confirm also that global geopolitical risks increase inflation, with the inflationary effect of higher commodity prices and currency depreciation more than offsetting the deflationary effects of lower consumer sentiment and tighter financial conditions.

In the same context, the rise in global oil prices especially Brent, is also negatively affecting inflation in Morocco. Ritahi & Echaoui 2025, findings reveal that Brent oil price increases lead to higher inflation and depreciation of the exchange rate, with both effects persisting in the short and long run. Oil price shocks have more pronounced influence on real GDP in some countries and in the inflation rate and the real exchange rate in other countries (Upadhyaya et al., 2025). Kilian & Zhou 2023, emphasize that only in the Euro area and in the U.K. energy price shocks are associated with a material increase in core consumer prices.

High crude oil prices, high food prices index, and geopolitical conflicts are external influences that have made the Moroccan economy vulnerable to economic instability, especially since it depends on importing commodities. At this stage, the intervention of the Central Bank becomes crucial, given that its main mandate is to maintain price stability and control inflation.

Given Morocco's dependence on imported cereals, the rise in global cereal prices has likewise added upward pressure on the consumer price index. The increase can be explained by strong demand for agricultural products coupled with Morocco's inability to achieve self-sufficiency. This shortage in domestic supply has disrupted the balance between supply and demand, leading to higher domestic prices. It should be noted that Morocco has been facing persistent drought conditions since the Covid-19 period, further aggravating the country's economic situation.

Taking Russian-Ukrainian conflict period, these results apply to what happened in the mentioned period, until Bank Al Maghreb intervened by raising its Policy rate interest. Here we return to the question raised earlier: Has this response really brought inflation under control? In fact, the increase in the interest rate has only worsened the situation. The increase in oil and oil-derivative prices has translated into higher production costs, which subsequently led to rising consumer prices and a slowdown in production activity. As demand grew, prices increased even further.

To conclude, if the inflation was externally caused, raising the interest rate has mainly benefited investors and suppliers rather than the overall economy, and has proven ineffective in controlling inflation. Regarding the hypothesis, central bank intervention did not contribute to reduce inflation effects in the period that witnessed the geopolitical conflict between Ukraine and Russia; as indicated in the impulse response. Since the hydrocarbon sector in Morocco is controlled by private companies, the intervention of the central bank on the other hand did not have the desired effect, but rather contributed to the benefit of these companies. This may cause us to reject the hypothesis.

The strong sensitivity of domestic prices to international conditions calls for enhanced coordination between monetary and fiscal policies, particularly through targeted mechanisms to protect households from imported price shocks. However, the limited stabilizing effect of the policy rate suggests the need to reconsider the available set of instruments to combat externally driven inflation, potentially by introducing macroprudential measures or strengthening the inflation targeting framework.

While the findings provide meaningful insights, the study inevitably faces certain methodological and empirical limitations. Although the BVAR model provides robust insights into the dynamic transmission of geopolitical and commodity shocks to Moroccan monetary policy, it remains sensitive to model specification and prior selection. Furthermore, the analysis relies on aggregated monthly data, which may obscure short-term or regime-dependent dynamics.

Future research could benefit from employing local projection methods or time-varying parameter models to compare responses across different subperiods, such as pre and post-crisis phases or periods of monetary policy transition. Incorporating additional structural variables such as fiscal policy indicators, financial market stress indices, or external balance measures could also enhance the understanding of how macroeconomic policy coordination mitigates imported inflation pressures. Despite these limitations, the study contributes valuable evidence on the constraints faced by small open economies like Morocco in managing externally driven inflation under geopolitical uncertainty.

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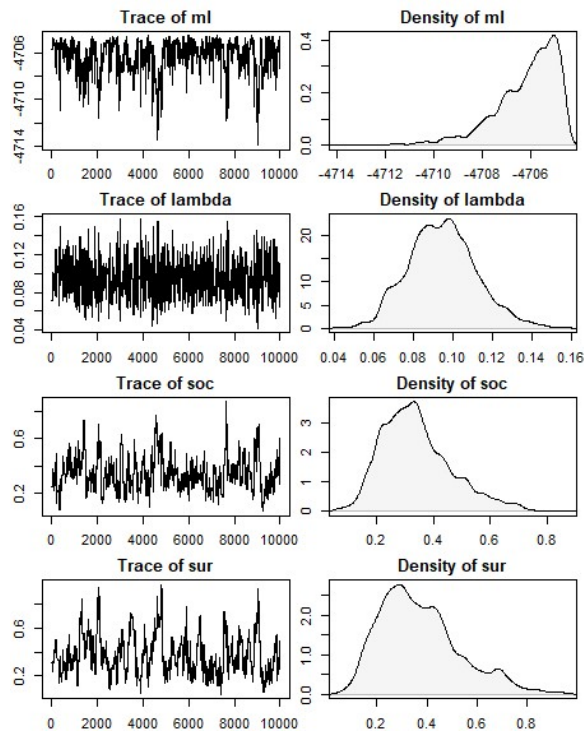
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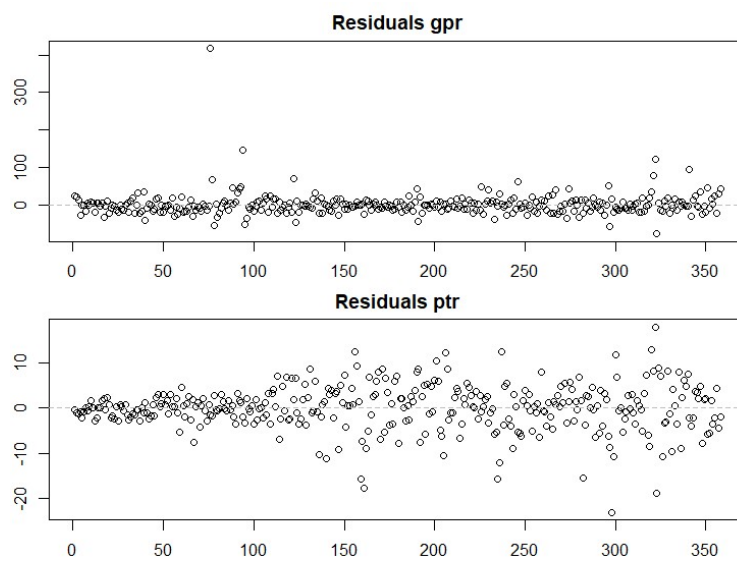
Appendices

Figure 2. Treated HP, trace and density plots

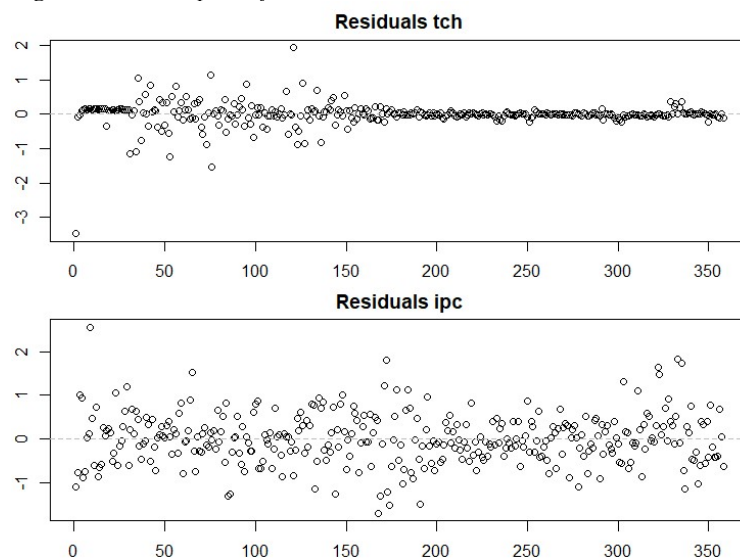


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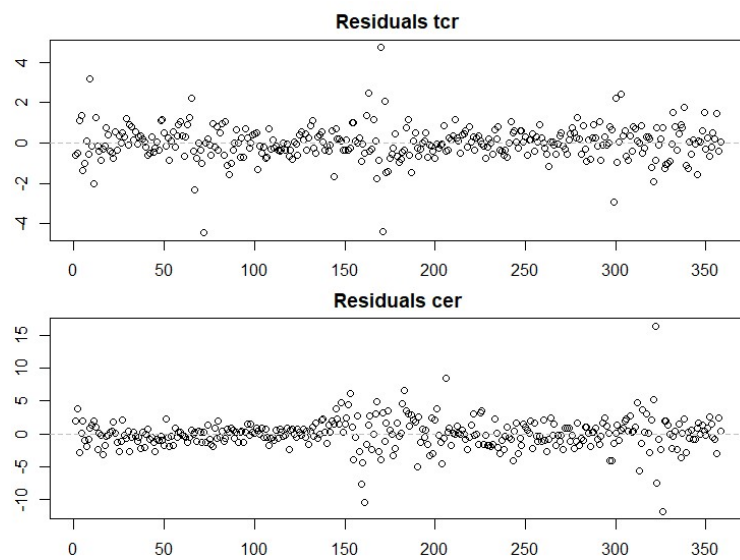
Figure 3. Residual plots of GPR and PTR



Source: Author's, R studio

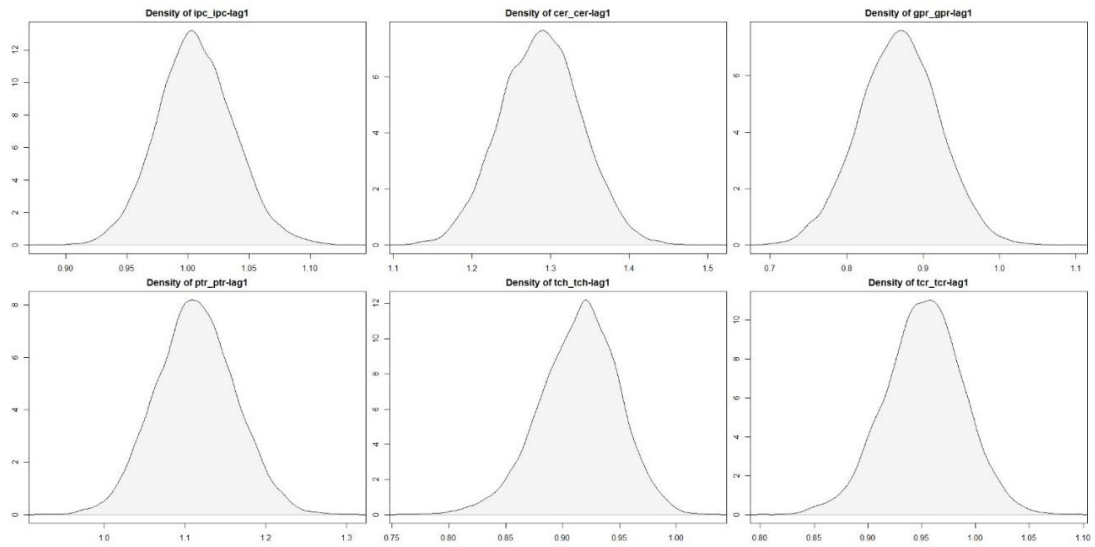
Figure 4. *Residual plots of TCH and IPC*

Source: Author's, R studio

Figure 5. *Residual plots of TCR and CER*

Source: Author's, R studio

Figure 6. Density plot for the autoregressive coefficient corresponding to the first lag of each variable in their equation



Source: Author's, R studio

Impact of growth and tax on pollution in the presence of corruption

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Abstract. *In the context of international environmental agreements, where both developed and developing countries commit to mitigating ecological risks, this paper develops a theoretical model to examine the growth-pollution nexus in the presence of rent-seeking behavior by a self-interested government and a firm. We analyze two cases: (1) when lobbying transfers are unilaterally determined by the firm, and (2) when they are jointly determined through a Nash bargaining framework. Furthermore, when tax revenues are endogenously allocated to stimulate growth, we find that higher environmental taxes may paradoxically increase pollution in the Nash bargaining case.*

Keywords: Pollution; Lobby payment; Corruption; Pollution tax; Economic growth.

JEL Classification: Q52, D72, O44.

1. Introduction

The relation between economic growth and environmental pollution was quite straightforward since the 1970s. Initially, the conventional path opted by both developed and developing nations dependent on non-renewable resources like coal, fossil fuel etc. as these were the cheapest means of achieving economic growth. Hence, with the increase in productive activities environmental degradation via rise in pollution also became inevitable. This view was challenged during the 1990s and more complexities of this relationship were explored by scholars both empirically and theoretically. There is a huge part of literature that deals with the growth pollution nexus. Understanding all aspects of this relationship is important in controlling the greenhouse emissions to combat with the climate change and to put the economy in a sustainable growth path.

Many studies have examined the growth-pollution nexus through the lens of the Environmental Kuznets Curve (EKC). The EKC hypothesis suggests an inverted U-shaped relationship between economic output and environmental degradation (Grossman and Krueger 1995; Selden and Song 1994; Shafik 1994; Stern 2004; Sharma 2011). At lower levels of development, countries prioritize material growth over environmental concerns, leading to higher pollution. However, as economies grow and reach a turning point, increased awareness and demand for environmental quality reduce pollution, making development more environmentally sensitive. Empirical evidence provides mixed results. For instance, Apergis and Ozturk (2015) confirm the inverted U-shaped EKC for 14 Asian countries, finding carbon emission initially rise with GDP but later decline. Similarly, Dogan and Seker (2016) validate the EKC for OECD countries, showing that real income increases CO₂ emission while squared GDP reduces them in the long run. In contrast, Ozcan (2013) reports a U-shaped relationship for 12 Middle Eastern countries, indicating that emissions initially decline with growth but rise again at higher income levels. Moreover, they find different country-level results, while some economies exhibit inverted U-shaped patterns, others U-shaped, and some show no significant link at all.

Another strand of EKC related literature focuses on broader growth-pollution relationship, often using different pollutants or energy use as proxies for environmental degradation (Copeland Taylor, 2003; Bese et al., 2018). A key finding in this line of research is the role of renewable energy in mitigating pollution. For instance, Marques et al. (2010) and Ito (2016) show that renewable energy consumption significantly reduces emissions, particularly in developed countries, highlighting the importance of clean energy in supporting sustainable growth.

While many empirical studies confirm the inverted U-shape of the EKC, they often focus on selected pollutants. However, conventional EKC pattern does not always hold, and a strand of literature challenges its validity. Some studies (Clausen and York 2008; Lee and Lee 2009; Coondoo and Dinda 2008) find no evidence of the EKC, showing instead that pollutant emissions continue to rise with higher income levels. In the case of Malaysia, Begum et al. (2015) and Go et al. (2021) also reject the EKC hypothesis, particularly for pollution-intensive sectors. Similarly, Masron and Subramaniam highlight instances where the relationship takes the opposite from the conventional EKC, indicating a direct rather than inverted U-shaped link between income and certain pollutants. The shape of EKC

depends on another factor apart from concerned pollutant, is the socio-political and institutional structures of the economy. The turning point of the inverted U-shaped EKC comes at a high-income level but that also depends on how environmental awareness is internalized by producers, consumers and governments. For producers, adopting cleaner technologies or abating pollution is often costly, while consumers face a trade-off: reduced pollution improves environmental quality but can increase price of goods previously produced with cheaper, polluting inputs. Governments, acting as a social planner, intervene through policies aimed at balancing growth with sustainability. These measures range from market-based mechanisms such as pollution taxes and cap-and-trade schemes to non-market-based approaches like command-and-control regulations and the promotion of green technologies.

International agreements such as the Kyoto Protocol (1992), the Paris Agreement (2015), and successive COP summits have reinforced the role of such measures. Yet, their success in curbing emissions varies significantly across countries depending on many factors like the nature of pollutants targeted, the technological capacity to adopt cleaner production, and political-economic factors such as corruption and lobbying. In this regard, the political economy of climate policy has drawn increasing attention. While corruption and bribery are often associated with developing countries, lobbying is more prevalent in developed nations, where firms attempt to influence environmental regulations in their favor.

The role of lobbying was particularly evident during COP28, held in November 2023 in the UAE⁽¹⁾. The summit witnessed an unprecedented number of fossil-fuel lobbyists, many representing major oil and gas companies such as Shell, Total and ExxonMobil. Climate activists argued that these summits are increasingly becoming platforms for greenwashing, allowing corporations to present a façade of climate action while obstructing meaningful progress. Although the primary aim of COP28 was to secure a commitment to phasing out fossil fuel use, negotiations were hindered by the resistance of major polluting nations⁽²⁾. This raises broader concerns about the EKC logic- where higher growth supposedly leads to environmental improvements-remains valid when political and lobbying pressure distort climate policy outcomes.

Thus, it is clear that relationship between growth and pollution might change when we consider other political economic factors which have an impact on this relationship. The theoretical evaluation of the impact of growth on pollution in the presence of lobbying has not been done extensively. Although there are empirical papers that have attempted to understand the impact of corruption on environmental efforts. There exists a small set of literature that deals with corruption and environment. Masron and Subramaniam (2018) find the direct and indirect impacts of corruption on environmental degradation using the panel data of 64 developing countries. Using the generalized method of moments (GMM) technique, this study shows that corruption exhibits a positive impact on pollution and there is also evidence that the level of pollution tends to be higher in countries with a higher level of corruption, eliminating the effectiveness of the role of income in creating environmental consciousness. Their results also suggest that environmental degradation is monotonically increasing with higher corruption and invalidate the presence of the conventional shape of EKC in the presence of corruption in case of a developing country. With the help of

simulation, they show that corruption tends to worsen environmental standards at the higher level of income and instead of going downward after the threshold income it moves upward for both carbon emission and ecological footprint.

A number of theoretical studies (Lopez and Mitra 2000; Fredriksson et al. 2004; Sheng et al. 2016) show the possibility that higher levels of corruption tend to reduce the stringency of environmental rules and regulations. Pellegrini and Gerlagh (2006) empirically analyze the relative impact of corruption, democracy, and environmental policies in 41 countries and show a positive relationship between income and environmental policy stringency (lower corruption). Furthermore, Cole (2007) finds that corruption attracts environmental pollution and a higher degree of corruption which, in turn, can speed up per capita emissions and, hence, affect the dynamics of environmental performance. Lopez and Mitra (2000) indicate that government institutions in developing nations are often weaker and less efficient than in developed countries and hence imposition of environmental policies become less stringent. Leita (2010) assert that higher corruption will delay governmental concern for and control of environmental quality and may result in postponing environmental laws and restricting the enforcement of these laws.

Now when it comes to lobbying in the literature it is either studied together with corruption or separately. Harstad and Svensson (2011) distinguish lobbying from the mere act of bribery by stating that when a firm faces a regulation it has three options, to comply, bribe the regulator or lobby the government to relax it. It is dependent on the developmental status of the economy. According to them when the level of development is low, firms are more prone to pay bribe and 'bend the rule' but it switches to lobbying when development level becomes sufficiently high. Unlike bribery, lobbying is generally perceived as a lumpsum transfer to the government by firms collectively. Harstad and Svensson (2011) argue that this lumpsum transfer is jointly paid by the several firms but the burden of each firm is determined via Nash bargaining. Even though the common narrative that prevails is lobbying helps 'bending the rules' for the big firms and eventually harming the environmental quality, there is a different view that shows how lobbying specifically green lobbying can sometime be helpful for achieving environmental goals too (Hu et al. ,2020, Binder and Neumayer, 2005, Fredriksson et al. ,2005). Anger et al. (2015) explain how lobbying efforts affect energy tax differentiation, showing that sectors with more lobbying, driven by inelastic energy demand, tend to face lower energy tax rates. Empirical studies on environmental tax reforms in Germany support these theoretical findings.

In this backdrop, this paper theoretically investigates the impact of increase in growth factor of an economy on the environmental pollution in the presence of lobby payment made by a polluting firm to a non-benevolent self-motivated government. In this paper we consider two cases of decision making. First, where firm is the sole decision maker the impact of growth on both pollution and corruption depends on the output elasticity of pollution. Second, when firm and self motivated government jointly decide the amount of lobby payment, increase in growth reduces both lobby payment and pollution. Finally, we consider a case where the semi-benevolent government invests the tax revenue collected from the polluting firm to boost the economic growth rate. In this case, we try to find the impact of increase in pollution tax on lobby payment and pollution. When the firm is the

sole decision maker with increase in pollution tax it reduces lobby payment and pollution while in case of Nash bargaining solution where the firm and the government jointly decide the lobby payment, with an increase in environmental tax, the firm pays higher lobby payment and pollute more. If government assigns higher weight on lobby payment that will also cause a rise in lobby payment, increase in pollution, increase in tax revenue and that will cause a rise in growth factor. Lastly, higher the weight of pollution in welfare, it will cause lowering the level of lobby payment as well as lowering the level of pollution.

As we have already mentioned, the impact of growth on pollution in the presence of corruption has been done empirically but theoretical work in this particular issue is scarce except a few (Lopez Mitra ,2000). Our work deviates from Lopez and Mitra (2000) in a number of ways like first, besides updating on the recent literature, we have complemented their work by considering a tax rate imposed on environmental pollution. The firm is assumed to make a lobby payment to reduce the tax rate. Self- interested (semi-benevolent) government's objective is to maximize the weighted sum of welfare of the society (as it helps to get the government votes), bribe amount and the tax revenue. In Lopez and Mitra (2000) though welfare and bribe amount are parts of government's objective function but, the tax revenue is not. We have also considered a separate section where the tax revenue is spent to enhance the growth rate which is not considered in Lopez Mitra (2000). Our findings are also different from their work. When the firm solely decides the lobby amount, we get through- out upward rising or downward sloping relationship between growth factor and pollution. When lobby amount is decided by the firm and the government jointly by Nash bargaining solution the relationship between growth factor and pollution is negative instead of an inverted U-shaped curve like conventional EKC, which has been found by Lopez Mitra (2000).

The rest of the paper is organized as follows: Section 2 talks about the theoretical model that we have mentioned above, the Section 3 discusses the impact of pollution tax when Government uses the tax revenue to boost the growth rate, Section 4 discusses the findings of the model and finally Section 5 concludes the paper.

2. The model

We build up a model where the firm produces output Y using two factors, namely, environmental pollution, x and external effect generated from economic growth (growth factor), $g^{(3)}$. Note that, we assume that this is a free input. The logic underlying including the economic growth rate as input in the production function is that firm in a fast-growing economy will be more productive than the same in a low growth economy.

Thus, the firm's production function can be written as

$$Y = x^\lambda g^{1-\lambda} \quad (1)$$

λ is the output elasticity of pollution and $0 \leq \lambda \leq 1$

The government imposes a per unit environmental tax τ on the pollution used by the firm. The firm makes a lobby payment 'c' to the government for reducing the tax rate on pollution. Higher the amount of lobby payment, lower is the tax rate imposed on pollution.

When the firm makes the lobby payment, the profit function of the firm is assumed to take the following form:

$$\Pi = x^\lambda g^{1-\lambda} - \frac{\tau}{c}x - c, \quad c \geq 1 \quad (2)$$

where π is the profit level of the firm, c is the amount of rent or lobby payment and τ is the environmental tax. The higher the amount of c , lower is the tax burden on the firm.

However, when lobby payment is equal to zero, it is assumed that tax rate imposed on polluting inputs becomes fixed.

Therefore, when the lobby payment is zero, the firm's profit function is

$$\pi^* = X^\lambda g^{1-\lambda} - \tau X \quad (3)$$

Where X denotes the amount of polluting input used in case of no bribe.

First, we consider the case when the firm is the sole decision maker of how much lobby it would pay to maximize its profit. Second, following Lopez and Mitra (2000), in this model we consider the case where the firm and the government decide pollution and lobby payment through a Nash bargaining solution.

We assume the government is engaged in rent seeking behavior and receives a lobby payment 'c' from the firm to reduce the tax rate on pollution. When firm is the sole decision maker it chooses the quantity of polluting inputs and lobby amount to pay to the government simultaneously by maximizing profit level. In the Nash bargaining solution, the firm considers 'c' to be given and takes the decision regarding how much polluting inputs to use by maximizing its profit level. Then, the lobby amount is decided jointly by the firm and the government by Nash bargaining solution. There are two possibilities in this model, either the firm strikes a deal with the government or the firm fails to strike a deal. So, in the first case, profit function is given by equation (2) and in the second case profit function is given by equation (3).

When firm makes a lobby payment profit maximizing level of pollution is obtained by maximizing (2) with respect to x ,

$$x = \left(\frac{\tau}{\lambda c}\right)^{\frac{1}{\lambda-1}} g \quad (4)$$

When no lobby payment is made, maximizing π^* given by (3) with respect to X gives,

$$X = \left(\frac{\tau}{\lambda}\right)^{\frac{1}{\lambda-1}} g \quad (5)$$

Substituting this X given by (5) in the profit function π^* given by (3) yields

$$\pi^* = \left(\frac{\tau}{\lambda}\right)^{\frac{\lambda}{\lambda-1}} g - \tau \left(\frac{\tau}{\lambda}\right)^{\frac{1}{\lambda-1}} g \quad (6)$$

In presence of lobby payment, we define the social welfare function as follows

$$W = \alpha \Pi - \beta x, \quad 1 \geq \alpha \geq 0, \quad 1 \geq \beta \geq 0 \quad (7)$$

Where α is the weight assigned to profit (economic output) in economic welfare, and β is the weight associated to pollution in it. Economic agents derive gain from economic output but dislikes the level of pollution as it harms the environmental quality they enjoy.

It is the existing political party that makes the government in any economy. In the presence of lobby payment, self-motivated government (existing political party) is assumed to have the following objective function,

$$G = (1 - a - b)(\alpha\Pi - \beta x) + bx\frac{\tau}{c} + ac, \quad 0 \leq a \leq 1, 0 \leq b \leq 1 \quad (8)$$

G is a weighted average of social welfare, tax revenue and lobby payments. As the welfare of the economy increases, people are more likely to choose the existing political party to rule. Though not modelled, it is assumed that the government spends the tax revenue for different welfare programs that would enhance welfare of the agents of all section of the society (Lopez Mitra 2000)⁽⁴⁾. Therefore, the popularity or vote bank of the ruling party is more when the tax revenue increases. The objective function also depends on the amount of lobby payment collected because officers who are direct beneficiaries of lobby payments are also assumed to form a large part of the vote bank. If the government's motive is to getting re-elected it should take care of both welfare of the society along with the tax revenue collected and the lobby payments received.

2.1. Firm is the sole decision maker

In this sub-section, it is assumed that the firm is the sole decision maker. The firm simultaneously chooses the quantity of polluting inputs to employ and the lobby to be paid to the government by maximizing its profit. The profit maximizing level of pollution is given by equation (4). Maximizing profit given by equation (2) with respect to c gives,

$$c = \sqrt{x\tau} \quad (9)$$

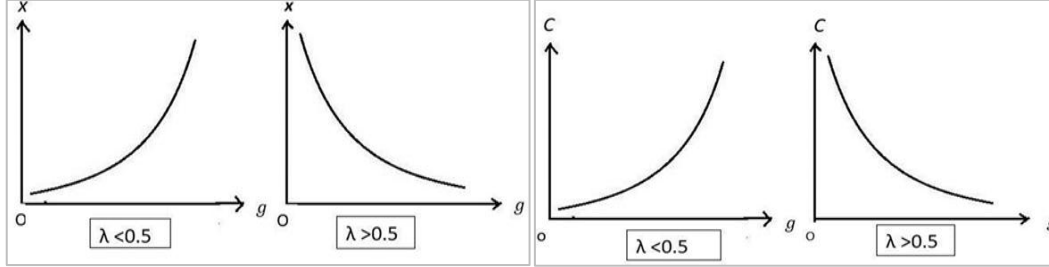
Now we try to derive the relation between growth and pollution as well as growth and lobby payment. Using (4) and (9) we get,

$$x = \lambda^{\frac{2}{1-2\lambda}} g^{\frac{2(1-\lambda)}{1-2\lambda}} \tau^{\frac{1}{2\lambda-1}} \quad (10)$$

$$c = \tau^{\lambda/(2\lambda-1)} g^{(1-\lambda)/(1-2\lambda)} \lambda^{1/(1-2\lambda)} \quad (11)$$

From equation (10), we observe that the relationship between g and x depends upon the factor $(\frac{2(1-\lambda)}{1-2\lambda})$ which in turn depends on λ (output elasticity of polluting inputs in production function). If λ is less than 0.5 pollution rises with growth and if λ is greater than 0.5, with rise in growth, pollution falls.

From equation (11), we can infer that at low level of λ with rise in g the level of corruption goes up and the result reverses when λ crosses 0.5. When λ is less than 0.5, output elasticity of g is high. With rise in g gain from using x that is the marginal product of polluting input goes up and outweighs the cost burden from using higher x for paying higher tax and higher lobby payment. When λ is greater than 0.5, the cost burden from using high x outweighs the gain from using higher x and paying higher lobby payment. So, it is optimal for the firm to use lesser x and pay less lobby payment as g rises.

Figure 1: Impact of growth on pollution and lobby payment when the polluting firm is the sole decision maker

Proposition 1: When a firm solely decides how much lobby amount to be paid so as to reduce the tax burden on polluting input, the impact of growth on both pollution and corruption depends on the output elasticity of pollution. If the output elasticity of pollution is less than 0.5, both pollution levels and lobby payments increase with growth; if it exceeds 0.5, this relationship reverses.

Though in this section we have considered the entire range of lambda. Kalaitzidakis (2008) Finds the lambda to be on average 0.008 for OECD nations, so it is fair to assume its value to be lower than 0.5, Thus, now onwards we will consider the value of lambda to be less than 0.5.

2.2. Nash bargaining solution and environmental pollution

In the Nash bargaining solution, the firm chooses how much polluting input to use by maximizing profit level then taking this into account the firm and the government jointly decide the amount of lobby payment given a level of pollution tax by bargaining with each other. The maximand of Nash bargaining solution can be written explicitly as

$$H = [\Pi - \pi^*] \left[(1 - a - b)(\alpha\Pi - \beta x) + \frac{b\tau x}{c} + ac - (1 - a - b)(\alpha\pi^* - \beta X) - b\tau x \right] \quad (12)$$

Using equations (2), (4), (6) and (8) we get,

$$H = \left[\left(\frac{\tau}{\lambda c} \right)^{\frac{\lambda}{\lambda-1}} g - \frac{\tau}{c} \left(\frac{\tau}{\lambda c} \right)^{\frac{1}{\lambda-1}} g - c - \left(\frac{\tau}{\lambda} \right)^{\frac{\lambda}{\lambda-1}} g - \tau \left(\frac{\tau}{\lambda} \right)^{\frac{1}{\lambda-1}} g \right] \\ \left[(1 - a - b) \left\{ \alpha \left(\frac{\tau}{\lambda c} \right)^{\frac{\lambda}{\lambda-1}} g - \alpha \frac{\tau}{c} \left(\frac{\tau}{\lambda c} \right)^{\frac{1}{\lambda-1}} g - \alpha c - \beta \left(\frac{\tau}{\lambda c} \right)^{\frac{1}{\lambda-1}} g \right\} + b \frac{\tau}{c} \left(\frac{\tau}{\lambda c} \right)^{\frac{1}{\lambda-1}} g + ac \right. \\ \left. - (1 - a - b) \left\{ \alpha \left(\frac{\tau}{\lambda} \right)^{\frac{\lambda}{\lambda-1}} g - \tau \alpha \left(\frac{\tau}{\lambda} \right)^{\frac{1}{\lambda-1}} g \right\} - b\tau \left(\frac{\tau}{\lambda} \right)^{\frac{1}{\lambda-1}} g \right] \quad (12')$$

H is maximized with respect to c. As solving the non-linear equation analytically is not possible and also getting empirical observation on these parameters which are consistent with this model is outside the scope of this paper, we have done our analysis numerically

by taking hypothetical values of the parameters. To operationalize the model, we calibrate the parameters to values that are both theoretically consistent and empirically grounded in literature. The calibration reflects political economy of developing countries, where economic growth is prioritized, environmental regulation is relatively weak, and government behavior is shaped by both fiscal needs and corruption incentives. Table 1 summarizes the chosen parameter values, along with their rationale and supporting literature. These values are not intended to replicate a single country but to capture stylized features common in developing economies, thereby ensuring that the model outcomes are realistic and comparable to existing findings. The environmental tax rate is fixed at 0.2, consistent with evidence that such economies typically impose modest environmental taxes (OECD, 2010). In the welfare function, economic profit receives a weight of 0.6, while pollution is weighted at 0.2, mirroring the prioritization of growth over environmental quality in developing contexts (Dasgupta et al. 2002). Within the government's objective function, tax revenue is assigned a weight of 0.2, whereas lobby payment receives a higher weight of 0.6, reflecting findings that corrupt governments value rent extraction more than fiscal gains (Shleifer and Vishny, 1993; Frederiksson & Svensson, 2003).

Table 1. Variable description and baseline values

Variables/ Parameters	Baseline value	Justification	Supporting Literature
Output elasticity of polluting input (λ)	0.2	A 1% rise in output raises pollution by 0.2%. Reflecting that production relies less on polluting inputs due to partial adoption of cleaner technologies, and regulation. This is especially relevant in developing countries transitioning toward greener growth.	Antweiler, Copeland & Taylor (2001); Brock & Taylor (2010); Cole (2004); Kalaitzidakis (2008)
Environmental tax (τ)	0.2	Developing countries generally set modest environmental taxes due to political resistance, weak enforcement capacity, and concerns about growth slowdown.	OECD (2010); Eskeland & Harrison (2003)
Weight assigned to lobby payment by self-motivated Government (α)	0.6	Corrupt governments derive higher utility from lobbying rents than from public tax revenue.	Shleifer & Vishny (1993); Ades & Di Tella (1999); Frederiksson & Svensson (2003)
Weight assigned to tax revenue by self-motivated Government (b)	0.2	Fiscal mobilization plays a limited role in rent-seeking states.	Tanzi & Davoodi (1997); Bird et al. (2008)
Weight assigned to eco- nomic profit in welfare (α)	0.6	Growth and industrial profitability are prioritized over environmental concerns in early stages of development.	Dasgupta et al. (2002); Lopez & Mitra (2000)
Weight associated to pollution in welfare (β)	0.2	Environmental quality is considered but plays a secondary role compared to growth and jobs, reflecting trade-offs in policy priorities.	Dasgupta et al. (2002); Lopez & Mitra (2000)

Table 2. Impact of growth on the amount of lobby payment and pollution level

g	c	x
0.01	$1.294538272 \times 10^{12}$	$1.380840823 \times 10^{13}$
0.02	$8.090864198 \times 10^{10}$	$8.630255144 \times 10^{11}$
0.03	$1.598195398 \times 10^{10}$	$1.704741758 \times 10^{11}$
0.04	5.056790132×10^9	$5.393909476 \times 10^{10}$
0.07	5.391663028×10^8	5.751107252×10^9
0.1	1.294538361×10^8	1.380840942×10^9
0.15	2.557113521×10^7	2.727587992×10^8
0.5	207134.6845	2.209459464×10^6

Baseline values: $\lambda = 0.2$, $\tau = 0.2$, $a = 0.6$, $b = 0.2$, $\alpha = 0.6$, $\beta = 0.2$

In Table 2, we observe that increase in growth factor reduces both the amount of lobby payment and pollution. We have considered growth level to vary from 1% to 50%. It is observed that with increase in growth rate, there is monotonous fall in the amount of lobby payment from $1.294538272 \times 10^{12}$ to 207134.6845 but interestingly corresponding pollution level also falls throughout from $1.380840823 \times 10^{13}$ to 2.209459464×10^6 . Thus, in our framework- where firm and government jointly determine lobbying through Nash bargaining- growth exerts a dual effect: it reduces pollution and lowers lobby payment. A plausible explanation is that higher growth increases output substantially, reducing the incentive for firms to pay government in exchange for pollution tax cuts. Existing literature supports our finding that, government corruption is higher in countries with lower growth. Mocan (2004) empirically tested that the correlation between per capita GDP and “gifts” to public officials for several countries and it is found to be negative. Triesman (2000) also finds that growth has negative impact on corruption. Bai et. al. (2013) has studied the growth corruption relation both theoretically and empirically for Vietnam) and has found that economic growth (of firms) reduces corruption (bribery) and prescribe that corruption is not needed to be rooted out rather growth subsidizes corruption. In our study we have built this theoretical model to understand the impact of growth on environmental pollution in the presence of corruption. Our finding is shown in Table 2 where we see that with the rise in growth factor, the endogenously determined amount of lobby payment falls which might be due to the fact that growth factor improves the institutional quality (Acemoglu, Johnson, and Robinson, 2005; Glaeser, La Porta, Lopez-de Silanes, and Shleifer, 2004) and polluting inputs becomes less important. Moreover, in this model, as the polluting inputs are taxed while growth factor is free, polluting inputs are relatively expensive. Therefore, the firm might take the decision to use lesser polluting inputs. Our finding is in same line of this literature where it is observed that lobby payment is lower when an economy is experiencing growth. In our model the firm and a corrupt government are coming to a co-operative solution via Nash bargaining.

Our finding also sheds light on the intertwined growth-pollution nexus which over the period of time has been investigated in a more complex manner. Initially, it was believed that growth increases pollution. This prompted discussions regarding the feasibility of achieving sustainable economic growth at regional, national, and global levels (Adebayo 2020; Adebayo & Odugbesan, 2021). Central to this discourse is the environmental Kuznets curve (EKC) theory, which suggests an inverted-U-shaped relationship between per capita GDP and per capita pollutant emissions, based on empirical observations (Grossman & Krueger, 1991). Historically, many developed countries followed a "Treatment after Pollution" approach during early economic development, eventually reaching a decline in pollutant emissions by the end of the 20th century. However, lessons from their environmental governance may not be directly applicable to developing countries, which are still ascending along the EKC curve and have yet to reach its turning point (Panayotou, 2000). This divergence reflects differing stages of economic development between developed and developing nations, resulting in distinct economic-environmental relationships (Lu et al., 2007).

The EKC hypothesis has garnered significant scholarly interest and has been applied to study various economies and time periods (Apergis & Ozturk, 2015; Destek et al., 2018).

However, while the EKC has been supported in some cases, evidence suggests it does not universally hold true (Perman & Stern, 2003; Stern, 2004; Robalino-Lopez et al., 2014; Lorente & Herranz, 2016). Studies on the relationship between economic growth and environmental pollution often use various curve shapes (inverted-U, N-shaped, inverted N-shaped, U-shaped), focusing on inflection points but not fully explaining the underlying dynamics.

3. Impact of pollution tax when Government uses the tax revenue to boost the growth rate

In this section, we consider the case where semi-benevolent government invests the tax revenue collected from the polluting firm to boost the economic growth rate, g . In the previous sections, we took the value of g as exogenously given and determined its impact on lobby payment and pollution level. But, in this section growth rate (g) is determined endogenously along with the value of lobby payment and pollution level. Here, we are interested in evaluating the impact of change in tax rate on corruption, pollution and the growth rate.

We assume that g takes the following form,

$$g = \delta \sqrt{\frac{x\tau}{c}}, \quad 0 \leq \delta \leq 1 \quad \text{When } c > 1 \quad (13)$$

3.1. Firm is the sole decision maker

Similar to subsection 2.1 here also the firm simultaneously chooses the quantity of polluting inputs to employ and the lobby to be paid to the government by maximizing its profit.

Substituting g from equation (13) in equation (2) and maximizing it with respect to lobby payment (c) and pollution (x) gives us the first order conditions,

$$\frac{\lambda+1}{2} x^{\frac{\lambda-1}{2}} \left(\frac{\tau}{c}\right)^{\frac{1-\lambda}{2}} \delta^{1-\lambda} - \frac{\tau}{c} = 0 \quad (14)$$

$$\frac{1-\lambda}{2} x^{\frac{\lambda+1}{2}} \left(\frac{\tau}{c}\right)^{-\left(\frac{\lambda+1}{2}\right)} \frac{\tau}{c^2} \delta^{1-\lambda} - \frac{\tau x}{c^2} + 1 = 0 \quad (15)$$

Solving equation (14) and equation (15) we determine the expression for c and x in terms of τ . Substituting these values of c and x in equation (13) we determine g in terms of τ . Since g is endogenously determined, the only exogenous variable here is the tax rate (τ) and we try to see the impact of change in tax rate on lobby payment (c) growth factor (g) and pollution (x). Due to non-linearity of the equations, it cannot be done analytically. Therefore, we have taken the benchmark value of output elasticity of pollution (λ) to be 0.2 and for different possible values of tax rate ranging from 0.004 to 0.36 tried to see the impact of it on these three endogenously determined variables. The results are shown in Table 3.

Table 3. Impact of change in tax rate on lobby payment (c) growth factor (g) and pollution (x) when firm is the sole decision maker and tax revenue is used to boost growth

τ	c	g	x
0.004	2.160000001	1.203732549	39.12224534
0.006	1.439999998	1.087695143	21.29545298
0.008	1.079999999	1.012214385	13.83180246
0.01	0.863999998	0.9572932615	9.897232189
0.08	0.10799	0.5692099784	0.4373999986
0.1	0.0863999992	0.5383255611	0.3129779622
0.2	0.0432000000	0.4526760345	0.1106544198
0.28	0.03085714281	0.4161553610	0.06680003821
0.36	0.02400000002	0.3908133374	0.04582051944

Output elasticity of pollution (λ) is assumed to be 0.2

From Table 3 we see that when the firm is taking the decision solely and government reinvest the collected tax revenue to boost growth factor, with the rise in tax rate all the three variables (growth factor, lobby payment and pollution) are falling. With higher tax rate, firms will prefer to pay less lobby payment and rather it would pollute less to avoid the tax burden. For this particular set of values, we observe that when tax rate is fairly less (less than 0.01) firms will be willing to pay lobby payment as $c > 1$ and beyond that if tax rate rises further $c < 1$, implying there will be no lobby payment. It is interesting to observe that with rise in tax rate, growth factor is also decreasing which means that even though tax revenue is reinvested in growth factor, when firm is the sole decision maker the reduction in pollution is higher in magnitude to dampen the impact of higher tax rate on growth factor by reducing the tax revenue in total.

3.2. The Nash bargaining solution

Like subsection 2.2 here again we consider the case where firm and the semi-benevolent government jointly decides the lobby payment via Nash bargaining and consequently the growth factor and pollution level are determined too. In this case the objective of the government changes from previous case since government no longer incorporates the tax revenue in its own objective function but uses it to enhance growth as described in equation (13).

The aforementioned objective function of the government, (8) changes to,

$$G = (1 - a)(\alpha\Pi - \beta x) + ac \quad (16)$$

So now the Nash bargaining maximand will become,

$$H = [\Pi - \pi^*][(1 - a)(\alpha\Pi - \beta x) + ac - (1 - a)(\alpha\pi^* - \beta X)] \quad (17)$$

Substituting Π , x , X , π^* and g from equation (2), equation (4), equation (5), equation (6) and equation (13) in equation (17), then maximizing it with respect to c , we determine the Nash bargaining solution of lobby payment. Using that c in the new profit maximizing level of pollution and equation (13) respectively we obtain x and g , given τ . As g is endogenously determined, here we have tried to investigate the impact of change in the other exogenous parameters of our model like tax rate (τ), weight assigned to lobby payment in Government's objective function (a) and weight of pollution in welfare function (β) on lobby payment (c), government expenditure (g) and pollution level (x).

With the baseline values of $\lambda = 0.2$, $\tau = 0.2$, $a = 0.6$, $b = 0.2$, $\alpha = 0.6$, $\beta = 0.2$, $\delta = 1$ the impact of change in τ , a and β on lobby payment, growth rate and pollution are shown in Table 4, 5 and 6 respectively. With the rise in environmental tax from 0.08 to 0.36, firms are paying high lobby payment from 0.514 to 8.723 and using higher polluting inputs from 5.019 to 33.2621. Here the results are completely opposite of what we got in the case of firm being the sole decision maker. Here for lower tax rates, firm will not pay any lobby payment ($c > 1$) but if tax rate is sufficiently high, firm will start paying lobby payment ($c < 1$) and that will keep on increasing as tax rate goes up and that results in continuous increase in growth factor too. May be due to rise the tax revenue outweighs the amount of lobby it eventually increases the growth factor of the economy from 0.841 to 1.171. If government assigns higher weight on lobby payment that will obviously cause a rise in c and a rise in growth factor. The third finding is intuitively obvious, where higher negative weight assigned to pollution in welfare function (government value the quality of environment they enjoy more) will cause lowering the level of lobby payment as well as optimum level of pollution. But in this case, growth rate will also fall might be because the fall in tax revenue will dominate over the fall in lobby payment.

Table 4. Impact of change in τ

τ	c	g	x
0.08	0.5140461072	0.8407504041	5.01945083
0.1	0.6868344215	0.8548739352	7.01654830
0.2	2.032964326	0.9428964561	9.037072554
0.28	4.462665463	1.055110969	17.74322568
0.36	8.723362242	1.171613627	33.26214369

Baseline values: $\lambda = 0.2$, $\tau = 0.2$, $a = 0.6$, $b = 0.2$, $\alpha = 0.6$, $\beta = 0.2$, $\delta = 1$

Table 5. Impact of change in a

a	c	g	x
0.6	2.032964326	0.9428964561	9.037072554
0.7	5.625868455	1.216127075	41.60231444
0.75	10.15800590	1.409722655	100.9359381
0.8	19.72226038	1.664066723	273.0663370

Baseline values: $\lambda = 0.2$, $\tau = 0.2$, $a = 0.6$, $b = 0.2$, $\alpha = 0.6$, $\beta = 0.2$, $\delta = 1$

Table 6. Impact of change in β

β	c	g	x
0.1	6.340611817	1.253038328	49.77713321
0.08	9.546475278	1.388009143	91.95973492
0.07	12.25553170	1.477456161	133.7615735
0.06	16.40598631	1.589213150	207.1746669

Baseline values: $\lambda = 0.2$, $\tau = 0.2$, $a = 0.6$, $b = 0.2$, $\alpha = 0.6$, $\beta = 0.2$, $\delta = 1$

4. Result and discussion

The major focus of this paper is to determine the impact of growth factor on pollution in the presence of corruption, specifically lobby payment. Lopez, Mitra (2000) has investigated the same and has concentrated on the shape of EKC in the presence of corruption. In their paper EKC is conventional shaped but the maximum point is shifted in

rightward direction because of corruption. However, in the present paper, unlike the conventional inverted U-shaped EKC we get a throughout upward or downward sloping curve, depending on how the decision on lobby payment is made. In the presence of lobby payment, we study the behavior of pollution level and lobby payment amount with the rise in growth level in two cases: firstly, when firm is the sole decision maker, secondly, in the case when firm and government are engaged in Nash bargaining. In the first case results depend on the output elasticity of pollution. If the output elasticity of pollution is less than 0.5 growth increases both the lobby payment as well as the pollution level and the result reverses when elasticity is over 0.5. Second, if the self-motivated government and firm jointly decides the amount of lobby payment by Nash bargaining solution, growth will have a negative impact on pollution and lobby payment. Next, we consider the case where self-motivated government invests back the tax revenue it receives into the growth factor. Here also we have examined the two cases, one where firm is the sole decision maker regarding the amount of lobby payment and polluting input. We investigate the impact of tax rate, (τ), for both cases. When firm is the sole decision maker at low level of tax rate, firm pays lobby payment. But, with rise in tax rate, eventually the amount of lobby payment, amount of polluting input and growth factor falls. But in case of Nash bargaining solution with the rise in environmental tax, firms are paying high lobby payment and polluting more. Therefore, rise in the tax revenue outweighs the effect of higher lobby payment and eventually increases the growth factor of the economy. In case of Nash bargaining, we have examined the impact of change in weight of lobby payment received (α) and weight of pollution in welfare function (β), that are included in the Government's objective function, on pollution, lobby payment and growth factor. If the government imposes higher weight on lobby payment that will cause not only a rise in c but a rise in growth factor. The third finding is in line with the literature, where higher the weight of pollution in welfare will cause lowering the level of lobby payment as well as the level of pollution. But in this case, growth factor will also fall because of a decrease in tax revenue. So, a country run by dishonest government may have higher growth rate while a country run by honest government who really cares for environment may have lower growth rate! This finding strengthens "grease the wheels" hypothesis. When the government is dishonest and assigns more weight to lobby payment, it is obvious that lobby payment would increase but at the same time pollution also increases. The increase in pollution increases the tax revenue and increases the growth rate too. On the contrary, when the government cares more for environment, it accepts less lobby payment to reduce tax cut. As a result, the firm has to reduce the pollution level that in turn reduces the tax revenue and consequently the growth rate.

5. Conclusion

This paper examines the impact of growth and pollution tax on pollution in the context of corruption, specifically lobby payments. We build a model based on the previous research that explored the shape of the Environmental Kuznets Curve (EKC) under corruption, revealing that, unlike the conventional inverted U-shape, we can observe consistently upward or downward sloping curves based on who decides on lobby payments and

pollution levels. If the polluting firm is the sole decision maker, output elasticity of pollution is a key factor. When a self-motivated government and firm jointly determine lobby payments through Nash bargaining, growth negatively affects both pollution and lobby payments. We also analyze scenarios where the semi-benevolent government reinvests tax revenue to enhance the growth factors. The impact of change in tax rate here also depends on how the amount of lobby payment and pollution level is decided.

When growth factor is exogenous, bargaining power to decide the lobby amount should not be concentrated to firm only. If it is inevitable, it should be jointly decided through Nash bargaining solution. However, when growth rate is no longer exogenous, we cannot recommend such set up to decide the lobby payment. In this case, we find that when the firm is the sole decision maker, increase in pollution tax reduces both pollution and corruption but when lobby payment is decided by Nash bargaining solution increase in tax increases lobby payment and pollution.

Competing interests

The authors declare none.

Notes

- (1) <https://www.theguardian.com/environment/2023/dec/05/record-number-of-fossil-fuel-lobbyists-get-access-to-cop28-climate-talks>
- (2) <https://www.bbc.com/news/science-environment-58982445>
- (3) This type of production function is used in Mitra Lopez (2000). Pollution is treated as an input also in Copeland Taylor (2003).
- (4) Tax revenue enhances people's confidence in the government by improving the budgetary position of the government. Spending the tax revenue for improving welfare is not modelled in this section. Modelling that would not change our results.

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Heterogeneous effect of financial inclusion on economic complexity in developing countries

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Abstract. *This paper investigates the heterogeneous effect of financial inclusion on economic complexity in developing countries. The empirical analysis relies on quantile via moments method, using data from 71 developing countries over the period 2011-2021. The results show that financial inclusion significantly increases economic complexity, with a stronger effect in countries with high level of economic complexity. These findings imply that the ability of developing countries to produce diversified and increasingly complex products depends on their level of financial inclusion. Therefore, policymakers in developing countries should promote financial inclusion to increase their economic complexity.*

Keywords: developing countries, heterogeneous effect, financial inclusion, economic complexity.

JEL Classification: E44, O14, O55.

1. Introduction

Economic complexity measures the amount of knowledge that is materialized in a country's production system (Hausmann and al., 2007; Hidalgo and Hausmann, 2009; Hausmann et al., 2014). The economic complexity indicator developed by Hidalgo and Hausmann (2009) measures the complexity of a country's productive structure based on the products it exports (Hidalgo and Hausmann, 2009; Hausmann and al., 2014). It reflects the diversification and ubiquity of the products exported by the country (Tacchella et al., 2012). A product is considered to be complex if it requires many exclusive capabilities that can be inferred from the ubiquity of that product and the diversity of exports by its main exporters. Thus, only a few countries, possessing many exclusive skills, export complex products (Poncet and Waldemar, 2013), which gives them a competitive advantage over others. Therefore, economic complexity is closely linked to a country's level of development and future economic growth (Hausmann and al., 2011; Hidalgo, 2021). It accelerates the process of structural transformation in developing countries (Hidalgo, 2021; McMillan and Rodrik, 2011) and contributes to reducing poverty and inequality (Hartmann et al., 2017; Lee and Vu, 2020). The issues surrounding economic complexity make it pertinent to analyze its determinants.

Previous works have highlighted some determinants of economic complexity, including internet use (Lapatinas, 2019), institutional quality (Hoang and Chu, 2023; Nguyen and al., 2023), international financial flows (Ogbuabor and al., 2023). Despite these contributions on the determinants of economic complexity, very little attention has been paid to the role of financial inclusion. Our paper fills this gap by investigating the heterogeneous effect of financial inclusion on economic complexity. Fan et al. (2015) showed that the introduction of innovative products requires considerable investment. In this context, improving financial inclusion could play an important role as a tool for financing innovation (Nguyen and Su, 2021). Theoretically, Fan and al. (2015) model establishes a strong link between economic complexity and financial inclusion. Indeed, their model shows that credit constraints force firms to produce low-quality products. It is therefore expected that improving financial inclusion will enable firms to access credit at low cost (Sviryzdenka, 2016; Lee and al., 2020; Canh and Thanh, 2020).

While theoretically, improved financial inclusion is expected to improve the economic complexity of countries, few empirical studies have focused on analyzing this link. It should be noted that some studies showed that financial development improves economic complexity (Zhu et al., 2020; Chu, 2020; Nguyen and Su, 2021; Emeka et al., 2024). These empirical studies make a major contribution to the analysis of the determinants of economic complexity. However, they do not shed sufficient light on the role of financial inclusion, as an indicator of financial development, in improving complexity, particularly in developing countries.

This research aims to analyze the effect of financial inclusion on economic complexity in developing countries. It makes two major contributions to the economic literature on the determinants of economic complexity in developing countries. First, unlike previous

studies that has analyzed the effect of financial development on economic complexity (Nguyen and Su, 2021; Njangang et al., 2021; Emeka and al., 2024), this research analyzes the effect of financial inclusion as a component of financial development on economic complexity. In analyzing the effect of financial development economic complexity, previous studies do not shed sufficient light on the effect of financial development components, notably financial inclusion on economic complexity. Second, previous studies have mainly relied on a single model to analyze the effect of financial development on economic complexity. As a result, these studies assume that the regression parameters are homogeneous over the entire distribution of economic complexity. These works do not therefore take into account the heterogeneity that exists between countries in terms of their level of economic complexity. Also, unlike previous studies which assume that the effect of financial development on economic complexity is linear, we take into account the non-linearity of the effect of financial inclusion on economic complexity. Indeed, this research takes into account both the heterogeneity and non-linearity of financial inclusion effect on economic complexity using quantile via moments regression method (Machado and Silva, 2019).

The remainder of the paper is organized into four sections. Section 2 is devoted to the literature review. Section 3 outlines the methodology and data employed. Section 4 presents and discusses the results. Section 5 concludes the paper and presents policy implications.

2. Literature review

In economic literature, a theoretical link has been clearly established between the financial sphere and economic complexity, thanks to models by Kletzer and Bardhan (1987) and Baldwin (1989). These authors develop models in which financial development is the fundamental element of each country's performance. Intuitively, their model implies that financial development mobilizes savings, reduces corporate transaction costs, diversifies technological risk and promotes access to information on investment projects. As a result, the development of the financial system not only encourages investment, but also makes it possible to select the most profitable projects. It is expected that countries that adopt a national policy to promote the development of the financial system will encourage the emergence of businesses and, in turn, the production of complex and sophisticated products (Ebireri, 2014).

Thus, the development of the financial system could be an effective instrument for promoting economic complexity. The financial sector plays an important role in terms of allocating scarce resources. Indeed, the development of the financial market creates a favorable environment for the expansion of innovative projects, which in turn enables the sophistication of the economic system. These effects are achieved through several channels. First, financial development reduces the cost of access to credit (Svirydzenka 2016). Second, financial development promotes access to the credit needed to finance investment in research and development (Maskus and al., 2012) and innovation (Hsu and al., 2014).

Empirically, a number of studies have examined the link between the financial sphere and economic complexity, albeit with controversial results. On the one hand, some find that financial development promotes economic complexity (Chu, 2020; Nguyen and Su, 2021; Emeka et al., 2024). For example, Chu (2020), using the GMM-system method applied to data covering 94 countries over the period 1968-2015, shows that the development of the banking system and stock market improves the economic complexity of the countries considered. Similarly, Nguyen and Su (2021) show using the fully modified ordinary least squares method and the GMM method that access to financial services and financial sector efficiency have a positive and significant impact on economic complexity in 86 countries over the period 2002-2017. Mobilizing data on 118 countries over the period 1995-2018, using GMM-system method, Avom and Ndoya (2024) find that financial development is one of the channels through which a country's stability improves its level of complexity. In the same vein, Njangang et al. (2021) mobilizing data on 24 African countries between 1983 and 2017. Using the Driscoll-Kraay and GMM-system methods, they show that financial development boosts economic complexity in Africa. However, Zhu et al (2020), using the GMM-system method on panel data covering 50 countries between 1990 and 2016, show that financial development has little or no significant positive impact on innovation. Nguyen and al (2020) analyze the impact of financial development overall and by component, as well as that of patents, on economic complexity in 52 countries. They use several estimation methods. Their results show a contrasting effect of financial development on economic complexity. Financial development, taken as a whole, improves economic complexity. However, analysis by component reveals divergent effects: financial institutions, taken as a whole, have a non-significant impact, the deepening and efficiency of financial institutions contribute positively to economic complexity, while accessibility to financial services has a significant negative impact on economic complexity.

The literature review shows that some studies highlighted the role of financial development and financial markets in improving the economic complexity of countries. However, few studies have focused exclusively on the effects of financial inclusion on economic complexity, particularly in developing countries. The present research aims to fill this gap by examining the effects of financial inclusion on economic complexity in developing countries. Moreover, while previous work tends to show, through various econometric techniques, that financial development promotes economic complexity, it does have some limitations. In fact, most of this work is based on a single model for analyzing the effect of financial development on economic complexity, assuming that the effect of financial development on economic complexity is constant over the entire distribution of the latter. However, there is a wide disparity in the level of economic complexity in different countries (Ndoya and al., 2024). As a result, these methods do not take into consideration this possible heterogeneity in the effect of financial development on the distribution of economic complexity.

3. Methodology

3.1 Empirical specification and estimation strategy

This section presents the empirical model used and the estimation strategy.

3.1.1. Estimation strategy

The model used to analyze the heterogeneous effect of financial inclusion on economic complexity is written as follows:

$$CE = f(IF, X) \quad (1)$$

Equation (1) states that economic complexity is a function of financial inclusion and control variables (X). These control variables include: GDP per capita, natural resource rents, trade openness and foreign direct investment.

To analyze the effect of financial inclusion on economic complexity in developing countries, we use quantile via moments regression method with fixed effect. This method has the advantage of being more robust than many estimators, notably ordinary least squares. Indeed, conventional linear regression (ordinary least squares) is based on the assumption that the relationships with the explanatory variables are uniformly distributed around the mean of the explained variable. The idea is to predict the conditional mean of the explained variable from the estimated parameters of the model. In some cases, however, it proves difficult to model the conditional mean, particularly when the distribution of the error terms does not follow a normal distribution, or when the error terms are heteroskedastic. In this context, quantile regressions offer an alternative to ordinary least squares regression. Initially developed by Koenker and Bassett (1978), quantile regression allows to study the effects of explanatory variables on different quantiles of the dependent variable distribution. The quantile regression method reinforces the information obtained and helps to analyze heterogeneous effect. Indeed, quantile regressions make it possible to describe and analyze the entire conditional distribution of the dependent variable. In fact, unlike the ordinary least squares, which is based on estimating the mean of the dependent variable, the quantile regression approach involves estimating the conditional quantiles of the dependent variable. Furthermore, the quantile regression approach is robust to outliers. It is suitable for censored or truncated variables, for extreme values and also in the presence of heterogeneity and nonlinearity in a panel data context. As a result, this approach appears to be suitable for the evaluation of public policies (Lokonon, 2023).

In this paper, this method is appropriate because it enriches the quantitative description of the effect of financial inclusion on economic complexity in developing countries. We analyze the effects of the model's independent variables at the 10%, 25%, 50%, 75% and 90% quantiles of the dependent variable distribution, considering heterogeneity between countries. Specifically, this research uses the estimator proposed by Machado and Silva (2019). The latter present two particular contexts in which their approach is suitable. These are panel data models with individual effects on the one hand, and models with endogenous explanatory variables on the other. Like classical quantile regressions, their model can estimate conditional quantiles based on the evaluation of conditional means. In the case of

quantile regression, however, conditional quantiles are obtained using the method of moments, by combining estimates of the location and scaling functions of the variable. The conditional mean and the conditional scaling function provide information comparable to that of conventional quantile regressions. They enable us to determine the influence of the explanatory variables on the conditional distribution as a whole. Thus, the estimator proposed by Machado and Silva (2019) is particularly suitable for panel data models with individual effects, as it differentiates individual effects while estimating regression quantiles. In addition, this estimator deals with endogeneity issue (Machado and Silva, 2019).

3.1.2. Model specification

The estimator thus proposed by Machado and Silva (2019) is written as an equation:

$$CE_{it} = \alpha_i + X'_{it} \times \beta + (\delta_i + Z'_{it} \times \gamma) \times U_{it} \quad (2)$$

In equation (2), CE_{it} represents the economic complexity, X_{it} the set of independent, independent and identically distributed variables for each individual i at date. U_{it} follows the same distribution as X_{it} and normalized X_{it} so as to fulfill the conditions necessary for estimating the quantile regression proposed by Machado and Silva (2019).

$(\alpha, \beta, \delta, \gamma)'$ are unknown parameters to be estimated.

(α_i, δ_i) avec $i = 1, \dots, n$ represent individual fixed effects;

The probability $P\{\delta_i + Z'_{it} \times \gamma > 0\} = 1$

Z_l is a known and differentiable transformation of X , given by:

$$Z_l = Z_l(X) \quad l = 1, \dots, n$$

The quantile regression of equation (2) gives:

$$Q_{CE}(\tau/X_{it}) = (\alpha_i + \delta_i \times q(\tau)) + X'_{it} \times \beta + Z'_{it} \times \gamma \times q(\tau) \quad (3)$$

$Q_{CE}(\tau / X_{it})$ represents the quantile distribution of economic complexity (CE_{it}).

$\alpha_i(\tau) \equiv \alpha_i + \delta_i(q)$ represents the fixed effect of quantile- τ for individual i . $q(\tau)$ is the τ -th quantile. It is estimated by solving the following optimization problem:

$$\min_q = \sum_i \sum_t \rho_\tau \times (R_{it} - (\delta_i + Z'_{it} \times \gamma) \times q) \quad (4)$$

Where $\rho_\tau(A) = (\tau - 1)AI\{A \leq 0\} + TAI\{A > 0\}$ represents the check function.

3.2. Justification for the choice of control variables

GDP per capita is used as a control variable. Theoretically, increasing national income per capita improves economic complexity, especially when driven by the export of highly sophisticated products (Gnangnon, 2021). Natural resources rents can provide financial

resource to exporting countries to producing highly sophisticated and diversified products (Bahar and Santos, 2018; Ross, 2019; Djimeu and Omgba, 2019). Trade openness is also used as a control variable. Indeed, according to the new theory of international trade, trade openness leads certain companies to specialize in the production of certain highly sophisticated products and to take advantage of increasing returns to scale (Dixit and Norman, 1980; Krugman, 1979; 1980). It can also enable the host country to easily access and adopt technologies developed abroad (Keller, 2004). Foreign direct investment promotes economic complexity by facilitating the transfer of technology and know-how to the host country (Antonietti and Franco, 2021; Gómez-Zaldívar and al., 2021; Gnangnon, 2021; Ajide, 2024).

3.3. Data

The data used in this research covers 71 developing countries over the period 2011-2021. The appendix provides the names of the countries in the sample. The choice of countries and period was dictated by data availability. Table 1 presents, describes and provides data sources for the variables used.

Table 1: *Definition and sources of the main variables*

Variables	Definition	Sources
Economic complexity	Reflects the diversification and ubiquity of products exported by countries. It reflects countries' level of structural transformation.	Atlas of economic complexity published by the Observatory of economic complexity.
Financial inclusion	The proportion of individuals aged 15 and over with an account in a financial institution.	Global Financial Inclusion (Global Findex) Database, World Bank (2022)
GDP per capita	Gross domestic product per capita	World Development Indicators (World Bank, 2024)
Natural resource rents.	Natural resource rents include rents from natural gas, oil, coal and minerals, and forests. These rents are expressed as a percentage of GDP.	World Development Indicators (World Bank, 2024)
Trade openness	Trade openness is measured by the sum of exports and imports in relation to gross domestic product.	World Development Indicators (World Bank, 2024)
Foreign direct investment	Net investment inflows to acquire a lasting stake in a investment company operating in an economy other than that of the investor.	World Development Indicators (World Bank, 2024)

Source: Authors

Table 2 presents the descriptive statistics for the variables. Over the period considered, the average economic complexity index is -0.478 on a scale from -2.5 to 2.5, where 2.5 represents the highest level of economic complexity. On average, the level of economic complexity is relatively low in the sample of developing countries considered, reinforcing the need to analyze the determinants of economic complexity in these countries. In addition, the level of economic complexity is relatively less dispersed.

Table 2: *Descriptive statistics for variables*

Variable	Obs	Mean	Std. Dev.	Min	Max
Economic complexity	284	-.478	.705	-2.442	1.349
Financial inclusion	262	40.297	23.592	.405	98.166
GDP per capita (in log)	284	7.877	.905	6.007	9.561
Natural resources rents (as % of GDP)	283	8.373	9.087	.003	51.844
Commercial opening	263	73.654	29.774	23.934	186.676
Foreign direct investment	284	4.639	7.173	-3.115	86.989

Source: Authors.

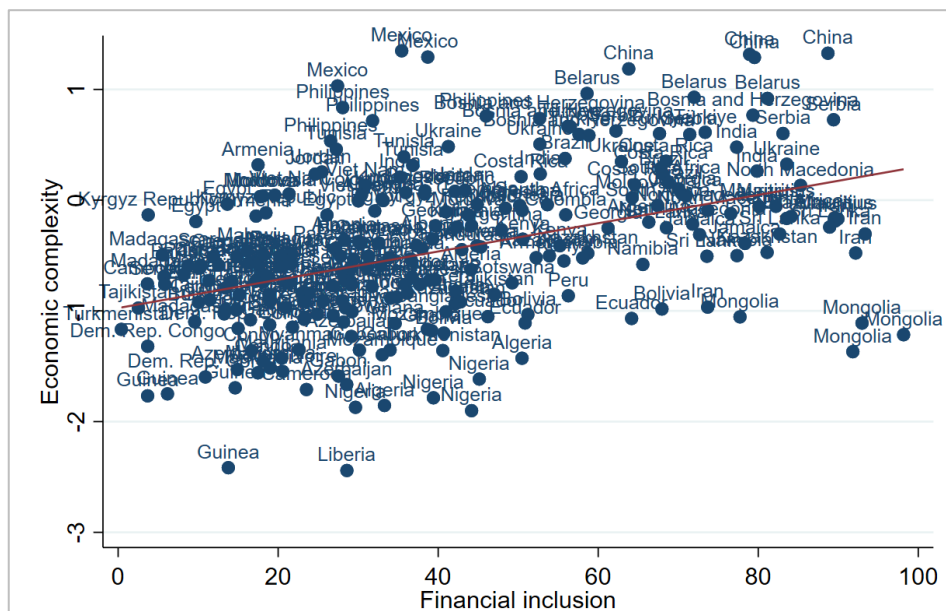
Table 3: Variable correlation matrix

Variables	(1)	(2)	(3)	(4)	(5)	(6)
(1) Economic complexity	1.000					
(2) Financial inclusion	0.430***	1.000				
(3) GDP per capita (in log)	0.487***	0.638***	1.000			
(4) Natural resources rents (in % of GDP)	-0.523***	-0.194***	-0.199***	1.000		
(5) Trade openness	0.062	0.035	0.024	0.057	1.000	
(6) Foreign direct investment	-0.152**	-0.082	-0.176***	0.275***	0.397***	1.000

Source: Authors.

Figure 1 confirms the existence of a positive correlation between financial inclusion and economic complexity. In other words, a high level of financial inclusion is associated with a high level of economic complexity. However, this relationship does not imply causality. The results of the empirical estimations that will be presented in the next section provide us with a more solid understanding of the relationship between these two variables.

Figure 1. *Correlation between financial inclusion and economic complexity in developing countries*



4. Empirical results

In this section, we present the results of our estimations. The results of the basic model are presented first, followed by robustness results.

4.1. Basic results

The results of the basic model are presented in Table 4.

Table 4: *Effect of financial inclusion on economic complexity*

VARIABLES	(1) location	(2) scale	(3) qtile_10	(4) qtile_25	(5) qtile_50	(6) qtile_75	(7) qtile_90
Financial inclusion	0.00499*** (0.00188)	3.78e-05 (0.00113)	0.00493** (0.00229)	0.00495** (0.00194)	0.00498*** (0.00185)	0.00502** (0.00231)	0.00505* (0.00284)
GDP per capita (in log)	0.229*** (0.0481)	0.0572** (0.0289)	0.142** (0.0590)	0.180*** (0.0498)	0.219*** (0.0476)	0.282*** (0.0594)	0.320*** (0.0732)
Natural resources rents (as % of GDP)	-0.0334*** (0.00445)	0.00282 (0.00268)	-0.0377*** (0.00544)	-0.0358*** (0.00461)	-0.0339*** (0.00440)	-0.0308*** (0.00549)	-0.0289*** (0.00674)
Commercial opening	0.00199 (0.00133)	0.00170** (0.000801)	-0.000579 (0.00163)	0.000543 (0.00138)	0.00170 (0.00132)	0.00356** (0.00164)	0.00470** (0.00203)
Foreign direct investment	-0.00643 (0.00605)	-0.01000*** (0.00364)	0.00867 (0.00746)	0.00207 (0.00627)	-0.00474 (0.00602)	-0.0157** (0.00749)	-0.0224** (0.00928)
Constant	-2.284*** (0.344)	-0.157 (0.207)	-2.047*** (0.420)	-2.151*** (0.356)	-2.258*** (0.339)	-2.430*** (0.424)	-2.535*** (0.520)
Observations	243	243	243	243	243	243	243

Note: Standard errors in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1.

Source: Authors.

As reported in Columns 1 and 2, the location and the scale parameters are both positive and statistically significant. The result means that improving financial inclusion increases the average economic complexity (location shift) and the dispersion of economic complexity (scale shift). In addition, the coefficients of financial inclusion reported in Column 3 to 7 are positive and significant. This result implies that financial inclusion increases economic complexity, regardless of the level of economic complexity. Furthermore, the magnitude of the coefficient for financial inclusion increases as ones moves from lower to higher quantiles. Therefore, the positive effect of financial inclusion on economic complexity is lower in countries with low level of economic complexity and higher in those with a high level of economic complexity.

Overall, these results indicate that improving financial inclusion increases economic complexity. These results corroborate the theoretical predictions that financial development increases economic complexity (Kletzer and Bardhan, 1987; Baldwin, 1989; Maskus and al., 2012; Hsu et al., 2014; Svirydenka 2016). In accordance with these theories, financial development can improve economic complexity by promoting access to the credit and resources needed to finance innovative projects and the production of highly sophisticated and diversified products. These results are also in line with several empirical works aux (Chu, 2019; Njangang et al., 2021; Nguyen and Su, 2021; Emeka et al., 2024) that argue that financial inclusion improves economic complexity. On the other hand, these results partially contrast those obtained by Ndoya and al. (2024) who found that financial inclusion has a non-negative but non-significant effect on economic complexity in countries characterized by an average level of financial development and economic complexity.

4.2 Robustness tests

To test the robustness of the basic results, two robustness checks are performed: (i) adding other control variables to the basic model and, (ii) using an alternative dependent variable.

4.2.1. Adding other control variables to the basic model

We test the robustness of our results by adding other variables to the basic model. These variables include: government effectiveness, remittances, and urbanization. We control for the effect of governance quality. In fact, good governance creates an environment conducive to the accumulation of human capital and productive capacities, thereby promoting the production and export of complex products (Chang and Andreoni, 2019; Vu, 2021). In line with Mini et al. (2025), we approximate the quality of governance using the “government effectiveness” indicator of World Bank (2024). This indicator reflects perceptions of the quality of public services, the quality of the civil service, and its independence from political pressures. Furthermore, remittances used for investment purposes can also enable recipient countries to produce and export highly sophisticated and diversified products (Saadi, 2020; Ajide and Osinubi, 2024). Finally, urbanization leads to the concentration of skilled workers and capital and the development of economic activities in urban centers, thereby stimulating innovation and the process of structural transformation (Abbas et al., 2023). Data on these variables come from the World Development Indicators (World Bank, 2024). The results are presented in Table 5.

Table 5: Robustness test by adding other control variables to the basic model

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	location	scale	qtile_10	qtile_25	qtile_50	qtile_75	qtile_90
Financial inclusion	0.00412** (0.00200)	0.000730 (0.00121)	0.00304 (0.00239)	0.00346* (0.00207)	0.00406** (0.00198)	0.00481* (0.00250)	0.00529* (0.00306)
GDP per capita (in log)	0.153* (0.0807)	0.0581 (0.0489)	0.0670 (0.0966)	0.101 (0.0834)	0.148* (0.0800)	0.208** (0.101)	0.246** (0.124)
Natural resources rents (as % of GDP)	-0.0260*** (0.00522)	0.00165 (0.00317)	-0.0284*** (0.00625)	-0.0274*** (0.00540)	-0.0261*** (0.00517)	-0.0244*** (0.00653)	-0.0233*** (0.00801)
Commercial opening	0.00136 (0.00147)	0.00217** (0.000889)	-0.00185 (0.00176)	-0.000593 (0.00152)	0.00117 (0.00146)	0.00339* (0.00185)	0.00483** (0.00226)
Foreign direct investment	-0.00713 (0.00616)	-0.00966*** (0.00373)	0.00722 (0.00741)	0.00160 (0.00638)	-0.00629 (0.00615)	-0.0162** (0.00775)	-0.0226** (0.00950)
Government efficiency	0.273** (0.106)	-0.0202 (0.0644)	0.303** (0.127)	0.292*** (0.110)	0.275*** (0.105)	0.254* (0.133)	0.241 (0.163)
Remittances	0.00949** (0.00480)	-0.00310 (0.00291)	0.0141** (0.00574)	0.0123** (0.00496)	0.00976** (0.00476)	0.00659 (0.00601)	0.00453 (0.00736)
Urbanization	0.00121 (0.00298)	-0.000336 (0.00181)	0.00171 (0.00357)	0.00151 (0.00308)	0.00124 (0.00295)	0.000895 (0.00373)	0.000673 (0.00457)
Constant	-1.664*** (0.530)	-0.202 (0.321)	-1.365** (0.634)	-1.482*** (0.548)	-1.646*** (0.525)	-1.853*** (0.663)	-1.986** (0.813)
Observations	243	243	243	243	243	243	243

Note: Standard errors in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1.

Source: Authors.

Additional control variables including government effectiveness, remittances and urbanization all have a positive effect on economic complexity. The coefficient associated with financial inclusion is positive and significant at 1% in all quantiles (with the exception of the 10% quantile, which is significant at 10%) and increases as one moves from lower

to higher quantiles. This result means that financial inclusion favors economic complexity, with a more marked effect in countries characterized by a high level of economic complexity. Thus, the introduction of additional control variables does not affect the results of the basic model.

4.2.2. Using an alternative dependent variable

The second robustness test involved the use of an alternative dependent variable. This variable comes from the Atlas of Economic Complexity published by the Observatory of Economic Complexity, an initiative of the MIT Media Lab and the Harvard Center for International Development. Table 6 presents the results of the effect of financial inclusion on economic complexity using the alternative dependent variable ECI_trade, which captures economic complexity linked solely to trade.

Table 6: Robustness test using an alternative dependent variable

VARIABLES	(1) location	(2) scale	(3) qtile 10	(4) qtile 25	(5) qtile 50	(6) qtile 75	(7) qtile 90
Financial inclusion	0.00715*** (0.00176)	0.000450 (0.00103)	0.00644*** (0.00247)	0.00674*** (0.00205)	0.00717*** (0.00175)	0.00753*** (0.00190)	0.00783*** (0.00226)
GDP per capita (in log)	0.301*** (0.0442)	0.0323 (0.0259)	0.250*** (0.0623)	0.272*** (0.0515)	0.302*** (0.0441)	0.328*** (0.0479)	0.350*** (0.0571)
Natural resources rents (as % of GDP)	-0.0260*** (0.00405)	0.00277 (0.00237)	-0.0304*** (0.00571)	-0.0285*** (0.00472)	-0.0259*** (0.00405)	-0.0237*** (0.00439)	-0.0218*** (0.00523)
Commercial opening	0.000893 (0.00121)	0.00122* (0.000708)	-0.00103 (0.00171)	-0.000215 (0.00141)	0.000939 (0.00121)	0.00191 (0.00131)	0.00274* (0.00157)
Foreign direct investment	-0.00942 (0.00635)	-0.00548 (0.00372)	-0.000761 (0.00896)	-0.00444 (0.00741)	-0.00962 (0.00635)	-0.0140** (0.00689)	-0.0177*** (0.00822)
Constant	-2.901*** (0.321)	0.00774 (0.188)	-2.913*** (0.453)	-2.908*** (0.374)	-2.900*** (0.321)	-2.894*** (0.347)	-2.889*** (0.414)
Observations	234	234	234	234	234	234	234

Note: Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Source: Authors.

Table 6 shows that financial inclusion improves economic complexity at all levels. Moreover, the effect of financial inclusion on economic complexity is low in countries characterized by a low level of economic complexity, and high in those with a high level of economic complexity. Thus, the use of an alternative dependent variable does not alter the results of the basic model.

5. Conclusion

The aim of this research is to explore the effect of financial inclusion on economic complexity in developing countries in a sample of 71 developing countries from 2011 to 2021. The empirical analysis relies on quantile via moments method. To measure economic complexity, we used the economic complexity index developed by Hidalgo and Hausmann (2009). The results show that improving financial inclusion significantly increases economic complexity in developing countries. Moreover, the positive effect of financial inclusion on economic complexity is higher in countries with high level of economic complexity and smaller in those with small level of economic complexity. These results suggest that financial inclusion has a positive and heterogeneous effect on economic

complexity in developing countries. This research underscores the need for governments in developing countries to promote financial inclusion to improve the sophistication and diversification of their exportations.

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Appendix: the countries in the sample are:

Algeria, Argentina, Armenia, Azerbaijan, Bangladesh, Belarus, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Burkina Faso, Cambodia, Cameroon, China, Colombia, Congo, Costa Rica, Côte d'Ivoire, Dem. Rep. Congo, Ecuador, Egypt, Ethiopia, Gabon, Georgia, Ghana, Guinea, Honduras, India, Indonesia, Iran, Jamaica, Jordan, Kazakhstan, Kenya, Kyrgyz Republic, Lao PDR, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mexico, Moldova, Mongolia, Mozambique, Myanmar, Namibia, Nicaragua, Nigeria, North Macedonia, Pakistan, Paraguay, Peru, Philippines, Senegal, Serbia, South Africa, Sri Lanka, Tajikistan, Tanzania, Togo, Tunisia, Turkmenistan, Türkiye, Uganda, Ukraine, Viet Nam, Zambia, Zimbabwe.

Human ethics vs. algorithmic ethics: the limits of automating moral decision-making

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Abstract. *This article investigates the constraints associated with the automation of moral decision-making by comparing ethical frameworks of humans and algorithms. It posits that moral judgments necessitate interpretation, accountability, and societal justification, elements that cannot be entirely formalized through computational means. Through conceptual analysis and empirical studies in various sectors, including healthcare, autonomous transportation, criminal justice, content moderation, and recruitment, the research highlights the inherent limitations of moral automation. It introduces a Hybrid Ethical Decision Model (HEDM) that differentiates epistemic support from normative authority while incorporating human oversight. The article concludes that the governance of artificial intelligence should focus on the enhancement of human moral agency rather than its substitution.*

Keywords: algorithmic ethics, moral decision-making, artificial intelligence governance, human AI interaction, responsibility in AI.

JEL Classification: D83, O33, Z13.

1. Introduction

The swift incorporation of artificial intelligence (AI) into sectors that have conventionally relied on human judgment has sparked considerable ethical discourse. Decision-making frameworks are now employed in various fields, including healthcare resource allocation, judicial risk assessments, autonomous vehicle operation, and the moderation of digital content. Although these frameworks offer the potential for increased efficiency and uniformity, they also provoke essential inquiries regarding the essence of moral agency and accountability. Researchers increasingly scrutinize whether moral reasoning—traditionally based in human cognition, empathy, and social constructs—can be effectively converted into computational algorithms (Floridi et al., 2018: pp. 689–707).

Human moral judgment is influenced by contextual awareness, emotional acumen, and values ingrained in culture. Established ethical frameworks such as utilitarianism, deontology, and virtue ethics demonstrate that morality involves more than mere adherence to rules; it requires nuanced interpretation and situational assessment (MacIntyre, 2007: pp. 204–225). In contrast, algorithmic systems function according to formalized regulations, statistical associations, and optimization objectives. Even the most sophisticated machine learning algorithms do not possess an "understanding" of morality; rather, they identify and replicate patterns derived from historical datasets (Russell, 2019: pp. 45–52).

This differentiation becomes crucial as algorithmic systems increasingly dictate decisions that carry moral implications. The phenomenon referred to as the "value alignment problem" underscores the challenges associated with ensuring that AI systems operate in harmony with human values, particularly when such values are diverse or contested (Gabriel, 2020: pp. 103–110). Furthermore, algorithmic decision-making processes may perpetuate societal biases encoded within the data, resulting in ethically dubious outcomes (O'Neil, 2016: pp. 3–15).

In this context, the current study explores the friction between human ethical principles and algorithmic ethics, concentrating on the intrinsic limitations of automating moral decision-making. The manuscript posits that while algorithms can enhance ethical discourse, they cannot supplant human moral agency without incurring significant philosophical and societal hazards. By juxtaposing human and algorithmic moral reasoning and evaluating real-world instances, this research endeavors to elucidate the boundaries of automation and the necessity for continued human oversight.

The discourse surrounding machine ethics also encompasses the issue of accountability. When an algorithm yields a harmful or discriminatory result, the attribution of responsibility becomes dispersed among developers, data sources, and institutional users. This diffusion poses a challenge to conventional frameworks of moral and legal accountability, which are predicated on the notion of intentional agency (Danaher, 2016: pp. 245–268). In contrast to humans, artificial intelligence systems do not possess consciousness, intentionality, or the ability for moral reasoning; nevertheless, their determinations may have significant moral implications.

Another issue pertains to the lack of transparency associated with intricate AI systems. Numerous machine learning frameworks, particularly those based on deep learning,

function as "black boxes," rendering it challenging for even their developers to thoroughly elucidate their outputs. This opacity is at odds with ethical demands for justification and accountability in decision-making processes (Burrell, 2016: pp. 1–12). When moral decisions cannot be articulated, their legitimacy may be subject to scrutiny, particularly in democratic societies that value public reasoning.

In light of these challenges, there is a growing advocacy among scholars for "human-in-the-loop" methodologies that maintain human oversight in ethically pertinent decisions. Such methodologies acknowledge the potential for algorithms to assist, yet argue that they should not supplant moral deliberation (Cath, 2018: pp. 1–14). This viewpoint shifts the emphasis from complete automation to responsible enhancement.

Consequently, this article explores not only the capability of machines to engage in moral decision-making, but also the question of whether they ought to do so. The primary research question framing this investigation is: To what extent can the automation of moral decision-making occur without compromising human ethical accountability? Addressing this query is imperative in a context where algorithmic systems are increasingly integrated into daily governance and social interactions.

2. Human Moral Reasoning

Human moral reasoning encompasses the mental and emotional activities that people use to assess what is right or wrong, fair or harmful, and their own responsibilities and obligations. Unlike reasoning that is purely based on logic, moral judgments incorporate empathy, social awareness, and sensitivity to different contexts. Psychological studies suggest that moral assessments often come from instinctive reactions, which are then explained through more thoughtful reasoning (Haidt, 2001: pp. 814–834).

Thus, moral cognition is not merely based on established rules but is significantly ingrained in social contexts (Appiah, 2006: pp. 33–57). This variability indicates that morality cannot simply be boiled down to a global set of computational rules without losing crucial subtleties. Traditional ethical theories such as utilitarianism, deontology, and virtue ethics show that moral reasoning requires interpretation rather than mechanical rule-following.

Crucially, emotions play a vital part in how moral decisions are made. Research in neuroscience indicates that emotional processing is central to moral judgments, rather than being in conflict with rationale (Greene, 2013: pp. 23–41).

At the same time, the limitations of human moral reasoning cannot be ignored. Factors such as cognitive biases, emotional favoritism, and situational influences can alter ethical decisions. Studies in behavioral ethics indicate that people frequently have an inflated perception of their moral steadfastness while also being swayed by framing effects and societal influences (Bazerman and Tenbrunsel, 2011: pp. 58–75). These insights call into question the belief that human moral agents consistently make trustworthy decisions.

Additionally, moral reasoning is often influenced by bounded rationality. People function under the limitations of inadequate information, time constraints, and restricted cognitive

abilities. According to Simon (1957: pp. 198–206), human decision-making is more about achieving satisfactory outcomes than seeking the best possible options. In ethical scenarios, this translates to individuals often selecting solutions that are “good enough” rather than the most ethically sound. Such limitations highlight that human morality, while nuanced and responsive to context, is also flawed.

Recognizing both the advantages and drawbacks of human moral reasoning is vital before assessing algorithmic alternatives. AI technologies are frequently considered to be more objective or consistent compared to humans; however, such comparisons may oversimplify the complex nature of morality itself. Therefore, the next section explores how moral reasoning is handled within algorithmic systems and the aspects that are transformed or lost in that process.

Moral accountability is fundamentally linked to both intentionality and awareness. For an individual to be deemed morally accountable, it is essential that they comprehend the impacts of their actions and have the autonomy to make different choices. This interplay between agency and responsibility is pivotal in both ethical ideologies and legal contexts (Fischer and Ravizza, 1998: pp. 12–25). Thus, human moral agents are assessed not solely by the results of their actions but also by their intentions and the thought processes involved.

These characteristics—development, intentionality, and dialogue—highlight the complexity of human moral existence. They portray morality as a vibrant practice rooted in social connections and individual development. Consequently, any effort to model morality using computational methods must address the challenge of portraying not only choices but also the developmental and conversational processes underlying those decisions.

With this viewpoint established, the following section investigates how ethical reasoning is framed within algorithmic systems. Grasping the distinctions between human and machine methods is essential for assessing the practicality and desirability of automating moral decision-making.

3. Algorithmic Ethics and AI Decision Systems

Algorithmic ethics involves the effort to incorporate moral principles, restrictions, or value judgments into computer systems that either make or assist in making decisions. As AI technologies progressively function within socially important areas, the inquiry into the capability of machines to behave ethically has transitioned from theoretical debate to urgent issue (Moor, 2006: pp. 18–25).

In contrast to human beings, artificial intelligence systems lack awareness, intentions, or an understanding of morality. Their operations are based on processing data, recognizing patterns, and applying optimization techniques. Specifically, machine learning algorithms base their actions on statistical correlations found in training data, differing from direct moral reasoning. Thus, what is identified as a “decision” is often driven by probabilistic reasoning rather than ethical contemplation (Mitchell, 2019: pp. 105–112).

The increasing dependence on data-oriented models has sparked worries concerning the impartiality of algorithms. Rather than being unbiased, algorithmic frameworks can echo and exacerbate the biases identified in their source data. When past data encapsulate societal disparities, automated systems may repeat biased outcomes in contexts like recruitment, loan approval, or law enforcement (Barocas and Selbst, 2016: pp. 671–732). This occurrence undermines the belief that algorithm-generated choices are intrinsically objective.

A key aspect of algorithmic decision-making is formalization. Ethical principles must be converted into quantifiable variables and executable guidelines. Nonetheless, numerous moral ideals—such as dignity, fairness, or proportionality—are challenging to quantify accurately. Efforts to formalize these concepts inevitably require simplifications and moral selections (Floridi and Cowls, 2019: pp. 689–707). Consequently, the creation of ethical AI systems inherently incorporates moral beliefs, whether they are openly recognized or not.

A significant issue in the realm of algorithmic ethics is what is known as the value alignment issue. This pertains to the challenge of guaranteeing that artificial intelligence systems aim for objectives that align with human values and priorities. Human values can often be implicit, reliant on context, and at times contradictory. Converting these values into goals that can be programmed necessitates determining which values to emphasize and how to navigate trade-offs (Russell, 2019: pp. 136–140). These choices are inherently about norms rather than purely technical matters.

In addition, AI systems aim for goals that have been defined in advance. If these goals are inadequately outlined, the systems may yield results that technically fulfill an objective while contravening more extensive ethical expectations. This occurrence, often referred to as “reward hacking,” demonstrates how optimization can stray from ethical intentions (Amodei et al., 2016: pp. 3–7). The concern here is not about harmful intent but rather the discord between set targets and the intricate nature of human values.

Explainability is another significant issue. Justifying ethical choices often necessitates the capacity to provide reasons and explanations. However, numerous high-performing AI models, particularly deep neural networks, lack the ability to be easily interpreted. Their inner workings are often unclear even to their developers. This lack of clarity makes accountability and public confidence more difficult, especially in crucial situations like healthcare or criminal justice (Doshi-Velez and Kim, 2017: pp. 1–5).

Consequently, researchers have highlighted the necessity for transparency and auditability in AI systems. Systems that are transparent enable stakeholders to investigate how decisions are made and to pinpoint possible biases or errors. Nonetheless, complete transparency is not always achievable due to technical complexities or proprietary limitations (Ananny and Crawford, 2018: pp. 973–989). The conflict between performance, transparency, and ethical governance continues to be unresolved.

Beyond the technical aspects of design, the ethics surrounding algorithmic systems also encompasses issues of governance and responsibility within institutions. Choices regarding acceptable levels of risk, fairness criteria, or privacy safeguards are frequently determined

at the level of organizations or regulatory bodies, rather than exclusively by engineers. This underscores that the ethics of algorithms extends beyond simply incorporating values into systems; it also involves creating frameworks for oversight and ensuring accountability (Cath et al., 2018: pp. 505–507).

New policy measures indicate an increasing acknowledgment of these complexities. Ethical standards for reliable AI stress concepts like fairness, responsibility, transparency, and human oversight. Nevertheless, it remains difficult to convert these broad principles into practical regulations. Different interpretations of principles may arise depending on the context, and their application can conflict with business or political agendas (Jobin, Ienca and Vayena, 2019: pp. 389–399).

Another issue pertains to the delegation of ethical authority. When organizations heavily depend on algorithmic suggestions, there is a danger that human decision-makers may yield to systems deemed as impartial or scientifically based. This phenomenon known as "automation bias" can diminish critical evaluation and transfer accountability away from human agents (Parasuraman and Riley, 1997: pp. 230–253). An excessive reliance on automated technologies may thus undermine ethical responsibility instead of reinforcing it.

In order to explore these matters more methodically, it is essential to directly compare the differences in structure and operation between human and algorithmic moral reasoning. Thus, the next section will delve into the significant distinctions between human ethics and algorithmic ethics.

4. Key Differences Between Human and Algorithmic Ethics

To effectively compare human ethics with algorithmic ethics, it is necessary to delve into deeper structural variations in the formation and application of moral judgment, rather than just looking at superficial differences. Human moral reasoning arises from a blend of cognitive assessment, emotional involvement, and societal context interpretation. In contrast, algorithmic systems function through established models that convert inputs into outputs based on predetermined structures and optimization standards. This difference is not just technical but signifies fundamentally different ways of understanding norms (Floridi, 2013: pp. 134–140).

A primary distinction lies in the significance of embodiment and personal experience. Human moral agents are contextual beings, and their judgments are influenced by vulnerability, relationships with others, and learned experiences. Ethical contemplation frequently stems from experiences involving suffering, responsibility, or dispute. Algorithms, on the other hand, do not possess this experiential aspect; they do not face consequences but instead recognize patterns. As critiqued by Dreyfus (1992: pp. 245–260) in his analysis of artificial intelligence, the lack of embodied comprehension hampers the ability of computational systems to understand context in a way similar to humans.

Another notable difference pertains to the flexibility of interpretation. Human individuals often interpret norms based on specific situations, balancing competing values and

adjusting priorities as needed. Moral guidelines are seldom applied rigidly; they are filtered through judgment. Conversely, algorithmic systems need clear formalization. Even systems designed to adapt are limited by the frameworks of representation and the data on which they were trained. Their adaptability is statistical rather than interpretive (Binns, 2018: pp. 543–546).

These distinctions suggest that human and algorithmic ethics are not simply different implementations of the same concept. They embody fundamentally different strategies for making decisions guided by norms. Acknowledging this difference is crucial before assessing assertions that AI has the potential to substitute or entirely replicate human moral agency.

A different structural aspect pertains to ethical accountability. The moral agency of humans is intricately tied to their ability to explain, rationalize actions, and be responsible within ethical societies. Holding someone accountable not only requires a link to outcomes but also necessitates intention and awareness. As Strawson noted, the customs of praise and blame stem from mutual expectations and emotional reactions among people. These customs rely on the premise that individuals can grasp and react to moral criticisms.

In contrast, algorithmic systems do not engage in such ethical frameworks. They lack the ability to comprehend blame, experience guilt, or adjust their behaviors due to moral censure. Consequently, accountability for the results produced by algorithms shifts to the creators, implementers, and governing bodies. This phenomenon has been referred to as a “responsibility gap,” where detrimental results happen without a definitive source of accountability. This gap is not just a matter of law but also a conceptual issue, illustrating a disconnect between technological and moral agency.

A further significant difference relates to the dimension of time. Human moral deliberation occurs gradually and involves recollection, foresight, and narrative identity. People analyze their current choices against the backdrop of earlier decisions and future goals. Ricoeur highlights that

Another significant distinction between ethical considerations in humans and algorithms is found in the way moral standards are socially grounded. Human ethics develop not in isolation, but rather in the context of interconnected social practices, institutions, and power dynamics. Moral norms are created through dialogue, disputes, and shared interpretations. Concepts of fairness and justice are frequently influenced by past conflicts and cultural stories instead of merely theoretical ideals (Taylor, 1989: pp. 36–52).

On the other hand, algorithmic systems commonly view norms as criteria to be defined and refined. However, choosing these criteria is a normative decision in itself. The choices made regarding data selection, outcome prioritization, and accepted trade-offs are influenced by specific social viewpoints. As Winner (1980: pp. 121–136) points out, technologies can reflect political and moral decisions, even when they are presented as impartial instruments. Thus, algorithmic systems are not separate from moral considerations but are actively involved in shaping them.

The element of power adds further complexity to this comparison. Human moral agents have the ability to challenge, resist, and reinterpret the norms imposed on them. They can partake in critical analysis and collective action. In contrast, algorithmic systems often function on a larger scale and with institutional support, affecting opportunities and limitations without mutual engagement. This imbalance raises issues surrounding legitimacy and the need for democratic accountability (Kitchin, 2017: pp. 14–16).

Cultural diversity is also a crucial factor. Ethical values vary among different societies, and the presence of ethical pluralism is a continual aspect of global contexts. Efforts to create uniformity in ethical decision-making through algorithms may inadvertently enforce prevailing value systems while sidelining others. This standardization could unintentionally generalize norms that are culturally specific (Ess, 2014: pp. 99–112).

Overall, these elements highlight that morality is deeply connected with social meanings and power relations. When algorithmic ethics are considered independently from these contexts, there is a risk of framing moral decisions as merely technical modifications rather than as socially contested choices.

The analysis conducted up to this point reveals that human ethics and algorithmic ethics not only vary in intensity but also in their fundamental nature. Human ethical reasoning is situated, extended over time, shaped through social interactions, and open to revision upon reflection. In stark contrast, algorithmic frameworks lack a physical embodiment, are organized in a formalized manner, and rely on established representational frameworks. Although these systems may mimic certain decision-making trends, they do not engage in the normative activities that imbue moral concepts with their significance.

This difference has consequences for the distribution of ethical authority. When the outcomes produced by algorithms are viewed as having moral weight, there arises a danger of treating technical processes as if they are normative evaluations. Such treatment can obscure the human decisions that influence the design and implementation of these systems. Jasanoff (2016: pp. 19–36) points out that sociotechnical systems jointly create knowledge and social structures; they do not only carry out unbiased functions. Acknowledging this joint production is essential for effective governance.

Additionally, the allure of algorithmic ethics often hinges on the promise of uniformity and neutrality. However, consistency does not always equate to fairness. Moral evaluations sometimes necessitate awareness of specific circumstances, compassion, or deviations from overarching principles. A system designed for consistency may overlook morally significant subtleties. This conflict demonstrates that the quality of ethics cannot merely be boiled down to procedural uniformity.

None of these insights mean that algorithmic systems lack moral significance. Instead, they imply that the role of these systems must be clearly defined. Algorithms can enhance human decision-making, reveal patterns, and mitigate certain biases, yet they cannot take on complete moral responsibility. Considering them as moral agents could lead to misconceptions about both technology and ethics.

These reflections raise a larger issue: what are the precise boundaries of automating moral choices? To answer this question, it is essential to explore the points at which algorithmic methods encounter inherent limitations. The next section will therefore focus on the constraints of automating moral judgments and the dangers linked with excessive delegation.

5. The Boundaries of Automating Ethical Choices

When considering the differences in framework between human ethics and those of algorithms, the focus shifts from whether algorithms can engage in moral decision-making to determining the extent of their involvement. Therefore, the idea of boundaries extends beyond just technical considerations to encompass normative aspects. It addresses the limits beyond which entrusting machines could compromise critical elements of moral agency.

A key limitation stems from the issue of moral underdetermination. Numerous ethical conflicts lack a definitive correct answer, often presenting tragic choices among conflicting values. Scenarios related to end-of-life treatment, distribution of resources, or competing rights typically necessitate a balance of principles that cannot be entirely harmonized (Berlin, 1969: pp. 167–172). In contrast, algorithms need clearly defined objective functions or decision-making criteria. In cases where values are truly incomparable, formal optimization cannot resolve the dilemma without inherently favoring one value over others.

Another related constraint involves the complexity of moral interpretation. Ethical reasoning is often influenced by the way a situation is conceptualized and perceived. The same set of facts might be interpreted differently based on narrative frameworks, relationship responsibilities, or symbolic implications. As articulated by Nussbaum (2001: pp. 292–297), moral judgment involves both perception and imagination, rather than strictly following established rules. Such interpretive richness is challenging to capture within computational frameworks.

A further restriction arises from ambiguity and the unprecedented nature of many situations. Real-life ethical dilemmas frequently present uncertainty, incomplete data, and novel conditions. Although machine learning models can identify trends from existing data, they depend on historical cases. New ethical situations might reside outside the scope of their training, potentially resulting in fragile or unsuitable responses (Marcus, 2018: pp. 1–5). In contrast, human beings can engage in analogical reasoning and creative thought when confronted with fresh challenges.

These insights indicate that automation faces limitations in areas where the complexity of moral life goes beyond formal definitions. The issue is not solely about enhancing algorithms but also recognizing the spheres where moral reasoning cannot be reliably transferred to technological systems.

A limitation of moral automation is associated with the concept of moral deskilling. As more decision-making responsibilities are transferred to automated systems, individuals may progressively diminish their ability and inclination for ethical reasoning. Similar

issues have been noted in various fields where automation lessens the necessity for active assessment. Over time, dependence on these systems can undermine practical reasoning abilities and lessen awareness of the ethical aspects of different situations.

This effect is not just cognitive but also normative. The capacity for moral agency is maintained through engagement, contemplation, and accountability. If people grow used to letting algorithms make decisions, they might detach from the duty of moral judgment. As Coeckelbergh highlights, technology can influence moral experiences in ways that alter how accountability is viewed and implemented. Therefore, delegation changes not only who makes decisions but also the interpretation of moral agency.

Automation may also foster what is referred to as “moral buffering.” When detrimental outcomes occur, people might blame the system instead of themselves or their organizations. This diffusion of responsibility weakens personal accountability and can lessen motivations for ethical attentiveness. Research in human–automation interactions indicates that individuals often place excessive trust in automated suggestions, even when recognizing their shortcomings.

Crucially, moral deskilling doesn't necessarily require complete automation. Even decision-support systems can gently steer focus away from ethical consideration towards following procedures. When ethical reasoning is substituted with mere compliance or performance metrics, moral judgment risks becoming more about processes than genuine reflection.

These elements illustrate that the constraints of automation are, to some extent, inherent to human agents. The inquiry is not solely about what machines are capable of, but rather what humans may stop doing as machines assume moral responsibilities.

This problem becomes especially pronounced when algorithmic decisions influence rights and opportunities. Automated mechanisms utilized in the distribution of welfare, anticipatory law enforcement, or credit assessment can significantly impact life circumstances. However, individuals affected by these systems might not have access to justifications or effective means to contest these decisions. This imbalance poses challenges to procedural fairness and raises concerns regarding due process.

Furthermore, the dependence of institutions on algorithmic systems can transfer normative responsibility to higher-level governance structures, removing it from identifiable human decision-makers. This may diminish democratic accountability by complicating the ability to trace how and why decisions are made. As Bovens discusses, accountability necessitates transparency and the potential for punishment—requirements that are hard to achieve in opaque algorithmic frameworks.

These issues indicate that the automation of morality in public decision-making is restricted not only by technical challenges but also by democratic principles. Ethical decision-making within collective settings demands justification, involvement, and the ability to change—a set of aspects that cannot be entirely assigned to machines.

When considered collectively, the boundaries previously mentioned indicate that moral automation faces limitations on conceptual, psychological, institutional, and cultural fronts.

These constraints are not merely short-term technical challenges but indicate more profound characteristics of moral existence. The process of ethical reasoning requires interpretation, conversation, accountability, and conflicts in values—all aspects that defy complete formalization.

Acknowledging these boundaries does not mean dismissing the role of AI in ethical contexts. Instead, it suggests a need to adjust our expectations. Automation can support human decision-makers by recognizing patterns, diminishing specific biases, or aiding in decision-making. Nonetheless, aid is not the same as replacement. The problem emerges when efficiency and consistency are favored at the expense of moral judgment and responsibility.

Additionally, there is a significant implication regarding the allocation of moral responsibilities. Assigning ethical duties to machines might seem to lighten the load on humans, but it also redistributes accountability in ways that may not be readily apparent. As Jonas cautioned in his discussion on responsibility, technological capability extends human obligations rather than lessening them. The existence of sophisticated systems heightens, rather than reduces, the requirement for ethical contemplation.

In the end, the central question isn't if machines can emulate moral reasoning, but whether societies should permit them to assume positions that influence morally significant results. Framing the dilemma around limitations aids in steering clear of both excessive technological enthusiasm and undue alarm. It fosters a nuanced perspective where AI is recognized as a potent instrument within the realm of human moral frameworks.

To anchor these theoretical considerations, the subsequent section explores specific areas where algorithmic systems are currently affecting morally pertinent decisions. Evaluating actual cases provides a clearer understanding of where and how the constraints of moral automation become apparent in practice.

6. Case Studies in Algorithmic Moral Decision-Making

To comprehend the real-world implications of the constraints outlined earlier, it is essential to investigate sectors where algorithmic technologies influence significant moral choices. By examining case studies, one can gain understanding into how ethical standards are implemented in actual situations and where conflicts between efficiency, fairness, and accountability arise. Instead of viewing algorithmic ethics as a theoretical discussion, this section focuses on tangible instances where moral implications are clear.

The field of healthcare stands out as one of the most ethically charged areas concerning algorithmic decision-making. AI technologies are increasingly being employed to assist with diagnoses, anticipate patient risks, and manage medical resources. In scenarios of limited availability—like organ donation or prioritizing patients in intensive care—algorithmic solutions can affect decisions that are critical for survival. These circumstances emphasize both the potential benefits and the drawbacks of automation.

A notable case involves predictive algorithms designed to identify patients who need additional medical assistance. Obermeyer et al. (2019: pp. 447–453) discovered that a commonly utilized healthcare algorithm in the United States significantly underestimated the needs of Black patients, as it relied on healthcare costs as a substitute for illness severity. Due to historical disparities affecting access to healthcare, cost information reflected racial biases. Consequently, the algorithm perpetuated systemic inequalities while seeming to rely on data.

This scenario highlights a larger ethical dilemma: when proxies are employed to bring moral objectives like fairness or necessity into practice, they can distort the very principles they are intended to reflect. The challenge lies not just in biased datasets but also in the ethical decision-making regarding chosen metrics. Determining what qualifies as "need" or "benefit" entails moral judgment that cannot be entirely assigned to statistical relationships.

Decisions in healthcare also necessitate empathy, clear communication, and regard for the autonomy of patients. Highly precise predictive models are incapable of having discussions with patients or their families about values and individual preferences. Clinical ethics often involves negotiation and sensitivity to context, aspects that go beyond algorithmic computations (Beauchamp and Childress, 2019: pp. 101–120).

These factors indicate that while algorithmic instruments in healthcare can assist, they cannot substitute for moral reasoning. They may enhance uniformity, but they cannot resolve the value conflicts that are intrinsic to medical practice.

Algorithmic decision-making within the field of criminal justice stands as one of the most debated uses of artificial intelligence in areas with significant ethical implications. Various jurisdictions employ risk assessment tools to assist in making choices regarding bail, sentencing, and parole. These technologies aim to forecast the probability of recidivism, thus enhancing both the efficiency and uniformity of judicial processes.

Nonetheless, the moral ramifications of such tools are highly contentious. A prominent example is the COMPAS risk assessment tool, which has been critiqued for demonstrating racial biases in its predictions. An investigative report by ProPublica contended that the tool unfairly classified Black defendants as being at higher risk (Angwin et al., 2016). While ongoing discussions have spotlighted the intricacies of the methodology, this situation illuminated how algorithm-driven systems can become central to larger discussions on justice and equal treatment.

Academic studies indicate that the notion of fairness itself is debated. Various statistical interpretations of fairness—such as matching false positive rates or achieving predictive equality—cannot always be fulfilled at the same time (Kleinberg, Mullainathan and Raghavan, 2017: pp. 43–48). The decision among these different standards involves ethical considerations rather than being purely a matter of technical adjustment. Thus, the issue of algorithmic fairness encompasses moral and political dimensions.

The deployment of predictive methodologies also stirs worries regarding due process rights. Defendants might face judgments influenced by algorithms whose workings remain hidden. Limited understanding of these processes or lack of opportunities to challenge their

validity can hinder procedural fairness (Loomis v. Wisconsin, 2016). When personal freedom is involved, the lack of transparency has profound ethical implications.

In addition, predictive algorithms may inadvertently reinforce existing social inequalities. If historical law enforcement actions were inequitably applied across different communities, the data used for training these algorithms might reflect those discrepancies. Consequently, algorithms might endorse and sustain disparities while appearing impartial (Richardson, Schultz and Crawford, 2019: pp. 192–195).

This scenario underscores a fundamental conflict: instruments meant to promote objectivity could unintentionally replicate unfair practices. Therefore, moral assessments need to extend beyond basic accuracy to consider social contexts and the historical background.

When considered collectively, the aforementioned case studies illustrate recurring trends in the ethical dilemmas associated with algorithmic decision-making. Within various sectors, including healthcare, transportation, criminal justice, content moderation, and employment, analogous conflicts arise between notions of efficiency, fairness, accountability, and contextual judgement. These conflicts are not incidental but rather indicative of structural characteristics inherent to algorithmic systems.

A prominent theme that emerges is the dependence on proxies. In instances where algorithms forecast medical necessity, job performance, or the likelihood of recidivism, they frequently rely on quantifiable indicators that represent complex human realities. While proxies can offer utility, they may also introduce moral distortions when they inadequately encapsulate fundamental values. The ethical challenge resides not only in the quality of the data but also in the normative assumptions underpinning the metrics utilized.

Another discernible pattern pertains to opacity and contestability. A significant number of algorithmic systems function in manners that render them difficult for affected individuals to comprehend or contest. This situation undermines procedural justice and complicates accountability frameworks. Nonetheless, moral legitimacy is contingent, in part, upon the feasibility of justification and evaluation.

A third insight pertains to scale. Algorithmic systems implement decisions uniformly across expansive populations, thereby exacerbating both advantages and detriments. Errors that may be confined within human decision-making processes can become systemic when applied at scale. Consequently, ethical risks are intensified rather than mitigated through automation.

These insights bolster the argument that algorithmic systems operate within moral ecosystems rather than existing independently. They are influential in shaping, and are shaped by, human values, institutional frameworks, and societal inequities. Acknowledging this interconnection is essential for responsible governance.

The subsequent section expands upon these observations by introducing a framework for hybrid ethical decision-making. Rather than perceiving human and algorithmic ethics as opposing alternatives, it investigates potential synergies between their respective strengths while respecting the limitations previously identified.

7. Toward a Hybrid Ethical Model

The earlier discussion has demonstrated that neither human judgment nor algorithmic systems on their own can sufficiently navigate the moral intricacies present in today's decision-making contexts. Human reasoning is sensitive to context and reflexive in nature; however, it is prone to biases and inconsistencies. Conversely, algorithmic systems provide scalability and are adept at pattern recognition but face challenges related to interpretation, legitimacy, and the accommodation of diverse values. Thus, framing the discourse purely as a choice between human ethics and machine ethics creates a misleading dichotomy.

An alternative perspective is to view ethical decision-making as a hybrid process that integrates human and algorithmic capabilities in organized manners. Hybrid models acknowledge that moral agency is inherently human, while also permitting computational systems to assist, inform, and at times, limit decision-making. The objective is not to replace human judgment but rather to enhance it.

Current discussions regarding “human-in-the-loop” systems frequently highlight the aspect of oversight yet fail to adequately develop the normative framework. The mere addition of a human reviewer does not ensure significant ethical engagement if the human's involvement is minimized to merely endorsing algorithmic outcomes. What is imperative is a principled framework that delineates when, how, and why human judgment should intervene in the decision-making process.

This article introduces a Hybrid Ethical Decision Model, abbreviated as HEDM, which positions algorithms as epistemic instruments rather than as moral agents. Within this model, artificial intelligence systems provide probabilistic evaluations and scenario analyses, while the responsibility for normative assessments lies with humans. The differentiation between epistemic support and moral judgment is crucial for maintaining accountability.

The HEDM framework is predicated on the understanding that ethical decision-making consists of layered processes, including data interpretation, value articulation, deliberation, and justification. Algorithms can primarily aid in the initial stage, partially in the second stage, and only in an indirect manner in the third stage. The concluding phase—normative justification within a community—cannot be mechanized without fundamentally altering the essence of moral responsibility.

The proposed Hybrid Ethical Decision Model (HEDM) is predicated on three normative principles: (1) epistemic reliability, (2) human normative authority, and (3) contextual revisability. Collectively, these principles endeavor to elucidate the appropriate distribution of moral responsibilities between humans and machines.

The initial principle, epistemic reliability, pertains to the circumstances under which input generated by algorithms is deemed informative. Systems should be harnessed when they demonstrably enhance the accuracy or consistency of factual evaluations, such as risk assessment or pattern recognition. However, the contribution of epistemic reliability does not equate to moral authority. Accurate predictions may inform decision-making but do not dictate what actions should be pursued (Enoch, 2011: pp. 45–49).

The second principle, human normative authority, maintains that ultimate moral accountability must reside with human agents or institutions. Decisions that pertain to rights, dignity, or distributive justice necessitate justifications that can withstand public scrutiny. This aligns with a broadly constructivist perspective on ethics, wherein norms derive their legitimacy from human reasoning and social practices (Rawls, 1999: pp. 17–22).

The third principle, contextual revisability, underscores the necessity for ethical decisions to remain amenable to reevaluation. Outputs generated by algorithms ought not to be regarded as definitive but rather as inputs subject to revision. This principle serves to mitigate automation bias and acknowledges the fluid nature of moral standards. Furthermore, it corresponds with fallibilist traditions in moral philosophy that consider ethical judgments to be subject to correction (Audi, 2004: pp. 109–114).

In conjunction, these principles delineate hybrid ethics as a dynamic interplay, rather than a static distribution of responsibilities. The model does not advocate for uniform solutions but rather delineates parameters for responsible delegation.

To transition from abstract principles to practical implementation, the Hybrid Ethical Decision Model (HEDM) incorporates various operational mechanisms. These mechanisms are specifically designed to formalize the interaction between algorithmic outputs and human deliberation, thereby preventing their relationship from becoming informal or ad hoc.

A primary mechanism utilized is the establishment of deliberative checkpoints. At predetermined points within decision-making processes—especially those that impact rights or significant interests—human evaluation is mandated. These checkpoints are not merely procedural; rather, they are deliberative, involving justification and contemplation. Their aim is to ensure that algorithmic recommendations are contextualized within broader ethical frameworks rather than being accepted without scrutiny.

Another mechanism pertains to the execution of algorithmic impact assessments prior to implementation. These assessments analyze potential social and ethical ramifications, encompassing risks of bias, distributive outcomes, and effects on vulnerable populations. Similar initiatives have been proposed in policy discussions as components of responsible AI governance (Mittelstadt, 2019: pp. 499–503). In the context of HEDM, impact assessments are not considered isolated occurrences but rather integral to ongoing oversight.

Additionally, the model incorporates contestability pathways. Individuals who are impacted by algorithmic decisions should have substantial opportunities to question and appeal these outcomes. Contestability serves to enhance accountability and acknowledges that moral legitimacy is contingent upon the ability to contest decisions. Systems that eliminate the possibility of contestation may jeopardize trust and fairness.

Finally, the HEDM underscores the importance of documentation and traceability. Decision-making processes ought to generate records that elucidate the manner in which

algorithmic input was utilized and how human judgment was applied. Traceability facilitates responsibility attribution and fosters institutional learning.

These mechanisms effectively translate the model's normative principles into procedural safeguards, thereby aiding in the alignment of technological capacities with ethical accountability.

No normative framework is without its inherent limitations, and the Hybrid Ethical Decision Model (HEDM) warrants a critical evaluation. The first limitation pertains to feasibility. Structured human oversight necessitates substantial time, expertise, and institutional resources. In high-volume decision-making contexts, such as extensive platform moderation or public administration, sustaining meaningful deliberation may prove challenging. If human review is relegated to mere formal compliance, hybrid models risk becoming purely symbolic.

The second challenge involves disparities in expertise. Effective oversight assumes that human reviewers possess an understanding of both the capabilities and limitations inherent to algorithmic systems. However, the technical complexity associated with these systems can engender epistemic dependence on specialized experts or vendors. Such reliance may undermine independent judgment and centralize authority within a select group of actors (Turner, 2001: pp. 123–125). Thus, hybrid governance must address knowledge deficits in addition to procedural design.

A further issue pertains to the diffusion of responsibility. When decision-making is shared among both humans and machines, accountability may become fragmented. The existence of shared responsibility does not inherently result in clearly defined accountability. In the absence of well-established accountability frameworks, hybrid systems may inadvertently perpetuate the very responsibility gaps they seek to address.

Additionally, there exists a danger of over-formalizing ethical considerations. The integration of ethical review into procedural frameworks can foster a checklist mentality, in which compliance is mistaken for genuine reflection. Nonetheless, ethical deliberation cannot be entirely proceduralized without sacrificing its complexity. As Schön (1983: pp. 68–70) posits in his discussion of reflective practice, responsible judgment necessitates situational awareness that transcends mere adherence to rules.

Acknowledging these limitations is crucial for the formulation of realistic governance. Hybrid ethics should be perceived as an evolving practice rather than a conclusive answer. Its merit lies in its capacity to facilitate structured reflection while not negating the complexities of moral dilemmas.

Recognizing these constraints does not diminish the validity of the Hybrid Ethical Decision Model (HEDM) but instead elucidates the contexts in which it may operate ethically. A primary response to concerns regarding feasibility is the principle of proportionality. Not every decision necessitates an identical degree of ethical examination. Consequently, HEDM endorses a tiered framework for oversight, wherein the extent of human participation is proportionate to the ethical implications of a given decision. Scenarios with

significant impact—such as those within healthcare or the criminal justice system—require more rigorous deliberative measures compared to those of lower risk.

To confront disparities in expertise, this model underscores the importance of interdisciplinary governance. Ethical oversight ought to engage not only technical specialists but also professionals from the fields of law, social sciences, and the communities impacted. This diversified framework diminishes epistemic centralization while expanding moral viewpoints. Additionally, it resonates with the advocacy for participatory methodologies in technology governance as highlighted by Jasanoff (2003: pp. 240–244).

In relation to the diffusion of responsibility, HEDM promotes the explicit mapping of accountability. Responsibilities and decision-making junctures must be distinctly articulated to ensure that accountability remains identifiable. The design of institutions is crucial in this regard. Responsibility should be aligned with decision-making authority, ensuring that individuals with control over implementation assume corresponding duties.

The issue of procedural ethics can be alleviated through the integration of reflective practices into organizational routines. An ethical review process should incorporate narrative reasoning and the discussion of specific cases, rather than focusing solely on compliance audits. Such methodologies help maintain moral awareness and foster learning from previous decisions.

In this context, HEDM represents more of a governance disposition than a rigid framework. Its objective is to uphold human moral engagement within technologically mediated settings while also leveraging computational resources.

The Hybrid Ethical Decision Model (HEDM) possesses significant implications for the design of policies and institutions. In instances where moral responsibility cannot be transferred to machines, governance frameworks must prioritize the maintenance of human accountability. Contemporary regulatory approaches to artificial intelligence (AI) increasingly acknowledge this necessity, focusing on aspects such as oversight, risk management, and obligations pertaining to transparency. HEDM serves to augment these endeavors by providing a normative justification for such requirements.

One notable implication relates to the design of regulations. Rather than concentrating exclusively on technical compliance, regulatory measures should integrate ethical risk assessments and review processes. This approach is consistent with evolving risk-based methodologies in AI governance, which differentiate obligations based on the societal ramifications of various systems (European Commission, 2021). A hybrid model advocates for proportional regulation that correlates the intensity of oversight with the moral stakes involved.

The prioritization of institutional capacity-building is another critical consideration. Organizations that implement AI systems should allocate resources towards ethical training and deliberative proficiency in addition to technical skills. Effective ethical governance necessitates abilities in interpretation, dialogue, and contextual assessment. In the absence of such competencies, formal oversight mechanisms may prove to be ineffective.

The role of professional norms should also be acknowledged. Codes of conduct for engineers, data scientists, and public officials can reinforce expectations regarding moral responsibility. Nevertheless, such codes are inadequate if they are not underpinned by institutional cultures that promote ethical reflection. Research in the field of organizational ethics indicates that cultures of responsibility are sustained through effective leadership and peer accountability (Kaptein, 2011: pp. 843–845).

Lastly, HEDM underscores the necessity of public engagement. Decisions involving technologies of significant moral consequence impact extensive communities and should not be limited to the purview of technical experts. Establishing mechanisms for stakeholder participation and public dialogue can serve to bolster legitimacy and foster trust.

These policy implications articulate that hybrid ethics transcends theoretical frameworks, representing a practical approach to governance in AI-driven societies.

The Hybrid Ethical Decision Model (HEDM) articulated in this article provides a framework for understanding the interplay between human and algorithmic decision-making without conflating the two. The primary assertion of this model is that moral judgment cannot be fully automated; however, it can be facilitated through structured and responsible methods. The differentiation between epistemic assistance and normative authority functions as a foundational principle throughout the framework.

The innovative contribution of HEDM resides in its ability to shift the discourse surrounding AI ethics from narratives focused on replacement to those centered on responsibility integration. Instead of posing the question of whether machines can possess morality, the model inquires how technological systems may be embedded in moral practices while maintaining human accountability. This transition redirects focus from the theoretical concept of machine morality to the governance of sociotechnical systems.

Significantly, HEDM does not presume that ethical conflicts can be entirely resolved. The moral landscape is characterized by continual disagreement, ambiguity, and the potential for change. A hybrid approach recognizes these dynamics rather than seeking to eradicate them through formalization. In this regard, the model resonates with pragmatic philosophies that conceptualize ethics as a continuous practice rather than a definitive system (Dewey, 1922/2002: pp. 164–168).

Furthermore, the framework contributes to contemporary discussions surrounding trustworthy AI by elucidating the nature of trust itself: it should not be placed in autonomous systems acting as moral agents, but rather in the institutional structures that uphold human responsibility. Trustworthiness, therefore, emerges as a characteristic of governance systems rather than of machine autonomy.

With the establishment of this model, the broader consequences of the study can now be integrated. The concluding section consolidates the findings and contemplates future pathways for research and policy in the realm of AI ethics.

8. Conclusion

This article has explored the interplay between human ethics and algorithmic ethics through the framework of moral boundaries. Instead of inquiring whether machines can emulate human moral reasoning, the investigation has concentrated on the specific instances and the reasons why automation faces inherent limitations. Human morality is intricately interwoven with social practices, interpretive judgment, and frameworks of responsibility that cannot be entirely transformed into computational formats.

The comparative examination revealed that algorithmic systems and human agents differ not merely in their capabilities but also in the essence of their involvement in moral existence. Algorithms engage in the processing of information and optimization based on specified criteria; however, they do not participate in justifying, conversing, or exercising reflexive accountability. Considering them as moral substitutes can lead to a misapprehension of both technological and ethical dimensions.

Simultaneously, this study has contended against a strictly adversarial perspective. Algorithmic systems have the potential to enhance decision-making by offering epistemic support, illuminating patterns, and mitigating certain biases. Their ethical significance resides in augmentation rather than independence. Acknowledging this differentiation permits a more nuanced assessment of the role of artificial intelligence in society.

The Hybrid Ethical Decision Model (HEDM) introduced in this article presents a framework for structuring such augmentation in a responsible manner. By differentiating epistemic assistance from normative authority and incorporating oversight, contestability, and contextual revisability, the model aims to uphold human moral agency while leveraging technological potentials.

Crucially, the limitations highlighted are not indicative of engineering failures; rather, they are manifestations of moral intricacy. Ethical life encompasses diverse values, uncertainties, and dynamic norms. No technical system can eradicate these characteristics without fundamentally altering the essence of morality itself.

Looking forward, subsequent research should delve deeper into the institutionalization of hybrid ethical frameworks across diverse cultural and regulatory contexts. Comparative analyses across different jurisdictions may illuminate the ways in which moral norms uniquely influence the governance of artificial intelligence. It will be crucial for interdisciplinary collaboration among philosophers, social scientists, engineers, and policymakers to foster the development of approaches that are sensitive to specific contexts.

Another promising avenue of inquiry involves empirical research on the interactions between human decision-makers and algorithmic systems in practical settings. Gaining insight into the circumstances under which individuals defer to algorithms, resist them, or reinterpret their outputs can contribute to the formulation of more pragmatic governance models. Ethical theory must remain aligned with observed practices to effectively guide responsible innovation.

For policymakers, the outcomes indicate that discussions surrounding AI ethics ought to progress beyond abstract theoretical principles toward functional institutional design. Mechanisms for oversight, requirements for transparency, and inclusive participatory processes should not be regarded merely as regulatory instruments but as integral components of the moral infrastructure within digital societies.

Ultimately, the challenge lies not in the creation of moral machines but in the maintenance of moral communities within technologically mediated environments. Artificial intelligence systems will persist in influencing decisions imbued with ethical implications; however, their legitimacy will be contingent upon how they are integrated into human practices of accountability and justification.

Consequently, acknowledging the limitations of automation should be viewed not as a pessimistic perspective but as a prerequisite for responsible innovation. By recognizing aspects that ought to remain under human control, societies can incorporate artificial intelligence in manners that enhance rather than undermine moral agency.

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Migrants remittances and economic growth in Morocco: A VAR model analysis

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Abstract. *This study examines the impact of remittances from Moroccan living abroad on Morocco's economic growth over the period 1974–2023. Based on a thorough review of the theoretical and empirical literature, it highlights the main transmission channels of remittances, particularly through consumption, productive investment, and human capital accumulation. The empirical analysis uses a time series approach, applying a bivariate VAR model between GDP and remittances. The results indicate that remittances have a positive and significant short-term effect on economic growth, as confirmed by impulse response functions and Granger causality tests. These findings emphasize the need for policies that better channel remittances into productive investments to enhance their contribution to sustainable economic development.*

Keywords: MRE, Remittances, Economic growth, VAR, Morocco.

JEL Classification: O1, O16.

Introduction

Migrant remittances currently represent one of the main sources of external financing for many developing countries. For Morocco, these flows play a key role in supporting domestic consumption, financing part of investment, and contributing to macroeconomic stability. However, the question of their actual impact on national economic growth remains debated.

Theoretical and empirical literature offers varied perspectives on the transmission channels of these remittances and their effectiveness in stimulating growth. While some studies highlight their ability to compensate for financial market failures and support the accumulation of human capital, others highlight the risks associated with the unproductive use of these funds and the development of rent-seeking behaviours.

This paper aims to analyse the effect of remittances from Moroccans Living Abroad on Morocco's economic growth over the period 1974–2023. Using an econometric approach based on a Vector Autoregressive (VAR) model, we will study the short-term dynamics between these two variables, emphasizing the role of consumption as the main transmission channel. We will first proceed through theoretical and empirical literature, before presenting the methodology of the empirical study, analysing the results and drawing lessons for public policies.

1. Theoretical Literature Review

Migrant remittances constitute a major source of external financing for many developing countries. They often represent a significant share of gross domestic product (GDP) and, in some cases, exceed flows of official development assistance and foreign direct investment.

The theoretical literature identifies several motivations for remittances: altruistic, strategic, insurance-related, or intergenerational exchange. These motivations underpin behaviours that influence the transmission channels through which remittances impact growth. According to the pure altruism model, migrants remit part of their income to improve the well-being of family members left behind. This logic implies a redistribution of income toward poorer households, potentially boosting consumption and reducing poverty, with indirect effects on growth via aggregate demand (Rapoport & Docquier, 2005).

Other approaches emphasize exchange or investment motives. Migrants may send money in exchange for services (property maintenance, family care) or as repayment for family investments that enabled their migration. Such remittances can be seen as a form of implicit contract within the household, contributing to an optimal intertemporal allocation of resources (Poirine, 1997).

Remittances can also serve as informal insurance against economic shocks in the country of origin. In this case, they help stabilize consumption and enable riskier but potentially more productive investments, thereby fostering economic growth (Rosenzweig, 1988).

At the macroeconomic level, remittances can influence growth through several channels, depending on the analytical framework used. From a Keynesian perspective, remittances increase household disposable income, thereby stimulating domestic consumption. This injection of aggregate demand can boost output and employment. However, the multiplier effect depends on the marginal propensity to consume of recipient households (Rapoport & Docquier, 2005); the higher this propensity, the stronger the effect.

In endogenous growth models, remittances can ease liquidity constraints by financing the accumulation of physical capital (entrepreneurial investment) or human capital (education). These productive investments enhance productive capacities and the creation of added value (Chami & All, 2005). For example, remittances used to finance children's education help increase human capital, which has positive dynamic effects on total factor productivity and long-term growth (Yang, 2008). Similarly, remittances can fund entrepreneurial ventures and start-ups, especially in contexts where the banking system is underdeveloped.

The impact of remittances on growth may also depend on their effects on income distribution.

According to some analyses, remittances reduce intra-national inequalities, which can enhance social stability and strengthen the multiplier effects of spending. However, this effect is not always monotonic: in contexts where only relatively well-off households can afford to finance migration, remittances may exacerbate income disparities (Rapoport & Docquier, 2005).

Several factors qualify the potential of remittances as an engine of growth. If recipients perceive themselves as “rentiers” of migrant remittances (Chami and All., 2003), such transfers may reduce the local labor supply. Also, if a large share of remittances is allocated to current consumption or real estate, the effect on the accumulation of productive capital may be limited. Finally, an economy overly dependent on external transfers may see its incentives for reform or diversification weakened.

In summary, migrant remittances can foster economic growth by alleviating financial constraints, supporting consumption, enabling human capital investment, and funding productive activities. However, the net impact depends on institutional structures, the behavior of economic agents, and the distribution and use of remittances.

2. Empirical Literature Review

Over the past two decades, empirical analysis of the macroeconomic effects of migrant remittances has intensified, due to their growing role in the economies of developing countries. According to Rapoport & Docquier (2005), migrant remittances represent on average more than 5% of GDP in many low- and middle-income countries. This economic significance has sparked a vast body of empirical research aimed at understanding to what extent these private flows actually contribute to economic growth.

Several empirical studies conclude that migrant remittances have a significant positive effect on economic growth, although the results vary depending on econometric specifications, study periods, and the structural characteristics of the countries analyzed.

For example, Giuliano, & Ruiz-Arranz (2009), using a panel of 100 countries over the period 1975–2002, find that remittances promote growth in countries with underdeveloped financial markets, acting as a substitute for bank credit in financing investment. Similarly, Mundaca (2009), based on data from Latin America, shows that remittances enhance growth when accompanied by good governance and an inclusive financial system. Furthermore, in a study of 62 developing countries, Rao & Hassan (2011) demonstrate that remittances have a significant impact on per capita GDP, provided they are used productively. The study distinguishes between short-term and long-term effects, with more pronounced positive effects over time.

Remittances can also stimulate growth indirectly by financing private investment and human capital. Several studies support this hypothesis. Adams & Cuecuecha (2010), using household data from Guatemala, find that remittances are partly used to finance education and healthcare, suggesting a long-term positive effect via human capital accumulation.

Similarly, Edwards & Ureta (2003) based on data from El Salvador, find that remittances reduce school dropout rates among children, thereby reinforcing the positive effect on future productivity. Moreover, Woodruff & Zenteno (2007) show that in Mexico, remittances have a positive effect on entrepreneurial activity, particularly in rural areas. They provide households with access to financial resources in the absence of a formal credit system, thus facilitating business creation.

Finally, several studies emphasize that the effect of remittances on growth is neither automatic nor homogeneous and depends significantly on structural variables such as the quality of institutions, trade openness, and the initial level of inequality. Barajas & All (2009), in an IMF study covering 84 countries from 1970–2005, estimate that the growth effects of remittances are on average weak or not significant once endogeneity biases are considered. According to the authors, remittances may induce rent-seeking behavior and reduce labor supply incentives, offsetting the expected positive effects. Likewise, Catrinescu & All (2009) find a weak positive effect on economic growth when remittances are accompanied by strong institutions. The authors stress the importance of macroeconomic stability, anti-corruption efforts, and governance quality for remittances to be effectively used for productive purposes.

Given the importance of remittances in Morocco, several studies have been conducted to assess their impact on the Moroccan economy.

The following table summarizes the main studies already carried out:

Table 1. *Summary of Studies on the Impact of Remittances on the Moroccan Economy*

Study	Period	Methodology	Main Findings	Comments
Makhlouf, F. (2019)	1975–2014	Threshold VAR model	Remittances have a positive effect on total factor productivity when they exceed 5.132% of GDP; negative effect below this threshold.	The impact is conditional on the level of remittances.
Lakhdar, G., & Bensbahou, H. (2017)	1975–2017	Error correction model	A 1% increase in remittances raises GDP per capita by 0.12%.	Significant long-term positive effect.
Tabit, R., & Moussir, C. (2017)	1975–2014	VAR and ECM models	Remittances positively affect GDP, investment, and consumption, with lower elasticity in the short term.	Effects are more pronounced in the long term.
Zghidi, N., Sghaier, I. M., & Abida, Z. (2016)	1980–2012	Panel GMM	Positive relationship between remittances and economic growth, strengthened by economic freedom.	The effect is amplified in the presence of favorable institutions.
OTRAGO. (2024)	2010–2024	Descriptive analysis	Less than 10% of remittances are allocated to productive projects; 70% go to real estate and 60% to family support.	Weak channeling into productive investments.

Source: Author

4. Analysis of the Evolution of Migrant Remittances Moroccan

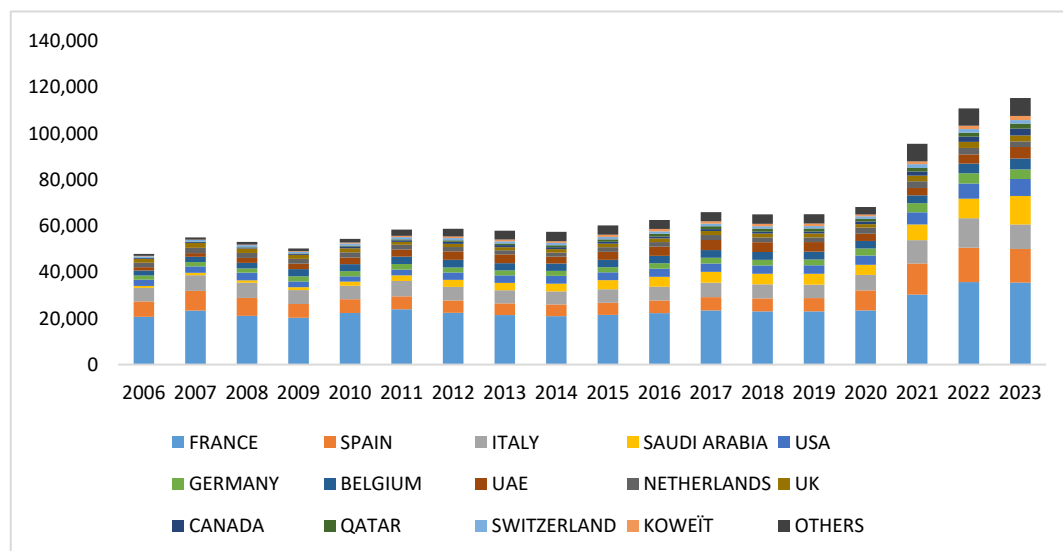
Emigration to Europe experienced significant growth starting in the 1960s, particularly following bilateral labour agreements such as the one signed with Belgium in 1964. These agreements facilitated the settlement of Moroccan workers in Europe, thereby generating the first flows of remittances to Morocco. During the 1960s, remittances from Moroccan workers abroad represented a minor component of the balance of payments, but they grew steadily, reaching substantial amounts by 1980. They contributed to the country's external account balance and helped reduce domestic unemployment.

Between 1997 and 2003, remittances from Moroccans Living Abroad (MLA) increased from 23 to 36.8 billion dirhams, marking a 60% rise. This growth was attributed to a proximity-based policy adopted by Moroccan banks toward MLAs and improvements in the reception of expatriates during their visits to Morocco. However, a large portion of these funds was directed toward non-productive investments, particularly in real estate.

In the 2000s, remittances continued to grow, reaching 54.10 billion dirhams in 2010, compared to 50.21 billion in 2009—an increase of 7.8%. Bank transfers remained the preferred method for sending money, accounting for the majority of remitted funds. France remained the primary source of remittances, followed by other European countries and the United States.

Despite global economic crises, remittances from MLA have shown remarkable resilience. In 2015, they surpassed \$6 billion, representing 7% of Morocco's GDP and constituting the third-largest source of foreign exchange after tourism and phosphate exports. This stability was supported by government policies aimed at encouraging MLA investment in Morocco.

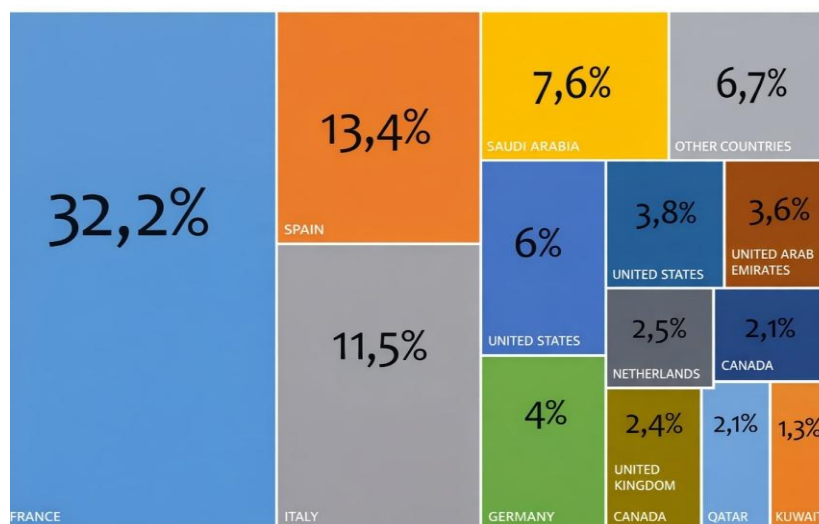
Graph 1. Evolution of remittances over the period 2006-2023 with breakdown by country of origin (Millions of Dirhams)



Source: Office de change

Recent years have been marked by exceptional growth in remittances from MLA. In 2020, despite the COVID-19 pandemic, remittances reached 68.14 billion dirhams. This upward trend continued, rising to 95.48 billion in 2021, 110.7 billion in 2022, and peaking at 117.71 billion dirhams in 2024. This growth was supported by a diversification of remittance source countries, with a notable increase in transfers from Saudi Arabia, the United Arab Emirates, and the United States.

Figure 1. Breakdown of remittances by country in % (2023)



Source: Office de change

In terms of geographical distribution, France remains the main source of remittances from Moroccans living abroad, accounting for 32.2%, followed by Spain (13.4%) and Italy (11.5%).

Remittances from MLA continue to be largely directed toward low-productivity uses. Nearly 71% of the transferred funds are allocated to everyday consumption, while 21% are deposited in financial institutions.

Only a small fraction—about 8%—is invested, with real estate capturing over 80% of that amount. Commerce and service sectors account for less than 20% of the investment portion, representing approximately 2% of total remittance flows. As such, the majority of remittances are used to cover essential household expenses in Morocco, particularly food, education, and healthcare. These resources play a critical socio-economic buffer role, especially during periods of inflation or economic crisis. Whether in rural or urban areas, they contribute to maintaining domestic consumption levels and thus help support economic growth.

The evolution of remittances from MLA reflects Morocco's migration and economic dynamics over the decades. These transfers have become an essential component of the Moroccan economy, supporting the balance of payments, domestic consumption, and investment. Government policies aimed at strengthening ties with the diaspora and facilitating remittance flows have played a crucial role in this positive development.

5. Empirical Analysis of the Relationship Between Remittances from Moroccans Living Abroad and Economic Growth in Morocco

In order to differentiate from previous studies conducted on the Moroccan case, we will undertake a bivariate analysis focusing solely on the dynamics of GDP and remittances over the longest possible period (1974–2023). Before proceeding with a time series analysis, it is essential to examine the stationarity of the variables. To this end, we will use the Augmented Dickey-Fuller (ADF) test. The test results are presented as follows:

Table 2. *Stationarity test of the GDP*

Null Hypothesis: GDP has a unit root		t-Statistic	Prob.*
Exogenous: Constant			
Lag Length: 0 (Automatic - based on SIC, maxlag=10)			
Augmented Dickey-Fuller test statistic		2.658684	1.0000
Test critical values:	1% level	-3.574446	
	5% level	-2.923780	
	10% level	-2.599925	
Null Hypothesis: D(GDP) has a unit root		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-10.09891	0.0000
Test critical values:	1% level	-3.574446	
	5% level	-2.923780	
	10% level	-2.599925	

Source: author

The ADF test indicates that the GDP and MRE transfer variables are stationary in first difference and therefore integrated of order (1), as shown in table 2 and 3.

Table 3. Stationarity test of the MRE variable

Null Hypothesis: MRE has a unit root		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		2.634012	1.0000
Test critical values:	1% level	-3.571310	
	5% level	-2.922449	
	10% level	-2.599224	
Null Hypothesis: D(MRE) has a unit root			
		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-4.674874	0.0004
Test critical values:	1% level	-3.574446	
	5% level	-2.923780	
	10% level	-2.599925	

Source: author

It is then possible to estimate a VAR model on the differenced variables to analyze the short-term dynamics between the two variables. The short-term dynamics are deemed most significant because remittances are primarily resources dedicated to boosting household consumption, thereby forming a key component of aggregate demand. Their analysis can be likened to studying the multiplier effect of one of the components of aggregate demand.

The reduced-form VAR model is expressed as follows:

$$Y_t = A(L)Y_{t-1} + \varepsilon_t$$

where Y_t represents the vector of endogenous variables, ε_t is the error vector, and L denotes the lag operator. In our study:

$$Y_t = [DGD P_t, DMRE_t]$$

Here, $DGD P_t$ and $DMRE_t$ are the first differences of GDP and MRE transfers, respectively. First, it is necessary to determine the optimal lag order for estimating the VAR model.

Table 4. Determination of the optimal number of lags of the VAR model

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-966.5281	NA	1.70e+16	43.04570	43.12599	43.07563
1	-955.2053	21.13599*	1.23e+16	42.72024	42.96112*	42.81004*
2	-951.8595	5.948109	1.26e+16	42.74931	43.15079	42.89898
3	-947.9446	6.611809	1.27e+16	42.75309	43.31517	42.96263
4	-942.4584	8.777847	1.20e+16*	42.68704*	43.40971	42.95644

Source: author

Three criteria indicate that a single lag is optimal for estimating the VAR model. This result is entirely plausible with annual data, as VAR models are typically estimated with 1 or 2 lags to avoid a significant loss of degrees of freedom. The estimation of the VAR model is presented as follows:

Table 5. Estimation of the VAR model

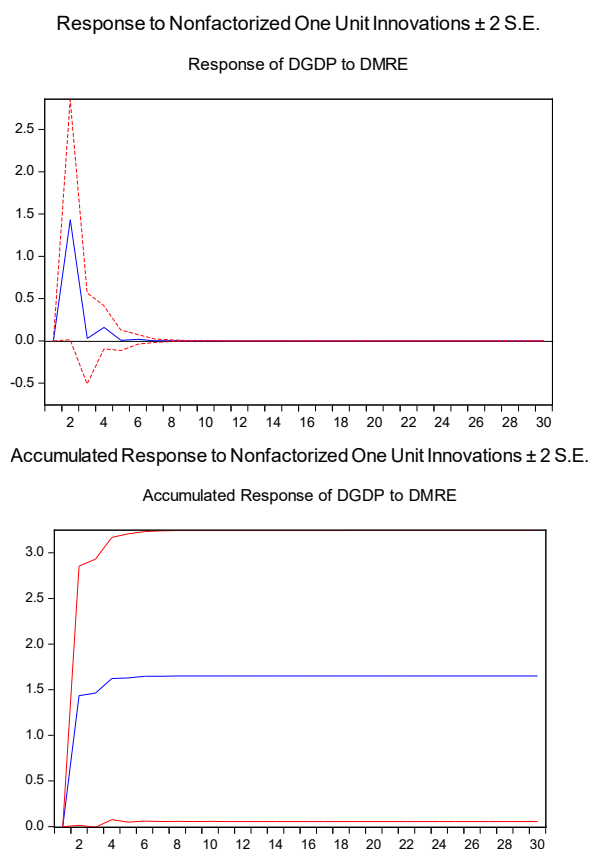
	DPIB	DMRE
DGDP(-1)	-0.473396	-0.085087
	(0.13992)	(0.02606)
	[-3.38344]	[-3.26556]
DMRE(-1)	1.434052	0.493097
	(0.71019)	(0.13225)
	[2.01927]	[3.72839]
C	28471.44	3041.318

	DPIB	DMRE
	(4403.21)	(819.991)
	[6.46606]	[3.70897]
R-squared	0.216466	0.293581
Adj. R-squared	0.181642	0.262185
Sum sq. resids	2.39E+10	8.28E+08
S.E. equation	23030.82	4288.928
F-statistic	6.216034	9.350803
Log likelihood	-548.7004	-468.0221
Akaike AIC	22.98752	19.62592
Schwarz SC	23.10447	19.74287
Mean dependent	21730.69	2367.708
S.D. dependent	25458.79	4993.155

Source: author

Within the VAR model framework, the analysis primarily focuses on impulse responses functions, which allow us to study the reaction of a variable following a shock to the other variables in the model. The graphs below show the response of GDP to a 1% shock in remittances (MRE).

Figure 2. Impulse responses (instantaneous and cumulative) of DPIB following a shock on DMRE



Source: Author

A 1% positive shock to remittances positively impacts economic growth, peaking at 1.5% after 8 quarters. The cumulative effect is reached after 4 years, amounting to 1.62%. Thus, our analysis confirms the existence of a significant short-term positive effect of remittances on economic growth.

To strengthen our analysis, we also perform a Granger causality test. This test examines whether the historical values of one variable explain the current value of another variable. If so, the explanatory variable is said to Granger-cause the dependent variable. The test results are summarized in the following table:

Table 6. *Granger Causality Test*

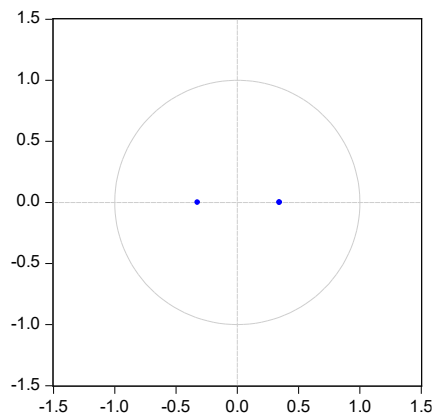
Null Hypothesis:	Obs	F-Statistic	Prob.
DMRE does not Granger Cause DGDP	48	4.07743	0.0494
DGDP does not Granger Cause DMRE		10.6639	0.0021

Source: author

The Granger causality test indicates the existence of bidirectional causality between economic growth and MRE transfers as the p-value is significant for both direction of causality.

All the necessary tests for the validation of the VAR model were conducted including the AR root graph (figure 3), the serial correlation LM test that indicates no serial correlation (table 7) and the portmanteau test that indicates no residual autocorrelation (table 8).

Figure 3. *AR Roots graph*



Source: Author

Table 7. *LM Tests*

Null hypothesis: No serial correlation at lag h						
Lag	LRE* stat	df	Prob.	Rao F-stat	df	Prob.
1	6.336661	4	0.1754	1.625360	(4, 84.0)	0.1754

Source: Author

Table 8. *Portmanteau tests*

Lags	Q-Stat	Prob.*	Adj Q-Stat	Prob.*	df
1	0.551950	---	0.563694	---	---
2	6.021075	0.1976	6.270607	0.1798	4

Source: Author

Conclusion

The analysis conducted over the period 1974–2023 confirms the positive impact of remittances on Morocco's economic growth, particularly in the short term. By boosting domestic consumption and supporting household income, these transfers play a key role in stimulating aggregate demand and cushioning economic shocks.

However, the study also highlights that the majority of transfers remain directed toward low-productivity uses, primarily daily consumption and real estate. This limits the transformative potential of these transfers on economic structure and long-term growth. In light of these findings, several public policy recommendations can be proposed:

- Channel transfers toward productive investments: Implement tax incentives, co-financing programs, and support mechanisms to encourage MREs to invest in high-potential sectors such as sustainable agriculture, industry, technology, or innovative services.
- Strengthen financial and banking services for MREs: Develop attractive, secure, and profitable savings and investment products to direct a larger share of transfers toward productive investments.
- Promote entrepreneurial investment by MREs: Facilitate business creation through training programs, mentorship, and administrative simplification for diaspora members seeking to launch ventures in Morocco.
- Improve the institutional environment: Enhance transparency, combat corruption, and guarantee investment protection to build MRE trust and encourage more sustainable financial commitments.
- Strengthen ties with the diaspora: Expand initiatives in economic diplomacy, public-private partnerships, and recognition of MRE skills to sustain their economic and emotional attachment to their home country.

In summary, while remittances represent a valuable resource for Morocco's economy, their long-term growth impact will depend on the government's ability to mobilize these flows toward value-added, job-creating uses.

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Determinants of inflation in Romania: A VAR approach

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Abstract. *This paper empirically analyzes the determinants of inflation in Romania using a vector autoregressive (VAR) framework. The study focuses on the role of monetary policy and real economic activity, proxied by the short-term interest rate (ROBOR 3M) and the output gap, in explaining the dynamics of adjusted CORE2 inflation. The model is estimated on quarterly data covering the period 2020-2024. The results indicate a high degree of inflation persistence, with core inflation dynamics being largely driven by its own shocks, while demand-side factors play a secondary but significant role. Monetary policy effects on inflation are found to be moderate and subject to transmission lags.*

Keywords: Inflation, Core inflation, VAR Model, Output gap, Monetary Policy.

JEL Classification: E31, E32, E52, C32.

Introduction

Inflation, known as the general increase in consumer prices, is one of the concerns of monetary policy in emerging economies.

In order to achieve its fundamental objective of ensuring and maintaining price stability, monetary policy actions are primarily aimed at directing short-term interest rates.

This article aims to study the determinants of inflation, starting from an econometric framework, estimating a VAR (Vector Autoregressive) model in the case of Romania, analyzing more precisely the role of monetary policy, using the short-term interest rate as a proxy, as well as the role of economic activity, which is measured by the output gap, in the evolution of CORE2 inflation.

For emerging economies, such as Romania, the analysis of the determinants of inflation is relevant, taking into account the important role of monetary policy in maintaining price stability, a point illustrated in Article 2 of Law no. 312/2004 regarding the Statute of the National Bank of Romania.

The role of a nominal anchor: the revolutionary developments in economic theory have coincided with increasing recognition among economists, policymakers, and the public of the high costs of inflation. They have also clarified why a nominal anchor—a variable that monetary policymakers use to control the price level, such as the inflation rate, an exchange rate, or the money supply—is such a crucial element in achieving price stability. Adhering to a nominal anchor that keeps the nominal variable within a narrow range supports price stability by directly promoting low and stable inflation expectations. With stable inflation expectations, markets do much of the work for monetary policymakers: low and stable inflation expectations lead to stabilizing behaviors in setting prices and wages, which reduces both the level and volatility of inflation.

Regarding the methodology, the paper uses the classic VAR econometric model (vector autoregressive), a type of model that allows the analysis of interactions between macroeconomic variables without imposing structural restrictions. The analysis period includes data from the first quarter of 2020 to the fourth quarter of 2024.

The contribution of the paper is providing an empirical assessment of the determinants of inflation in Romania, in a context marked by uncertainty (the Covid-19 pandemic). By focusing on a limited number of variables, yet relevant for the central bank, the study offers results that are easy to interpret, useful, and relevant from the perspective of monetary policy.

The structure of the paper is as follows: section 1 introduces the literature review, section 2 presents the data used and the methodology, section 3 illustrates the empirical results obtained from running the VAR model, and section 4 concludes the findings.

1. Literature review

The specialized literature on inflation dynamics highlights the central role of monetary policy and the cyclical conditions of the economy in determining price developments.

Modern macroeconomic models emphasize that core inflation primarily reflects persistent pressures in the economy, being influenced by factors such as aggregate demand, marginal cost etc.

An important direction in the empirical literature is represented by the use of vector autoregressive (VAR) models in order to analyze the determinants of inflation. This type of models allow to capture the dynamic relationships between macroeconomic variables without strict structural restrictions, that are widely used in evaluating the transmission mechanisms of monetary policy.

These were popularized by Christopher Sims (1986), who highlighted that, instead of imposing rigid theoretical relationships (as in structural models), one can let the data speak through a flexible approach – unrestricted VARs, which model each variable based on its own lags and those of the other variables in the model.

In the paper “Monetary transmission mechanism in transition economies: surveying the surveyable,” the authors refer to the fact that VAR (vector autoregressive) studies provide a black-box framework in which the impact of monetary policy shocks on prices, output, and macroeconomic variables can be quantified (it can be seen what happens when a shock occurs, but not always can be understood the actual mechanism through which these effects take place).

In the context of developing economies, the literature shows the importance of the output gap and interest rates as determinants of core inflation, although the estimated relationships may vary depending on the structural specifics of each period analyzed and of each economy.

One of the fundamental contributions to the development of Bayesian VAR models belongs to Litterman (1984), who documented the use of BVARs over a four-year period at the Federal Reserve Bank of Minneapolis. The author proposes this approach as a pragmatic alternative to structural models, in the context of high theoretical uncertainty regarding the mechanisms of economic cycles. The model uses the Minnesota prior, which limits the over-parameterization typical of classical VARs, favoring stable and efficient estimation. One of the most important advantages of Bayesian VAR models is that no adjustment by the researcher is required.

The literature has generated the so-called 'price puzzle,' according to which a monetary policy tightening leads to an increase in the inflation rate instead of a decrease (this is an anomaly in VAR models: if central banks anticipate a future increase in inflation and respond by raising interest rates, but the VAR model does not include all relevant factors, it may misinterpret the causal relationship, suggesting that an interest rate increase causes a rise in inflation rather than a reduction), according to Balázs and McDonald (2006).

An interesting article is by Kenji Moriyama (2008), which uses a structural VAR approach to analyze inflation dynamics in Sudan (a low-income country in Africa), and the variables used are: inflation, money supply, exchange rate developments, and real GDP. The study shows that inflation is largely determined by the growth of the money supply.

In the Romanian context, understanding the dynamics of inflation requires consideration of the country's evolving monetary policy framework. In a Study Notebook published by the NBR in 2009, by Popa and colleagues (2009), it is illustrated that the issue of gradually abandoning the strategy based on the monetary anchor and transitioning to a new monetary policy strategy has been a topic discussed by the National Bank of Romania (NBR) since

2000. In 2002, within the Pre-Accession Economic Program, developed by the Government in the context of Romania's EU accession negotiation stages, the idea of direct inflation targeting was presented as the primary option for a monetary policy strategy that the NBR sought to implement. It was considered by the NBR as the most viable option for the monetary policy strategy applied at that time. However, the fact that Romania did not meet the initially established preconditions required a reconsideration of the previously planned timing, yet the NBR's commitment to moving towards direct inflation targeting remained firm.

Ensuring and maintaining price stability has been the fundamental objective of the National Bank of Romania (NBR) since August 2005, within the framework of the inflation targeting strategy, in line with international best practices, particularly those promoted by the European Central Bank.

In this context, the NBR places strong emphasis on active communication with the public, primarily through its key instrument—the *Inflation Report*. By preparing and publishing this report quarterly, the NBR offers greater transparency and insight into its analytical framework and the rationale behind monetary policy decisions. The goal of ensuring transparency and predictability is to enhance the credibility of monetary policy and contribute to the anchoring of inflation expectations and the preservation of price stability.

In the case of this strategy, the inflation rate becomes the nominal anchor, and the main objective of the monetary authority is to maintain inflation within the targeted range of $2.5\% \pm 1$ percentage point.

Ciurilă and Murărașu (2008) highlight the significant role of inflation persistence in Romanian inflation dynamics. Their analysis also emphasizes the importance of real economic activity, proxied by the output gap, in shaping the underlying inflationary pressures.

In line with this literature, this study uses a VAR approach to reassess inflation dynamics in Romania, relying on more recent data.

2. Methodology

The classical VAR model is estimated using the BEAR toolbox in Matlab. The sample covers the period Q1 2020-Q4 2024 to ensure data consistency and avoid the use of preliminary observations for the year 2025, subject to subsequent revisions.

The VAR model describes stochastic processes, being used to capture linear interdependencies between time series. Each variable in the model has an equation that explains its evolution based on its own past values, the past values of other variables, and the model's residual. In recent years, VAR models have been used extensively, especially for the analysis and forecasting of macroeconomic series.

In general, models that have non-stationary variables are explosive models that lead to incorrect analyses. However, sometimes removing the trend from non-stationary variables can result in a loss of information. VAR models can be suitable even if some variables in the model are non-stationary.

The endogenous variables used are: domestic outputgap, *dl_core2_xtva_sa* (adjusted CORE2 inflation), and ROBOR 3M. The data sources used are: the National Institute of

Statistics, the National Bank of Romania, and Eurostat, using already seasonally adjusted series for domestic GDP (Gross Domestic Product) and adjusted CORE 2 (BNR). The ROBOR 3M series does not show any obvious seasonality, as it is not subject to recurring calendar influences, and is included in the model in its raw form. GDP, for example, which is an activity variable, is affected by calendar cycles and also the inflation (prices vary from year to year repeatedly, and even CORE 2 can retain seasonal influences (in services).

The data were processed as follows:

- Output gap: the series of Romania's Gross Domestic Product, seasonally adjusted, expressed in millions of RON, with volumes chained to the 2020 base year, was logarithmized and multiplied by 100. Then, in the Eviews software, the Hodrick-Prescott filter was applied to the series (coefficient $\lambda=1600$) and obtained the GDP gap (the deviation of GDP from potential, expressed as a percentage, because the series was logarithmized and multiplied by 100). The deviation of GDP from its potential level is used as a proxy in this model for the effects of the real economy on inflation.
- `dl_core2_xtva_sa`: The CORE 2 index adjusted exclusively for the first-round effects of VAT changes (at constant taxes) with a fixed base year of 2000 (using information from the NBR Inflation Reports): the series was logarithmized and multiplied by 100, then differenced once for the standard VAR model; The adjusted CORE 2 inflation is a measure of inflation that excludes the most volatile components to highlight the underlying trends in price growth. This index excludes administered prices (set by authorities) and volatile prices (food, fuel), as well as the direct first-round effects of VAT changes. It shows the real trends of inflation and provides a clearer picture of inflationary pressures. This variable is used because although CPI is the BNR's target, it contains volatile components.

The analysis period is 2020-2024, with quarterly data (for the case of Romania), which have been transformed according to stationarity requirements.

Next, the analysis of the stationarity of the data series was conducted in Eviews, using ADF test (Augmented Dickey Fuller) before running the simple VAR model.

- `l_y` (the log-transformed domestic GDP series): visually, the series shows an upward trend, with an almost linear growth trend, as expected from log (GDP), indicating non-stationarity at level. In the ADF test, the t-statistic (-0.1971) is higher than all critical values and the p-value is $0.9856 > 0.05$, so the series is not stationary.
- Output gap series: from a visual point of view, the series does not have a visible deterministic trend. However, the ADF test was applied to check: ADF t statistic (-2.888438) is more negative than the 10% critical value (-2.655194), so the null hypothesis of a unit root at the 10% significance level can be rejected.
- The “ROBOR 3M” series does not have a clear long-term linear trend, and the ADF test (t-statistic is -2.7115, higher than the critical values for all three) shows that the series is non-stationary. Interest rates exhibit a “mean-reverting” behavior, and the test performed may not have enough statistical power to reject H_0 , while differencing them, unfortunately, could remove relevant economic signals, especially for IRFs. Nevertheless, considering the medium-term economic behavior of interest rates, the lack of a clear deterministic trend, as well as the importance of retaining level

information for analyzing responses to monetary shocks, the series are kept in levels within the estimated VAR models.

- `l_core2_xtva_sa`: visually, the series exhibits an increasing trend. The ADF test statistic (-4.7342) is smaller than all critical values, and the p-value is 0.0081, which is less than 0.05, indicating that the series is stationary.
- In the simple VAR model, the series `dl_core2_xtva_sa` is included in its differenced form only once, justifying the choice both through economic considerations and through the robustness of the resulting estimates. Over-differencing (a second differencing) results in the loss of economic signal.

The VAR model satisfies the stability condition, with all the roots lying inside the unit circle, ensuring that the impulse response functions of the model are reliable.

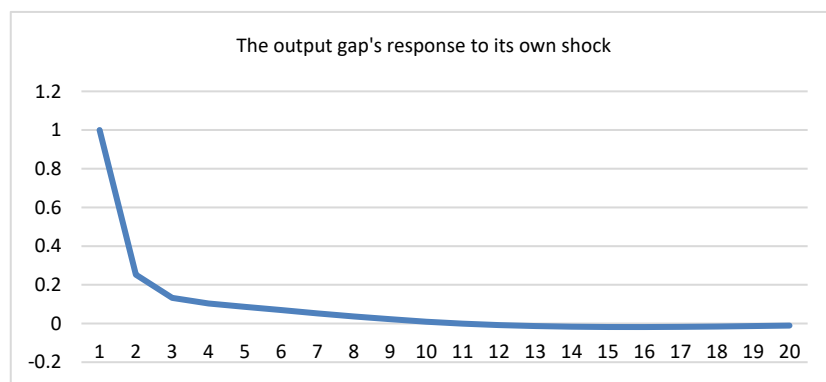
3. Empirical results and discussions

The behavior of the variables following a structural shock is further analyzed using IRFs (impulse response functions), which provide a graphical representation of how a shock to one variable in the model impacts each variable over a given time horizon.

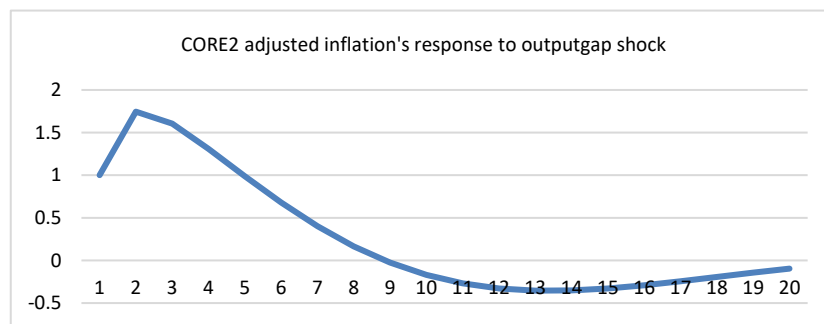
Impulse Response Functions are essential elements for understanding the monetary policy transmission mechanism, as they show the direction, persistence, and magnitude of shocks on key macroeconomic indicators like inflation and exchange rates. This analysis helps assess whether the responses align with economic theory and are statistically significant. IRFs thus support the interpretative validation of the model.

For a more intuitive and comparable economic interpretation of impulse response functions (IRFs), the results implicitly generated by Matlab are standardized so that the shocks are expressed in terms of 1 percentage point (p.p.), rather than in standard deviation units. The responses of the variables to shocks reflect the impact of 1 p.p. changes in the variable that generated the shock, which facilitates the interpretation and practical relevance of the results.

Figure 1. *Impulse response of the output gap to its own shock*

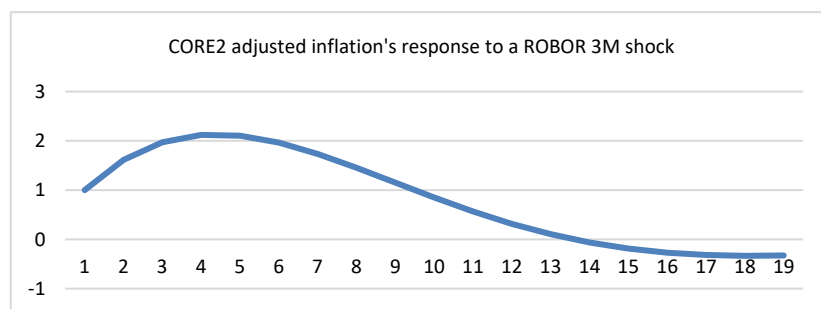


Source: INS, NBR, Eurostat, author's calculations

Figure 2. *Impulse response of adjusted CORE2 to an output gap shock*

Source: INS, NBR, Eurostat, author's calculations

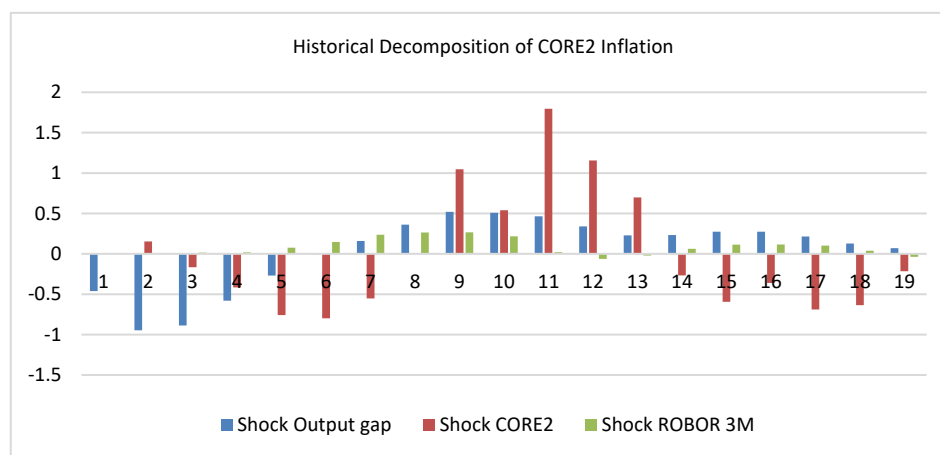
For a 1 p.p. shock to the domestic output gap, core inflation 2 responds with 1.74 p.p. in the first quarter and reaches a minimum around quarter 13, leading to inflationary pressures, result that is consistent with the economic theory.

Figure 3. *Impulse response of adjusted CORE2 to a monetary policy shock (ROBOR 3M)*

Source: INS, NBR, Eurostat, author's calculations

The response of the variable `dl_core2ajtva_sa` is null in the first quarter, indicating the absence of an immediate reaction to a standardized 3-month ROBOR rate shock. Subsequently, adjusted core inflation rises, reaching a peak around periods 4–6, when the response is about 2 percentage points. After this peak, the effect gradually diminishes, becoming negative from period 15 onwards, suggesting the dissipation and correction of the initial impact of the monetary shock. The trajectory is consistent with economic theory, reflecting the delayed transmission of monetary policy to core inflation.

The historical decomposition highlights that variations in CORE2 adjusted inflation are mainly explained by inflation's own shocks, which dominate across the entire sample and contribute significantly to the sharp increases during the 2021–2023 period. The output gap has a secondary, yet relevant, contribution, particularly during phases of economic expansion, indicating demand-driven inflationary pressures. In comparison, shocks associated with the 3-month ROBOR rate have the smallest contribution to inflation dynamics, their effect being limited and volatile. These results suggest that core inflation is predominantly determined by inertial and demand factors, while monetary policy influences inflation to a more modest extent and with a delay.

Figure 4. *Historical decomposition of CORE2 inflation*

Source: INS, NBR, Eurostat, author's calculations

The decomposition of the forecast error variance indicates that the dynamics of adjusted CORE2 inflation are predominantly explained by its own shocks, which account for over 80% of its variation across the entire forecast horizon. The contribution of the output gap is relatively small, around 10–15%, while the shocks to the 3-month ROBOR rate play a marginal role.

These results suggest a high degree of inertia in core inflation, as well as a limited transmission of monetary policy to fundamental inflation within the standard VAR model.

4. Conclusions

This paper aims to empirically assess the main determinants of core inflation in Romania using a vector autoregressive (VAR) framework, with a particular focus on monetary policy and economic activity. By selecting a limited but policy-relevant set of variables- the output gap, the adjusted CORE2 inflation and the short-term interest rate (ROBOR 3M)- the analysis aimed to provide a transparent and intuitive evaluation of inflation dynamics in an emerging economy context marked by heightened uncertainty.

The empirical results confirm that core inflation in Romania shows a high degree of persistence, as evidenced by the dominance of its own shocks, both in the impulse response function results and also in the forecast error variance decomposition. This finding is consistent with the macroeconomic theory, which emphasizes that past inflation plays a key role in shaping the current inflation dynamics.

The output gap is shown as a second determinant of inflation, having a more moderate contribution. The impulse response analysis shows that a positive shock in demand leads to an increase in inflation, in line with standard macroeconomic theory. The results align with the view that cyclical conditions of the economy matter for inflation developments in Romania, reinforcing the relevance of the real economic activity in the inflation targeting framework adopted by the National Bank of Romania.

Regarding the monetary policy, the impulse response functions indicate a delayed and moderate transmission of interest rate shocks to core inflation. Following a tightening shock, inflation increases before gradually declining, a pattern that is consistent with the presence of information effects and transmission lags commonly identified in VAR-based studies.

The monetary policy influences inflation indirectly and with delay, rather than being the dominant short-term driver of core inflation evolution.

Overall, the results of this paper support the initial hypothesis: for Romania's case, core inflation is driven by its persistence and by demand-related factors, while the monetary policy acts indirectly and in a gradual manner.

Future research could extend this framework by incorporating other variables, like the exchange rate dynamics, using a Bayesian VAR approach to refine the identification of monetary policy shocks.

This study provides empirical evidence that is informative for the conduct of monetary policy in Romania, contributing to the literature of inflation dynamics in an emerging economy and illustrating the usefulness of VAR- based approaches as practical tools for policy-oriented inflation analysis.

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Annex 1. *The standardized responses of the variables to shocks in percentage points*

	Standardized response of outputgap_ro to outputgap_ro shocks	Standardized response of CORE2 inflation to outputgap_ro shocks	Standardized response of CORE2 inflation to robor3m shocks
1	1	1	NA
2	0.252415664	1.745335324	1
3	0.132180214	1.605605322	1.613898374
4	0.103562769	1.308431913	1.970431156
5	0.086269779	0.987211383	2.120031743
6	0.069445621	0.679227436	2.104159203
7	0.052596467	0.402040943	1.963127077
8	0.036543866	0.165633964	1.735166776
9	0.022049724	-0.025102312	1.454770917
10	0.009628613	-0.169264687	1.151493337
11	-0.000449067	-0.269020956	0.849309907
12	-0.008119621	-0.328747323	0.566468037
13	-0.013481708	-0.354238219	0.31572195
14	-0.016752044	-0.352016464	0.104848712
15	-0.018224272	-0.328761798	-0.062652799
16	-0.018232812	-0.290864757	-0.186765967
17	-0.017122756	-0.244103609	-0.27013521
18	-0.015226213	-0.193435056	-0.317275691
19	-0.012845039	-0.142884688	-0.333855077
20	-0.010239491	-0.095520307	-0.326074316

Annex 2. *Historical decomposition results*

Quarter	Shock Output gap	Shock CORE2	Shock ROBOR 3M
2020q2	-0.460540298	0.007066725	0
2020q3	-0.94730823	0.153717334	0.009906788
2020q4	-0.887630601	-0.165155126	0.015219729
2021q1	-0.580866597	-0.414667676	0.017708503
2021q2	-0.269136729	-0.758059794	0.075102459
2021q3	-0.00492472	-0.797709481	0.148085779
2021q4	0.159406312	-0.551472873	0.237391672
2022q1	0.361928034	0.007035118	0.263252077
2022q2	0.518937096	1.047627127	0.266943224
2022q3	0.507528864	0.538868109	0.215731971
2022q4	0.463837299	1.796574555	0.019472914
2023q1	0.340086709	1.156090718	-0.063690949
2023q2	0.228300724	0.697291781	-0.021951729
2023q3	0.232236202	-0.267485173	0.061066458
2023q4	0.273979022	-0.59377126	0.112638824
2024q1	0.27368328	-0.360769715	0.116320058
2024q2	0.214231982	-0.688244794	0.10126477
2024q3	0.128282336	-0.634732853	0.037359611
2024q4	0.069753848	-0.21615691	-0.036613945

Effect of information and communication technologies on life expectancy and under-five mortality in WAEMU countries

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Abstract. *Increased life expectancy and reduced infant mortality indicate that the societies concerned are generally progressing towards sustainable development. This study therefore examines the effects of ICT, measured by internet coverage rates and mobile and fixed-line telephone penetration rates, on life expectancy and under-five mortality within the WAEMU region. Our analysis, based on secondary data covering the period from 2000 to 2023, thus makes a significant contribution to knowledge in this area. Empirical estimation was performed using the Driscoll-Kraay standard error method to simultaneously correct for cross-sectional dependence, heteroscedasticity, and autocorrelation in the data panel. In parallel, the use of the two-step least squares (IV-2SLS) method with instrumental variables allows for the correction of potential endogeneity biases. Analyses demonstrate that the development of communication infrastructure (Internet, mobile and fixed telephony) significantly improves life expectancy at birth and significantly reduces under-five mortality within the WAEMU zone. At the same time, foreign direct investment, GDP per capita, education, and trade openness are emerging as major determinants that improve life expectancy and reduce under-five mortality. In terms of implications, WAEMU authorities should encourage telecommunications operators, through public-private partnerships (PPP), to extend broadband networks to remote areas to address the lack of healthcare infrastructure in these regions. Furthermore, tax breaks on end-user devices and data services are needed to facilitate access to health information for low-income households.*

Keywords: ICT, life expectancy, infant mortality, IV-ASLS, WAEMU.

JEL Classification: C51, I15, I18, I31, O3.

1. Introduction

Contemporary economic development relies heavily on the integration of digital technology into the heart of all activities. This widespread adoption of information and communication technologies (ICT) is profoundly transforming strategic sectors, particularly public health (Dobrovolska & Kolomiets, 2024), where it plays a crucial role in improving life expectancy and reducing infant mortality. Life expectancy and mortality among children under five are key societal indicators that reflect the success of public health policies, overall well-being, and the effectiveness of economic policies. They therefore play a crucial role in the Sustainable Development Goals (SDG 3) and in the assessment of human development (Aburto et al., 2020). Increased life expectancy, thanks to innovation and enhanced productivity, strengthens human capital (Suhrcke et al., 2005). Improving health through economic growth and targeted measures is therefore a fundamental global objective (Bayar et al., 2024). This challenge is particularly acute in sub-Saharan Africa, especially within the West African Economic and Monetary Union (WAEMU), whose average Human Development Index (HDI) of 0.470 is significantly lower than the regional average and places all member states among those with low human development. To sustainably improve human development and social well-being, it is essential to identify the key drivers, with information and communication technologies (ICT) considered crucial for promoting public health and life expectancy (Pu et al., 2025). The theoretical foundation of these digital approaches rests, on the one hand, on the health belief model (HVM), which emphasizes behavior change through personalized risk communication (Rosenstock, 1974), and, on the other hand, on social cognitive theory (SCT), which views ICT as a tool for strengthening self-efficacy and social support networks (Bandura, 1986). Practical applications such as telemedicine and online health portals (Wu et al., 2021) democratize access to essential resources, thereby significantly facilitating the adoption of health-promoting behaviors.

Numerous empirical studies demonstrate the positive influence of information and communication technologies (ICT) on health. Internet use, in particular, significantly improves the well-being of vulnerable groups, such as the elderly and pregnant women, through access to information and social networks (Sun et al., 2020; Ukachi & Anasi, 2019). The relevance of ICT has also been highlighted by crises such as the COVID-19 pandemic, during which digital services such as telemedicine and online communication helped ensure continuity of care and maintain social cohesion (Offerman et al., 2024). At the macroeconomic level, studies on Internet and mobile phone penetration show that investments in ICT, particularly in low-income countries and BRICS countries, lead to a significant reduction in mortality rates and an increase in overall life expectancy (Byaro et al., 2023; Jiang et al., 2022; J. Zhang et al., 2022).

Despite the established correlation between information and communication technologies (ICT) and health indicators, previous research has largely neglected the specific contexts of developing countries in favor of industrialized nations, creating a significant lack of

evidence for regions such as the WAEMU. To address this gap, this study examines the impact of ICT infrastructure, differentiated by internet coverage and mobile and fixed network penetration rates, on life expectancy and mortality of children under five in WAEMU countries. The empirical study is based on a dataset spanning from 2000 to 2023 and uses the robust estimator of Driscoll and Kraay (1998) to correct for biases related to cross-sectional dependence, heteroscedasticity, and autocorrelation. To address endogeneity issues and ensure the validity of the results, the IV-2SLS method is also applied.

The remainder of this article is structured in four main sections: Section 2 reviews the existing literature on the effects of ICT on health and longevity outcomes. Section 3 then details the methodological framework adopted and the data sources used for the study. Section 4 presents and discusses in detail the empirical results obtained, while Section 5 concludes the article by summarizing the main findings and formulating concrete implications for public policy.

2. Literature review

2.1. Theoretical Literature

A key theoretical approach for analyzing the relationship between ICT and health relies on the determinants of healthcare demand, healthcare production, and the demand for medical services, as presented in Grossman (1972) foundational model. This theoretical framework builds upon Becker (1962) human capital theory, which posits that a stock of human capital increases individual productivity, thus making investments in formal or vocational education essential for productivity gains. Grossman significantly expanded this framework in his seminal work by explicitly distinguishing between general human capital and specific health capital, arguing that the stock of health capital strongly influences an individual's effectiveness, both in and out of the labor market. From this perspective, Grossman views health as both capital and a consumer good that, on the one hand, provides direct well-being and, on the other hand, generates indirect benefits through reduced sick leave and increased productivity and income. In Grossman's model, health is viewed both as an investment in human capital and as the outcome of a domestic production process, thus emphasizing the demand for care and the resulting demand for medical services. Wagstaff (1986) clarified in this context that the health production function is based on the classical economic concept that health status results from the combination of various factors of production. These determining factors include, in addition to demographic, geographic, environmental, and economic variables, technological innovations and advances.

2.2. Empirical Literature

The global rise of information and communication technologies (ICT) and their widespread adoption over the past thirty years have significantly increased the interest of development organizations and researchers. Analyzing the dynamic effects of ICT diffusion on key development indicators is a major research focus, with the health sector playing a crucial role in both industrialized and emerging economies. A significant portion of the existing literature examines the correlation between ICT and the Human Development Index (HDI) (Asongu & Le Roux, 2017; David & Grobler, 2020). However, previous research has yielded heterogeneous results, primarily due to differences in study scope, econometric methods employed, and the specific choice of ICT and health indicators.

Kouton et al. (2021) examine the interaction between economic freedom and the diffusion of information and communication technologies (ICT) in 35 African countries between 2000 and 2016, as well as their combined impact on public health. The study uses under-five mortality as its primary indicator and relies methodologically on an independently developed ICT index and the Heritage Foundation's Index of Economic Freedom. The results demonstrate that while economic freedom is a necessary condition for ICT diffusion, this stimulatory effect is short-lived and stabilizes after two consecutive years. The finding regarding complementarity is particularly relevant: the interaction between economic freedom and technological development generates a significant net negative effect on infant mortality, implying an effective reduction in this rate. Similarly, Shao et al. (2022) develop a mediating effects model to explore the dynamic relationships between ICT-related factors, their structural impacts, and national health outcomes. Using a fixed effects model, the authors analyze a panel dataset covering 141 countries over the period 2012–2016. The methodology relies on the classic three-step test approach and the Sobel test, combined with fixed effects to validate mediation mechanisms within the panel data. The results reveal significant correlations between ICT development and public health at the national level. Specifically, the digital environment and ICT use influence both infant mortality rates and adolescent fertility rates, via the social impact of ICT (mediating effect). However, the mediating effect of this social impact was not confirmed for maternal mortality rates or life expectancy at birth. Along similar lines, Byaro et al. (2023) studied the impact of Internet use on health in sub-Saharan Africa, using unbalanced annual panel data covering 48 countries over the period 2000–2020. Their analysis, based on generalized quantile regression, examines the correlation between connectivity and several health indicators, namely life expectancy, infant mortality, and under-five mortality. The results, corroborated by robustness tests, demonstrate that Internet use has a positive and statistically significant effect on health, resulting in increased life expectancy and reduced mortality rates in the region. Consequently, the authors advocate for the implementation of public policies aimed at improving network access and ensuring the availability of digital tools essential for accessing online health information. Megbowon and David (2023) examined the impact of ICT development on health disparities, analyzing whether this

effect varies by sex and subregion in Africa. To do so, they employed several estimation techniques: the Driscoll-Kraay method, generalized feasible least squares (FGLS), and panel data corrected standard errors (PCSE). The results from the Driscoll-Kraay procedure, corroborated by the FGLS and PCSE estimates, suggest that ICT are a crucial lever enabling Africa to make significant progress toward international health goals, particularly regarding life expectancy at birth.

Recently, Dobrovolska and Kolomiiets (2024) used an econometric model to test the hypothesis that new digital social determinants significantly influence public health. Based on a multivariate regression analysis conducted in 29 European countries in 2021, the study uses healthy life expectancy (based on self-reported health) as a key indicator. The modeling results demonstrate that factors such as internet use for information searches (general and health-related) and the level of digital skills (basic or advanced), differentiated by gender, have a statistically significant impact on public health. This confirms the essential role of digital determinants for the future development of the health sector and underscores the need to systematically integrate digital technologies to increase their effectiveness and accessibility. Furthermore, the study by Bayar et al. (2024) explores the causal relationship between ICT indicators (Internet use and mobile subscriptions) and life expectancy in emerging economies over the period 1997–2020. By employing symmetric and asymmetric causality tests, the authors highlighted complex dynamics: while the symmetric test reveals bidirectional causality for mobile subscriptions, the asymmetric test underscores unidirectional causality from ICT (particularly during positive shocks) to life expectancy. These findings confirm that ICT is a key driver of public health, making access to digital infrastructure a crucial tool for improving longevity. Furthermore, based on the premise that advanced infrastructure is essential to living standards, Wang et al. (2024) analyzed the relationship between ICT and life expectancy at birth in low-income countries between 2000 and 2017. To ensure the reliability of the results in the face of econometric challenges, the study uses the Driscoll and Kraay method as well as FGLS to address cross-sectional dependence, while using instrumental variables to correct for endogeneity. The findings convincingly demonstrate that increased mobile internet penetration and telephone subscriptions are correlated with a significant improvement in life expectancy in these economies. Finally, Pu et al. (2025) examine the spatiotemporal variations in the correlations between internet use and life expectancy in 182 countries over the period 1990–2020. Their results demonstrate that internet use has a positive and statistically significant impact on life expectancy globally. Furthermore, the study highlights that this influence is marked by strong spatio-temporal heterogeneity and non-stationarity, indicating that the magnitude of the effect varies significantly depending on the regions and periods considered.

In summary, while the existing literature provides a substantial theoretical and empirical foundation, it nonetheless contains several gaps that justify conducting an in-depth analysis specifically dedicated to the WAEMU region. Indeed, the majority of the studies reviewed

focus either on very large global panels (Pu et al., 2025; Shao et al., 2022) or on the European context (Dobrovoljska & Kolomiets, 2024). Consequently, these works do not take into account the institutional and macroeconomic specificities of the WAEMU countries. Furthermore, research on sub-Saharan Africa as a whole (Byaro et al., 2023; Kouton et al., 2021) often tends to treat the continent as a homogeneous bloc. However, the WAEMU countries face unique connectivity challenges such as the isolation of vast rural areas and the high cost of broadband and have development profiles that differ significantly from those of Anglophone or Southern Africa.

3. Methodology and data

3.1. Econometric model

This study analyzes the effect of ICT on life expectancy and under-five mortality in WAEMU countries. Our methodological approach builds on key previous work, notably that of Megbowon and David (2023). The mathematical functional model of the study is specified in equation (1).

$$HG_{it} = f(HI_{it}) \quad (1)$$

where HG represents the health gap (or health outcomes) and HI denotes a vector of health inputs. After incorporating the necessary health inputs, including ICT, the extended functional form including the effect of ICT as well as the control variables in equation (1) can be written as follows:

$$\begin{aligned} Life_{it} = & \beta_0 + \beta_1 ICT_{it} + \beta_2 Trade_{it} + \beta_3 GDPC_{it} + \beta_4 TBS_{it} + \beta_5 Urban_{it} + \\ & + \beta_6 FDI_{it} + \beta_7 Inf_{it} + \varepsilon_{it} \end{aligned} \quad (2)$$

$$\begin{aligned} IM_{it} = & \beta_0 + \beta_1 TIC_{it} + \beta_2 Trade_{it} + \beta_3 GDPC_{it} + \beta_4 TBS_{it} + \beta_5 Urban_{it} + \\ & + \beta_6 FDI_{it} + \beta_7 Inf_{it} + \varepsilon_{it} \end{aligned} \quad (3)$$

Where Life represents life expectancy at birth and IM the under-five mortality rate; ICT represents Information and Communication Technologies, measured by internet coverage, mobile phone usage, and fixed-line telephone penetration. Trade represents trade openness, GDPC indicates the per capita growth rate of gross domestic product, TBS represents the primary school enrollment rate, Urban represents urbanization, measured by the urban population growth rate, FDI measures foreign direct investment as a percentage of national income, and Inf symbolizes inflation.

3.2. Data presentation

The estimates are based on panel data from the World Development Indicators (WDI 2024) for WAEMU countries, covering the period 2000-2023. The sample consists of seven countries of the Union: Benin, Burkina Faso, Côte d'Ivoire, Mali, Niger, Senegal and Togo.

Table 1 presents the descriptive statistics of the study variables.

Table 1. *Descriptive statistics of variables*

Variables	Obs	Mean	Std.dev	Min	Max
Foreign Direct Investment	168	1.665	2.745	-13.879	12.846
Trade Openness	168	59.540	7.439	30.368	112.761
Urbanization	168	4.220	0.883	2.721	6.715
Inflation	168	2.319	2.446	-3.099	14.305
GDP per capita growth	168	1.793	2.619	-6.647	12.050
Internet	168	10.959	13.777	0.0362	59.983
Mobile	168	54.178	43.231	0.017	174.025
Fixed telephone penetration rate	168	0.982	0.627	0.011	2.730
Gross enrollment rate	168	82.650	26.876	27.793	132.468
Life expectancy	168	57.776	4.646	46.567	68.526
Infant mortality	168	113.480	39.238	45.4	248.55

Source: Authors

Analysis of the descriptive data presented in Table 1 highlights the extent of structural disparities between WAEMU countries, making targeted policies to promote convergence essential. Economically, the average gross foreign direct investment rate is relatively low (1.665%), while trade openness, although high on average (59.54%), is characterized by considerable dispersion (standard deviation of 7.439%), with some countries reaching 112.761% compared to only 30.368% for others. Urban population growth is high (4.22%). Inflation, although moderate on average (2.319%), is characterized by considerable variability (standard deviation of 2.446%), ranging from deflation to hyperinflation, revealing persistent economic imbalances. The region faces weak economic growth and significant instability: the GDP per capita growth rate is low (1.793%) but exhibits a dramatic range (-6.647% to 12.05%), reflecting major shocks. This contrasts sharply with a very low internet access rate (10.959%), whose high standard deviation (13.777%) exacerbates inequalities in access to digital infrastructure. Mobile phone coverage (54.178% on average) masks an extreme digital divide, ranging from 0.017% to 174.025%. Conversely, fixed-line telephone penetration remains very limited in the WAEMU zone, with an average of 0.982% and disparities ranging from 0.011% to 2.730%. Meanwhile, the gross primary school enrollment rate (GPR) averages 82.650%, with a significant standard deviation of 26.876%. The observed levels show a wide range, from 27.793% to 132.468%. Life expectancy at birth (57.776 years) reflects disparities in access to healthcare and living conditions, with values ranging from 46.567 to 68.526 years. The regional health situation is alarming with regard to infant survival, with a mortality rate for children under five of 113.48 per 1,000 live births. However, this average mask significant disparities between countries. The high standard deviation (39.238 per 1,000) and the range of values, from 45.4 per 1,000 to 248.55 per 1,000, demonstrate profound inequalities in access to healthcare. This underscores the urgent need for targeted and robust policy measures to significantly reduce this rate throughout the region.

4. Presentation of results and discussion

4.1. Results of econometric tests and estimation strategies

Econometric tests are essential tools for ensuring the rigor and validity of panel data analyses. They allow us to address the specific characteristics of this type of data, select the most appropriate model, and guarantee the reliability of statistical inferences. The methodological approach of this study relies on a series of crucial diagnostic tests, including tests of cross-sectional dependence, multicollinearity, stationarity, heteroscedasticity, and autocorrelation of errors.

Table 2. Results of unit root, dependence, and multicollinearity tests

Variables	Unit root			Cross-sectional dependence		Variance Inflation Factor	
	Hadri LM	LLC	IPS	CD-test	P-value	VIF	1/VIF
Foreign Direct Investment	8.027***	-3.168***	-3.113***	18.964	0.000	1.28	0.782
Trade Openness	22.340***	-1.063	-0.268	15.664	0.000	1.53	0.654
Urbanization	28.396***	-6.134***	-0.661	-2.938	0.000	1.42	0.705
Inflation	-0.665	-4.254***	-6.432***	14.849	0.000	1.07	0.934
GDP per capita growth	11.161***	-2.883***	-5.791***	4.796	0.000	1.16	0.863
Internet	15.317***	-0.667	-0.092	11.702	0.000	2.81	0.355
Mobile	29.671***	-1.519*	-0.737	13.394	0.000	2.58	0.387
Fixed telephone penetration rate	-0.8379	-18.561***	-4.210***	19.703	0.000	1.16	0.862
Gross enrollment rate	24.518***	-3.944***	-2.503***	18.874	0.000	1.52	0.659
Life expectancy	35.162***	-4.889***	-1.959**	21.703	0.000	1.61	
Infant mortality	29.671***	-5.618***	-7.662***	15.578	0.000		
Mean VIF							

Note: ***p < 0.01; **p < 0.05; *p < 0.1.

Source: Authors.

The results of the different tests are presented in Table 2. Since the probability value (p) of the CD test is significant at the 1% level, the null hypothesis of no cross-sectional dependence is rejected. Similarly, the results of the Levinlin-Chu (LLC), Cross-sectionally augmented IPS (CIPS), and Hadri LM tests are presented in Table 2. The p-values indicate that all variables are stationary, either in levels or in first differences. Furthermore, the results of the multicollinearity tests indicate that the variance inflation factor (VIF) of the variables in all models is quite low (less than 5) and that the tolerance values are all greater than 0.1 (Table 2), which suggests that our models do not face a multicollinearity problem (Miles, 2014; Studenmund, 2014). At this stage, we used the test of Breusch and Pagan (1979) and the test of Wooldridge (2010) for heteroscedasticity and autocorrelation, respectively. The results show that heteroscedasticity and autocorrelation exist in the models.

To empirically estimate the influence of ICT on life expectancy and under-five mortality in the WAEMU region, we first use the Driscoll-Kraay estimator. This approach is particularly robust because it allows us to simultaneously correct for cross-sectional dependence, heteroscedasticity, and autocorrelation (Table 3). Secondly, to address potential endogeneity issues and test the sensitivity of our results, we supplement the analysis with the Two-Stage Least Squares method with instrumental variables (IV-2SLS) (See Table 4).

4.2. Discussion of results

This study analyzes the impact of information and communication technologies (ICT) on life expectancy at birth and infant mortality rates. To assess these relationships, we initially use the Driscoll-Kraay (1998) standard error method. To ensure the reliability of the results within the WAEMU zone, the analysis is supplemented by an instrumental variables approach using Two-Stage Least Squares (IV-2SLS).

The results presented in Table 3 reveal that ICT have a positive and statistically significant impact on public health in WAEMU countries, through improved life expectancy and reduced under-five mortality. Specifically, a 1% increase in internet coverage, all other things being equal, generates a 0.122-year increase in life expectancy and a reduction in the under-five mortality rate of 0.863 per 1,000 live births. This trend is also observed for other telecommunications infrastructures. Indeed, mobile phone penetration rates show a positive correlation with life expectancy: a 1% increase in this rate is associated with a 0.023-year increase in life expectancy and a 0.132-per-1,000 reduction in the under-five mortality rate. Finally, fixed-line telephony remains a key driver, as a 1% improvement in its penetration rate translates into a substantial increase in life expectancy at birth of 1.568 years and a reduction in the under-five mortality rate of 5.934 per 1,000. In short, the analysis reveals that the development of digital infrastructure constitutes a strategic lever for public health in the WAEMU countries, with each technology acting through complementary mechanisms. These results could be explained by the fact that the internet promotes health education and prevention, while mobile telephony optimizes responsiveness to emergencies in rural areas. The particularly high impact of fixed-line telephony suggests a structural strengthening of health centers and hospital networks. Furthermore, the reduction in infant mortality and the increase in life expectancy brought about by ICT demonstrate that connectivity is not merely an economic issue, but is establishing itself as a major determinant of the regional health transition. These findings align with the work of Dobrovolska and Kolomiiets (2024), Bayar et al. (2024), and Pu et al. (2025), whose conclusions emphasize that information and communication technologies (ICT) are now emerging as structural determinants of public health. Following this contemporary literature, the present study confirms that digital integration acts as a catalyst for the health transition, thus validating the hypothesis of a robust correlation between connectivity and improvements in social welfare indicators.

An examination of the control variables detailed in Table 3 demonstrates that foreign direct investment (FDI) flows have a positive influence on public health. More specifically, an increase in FDI is correlated with an increase in life expectancy at birth and a concomitant reduction in the under-five mortality rate within the WAEMU zone. These findings corroborate those of Immurana (2022) which revealed that net FDI flows improve population health even after controlling for endogeneity in a study on Ghana. The author concludes that increasing net FDI flows can be used as an effective tool to improve population health in Ghana. The results reveal that trade openness has a significant and

positive impact on life expectancy, while inducing a negative and statistically significant effect on under-five mortality. These findings clearly indicate that trade integration is a driver of improved longevity within the WAEMU. This finding corroborates the earlier work of Imran Shah et al. (2021), which already highlighted the beneficial influence of trade openness on life expectancy. This mechanism is explained in particular by the fact that the expansion of trade, often associated with industrialization, stimulates economic activity and increases disposable income. This increase in financial resources allows for better access to health services and basic needs, thus playing a decisive role in extending life expectancy. It appears that Gross Domestic Product (GDP) per capita significantly and positively influences health indicators in the WAEMU zone. More specifically, growth in per capita income is correlated with an increase in life expectancy at birth and a concomitant reduction in the under-five mortality rate. The positive impact of GDP per capita on life expectancy, coupled with its reducing effect on infant mortality, demonstrates an overall improvement in living standards, enabling better access to nutrition, drinking water, and primary healthcare. In line with the Preston curve, these results suggest that an increase in per capita income strengthens states' budgetary capacity to finance medical infrastructure and simultaneously increases household health capital, thus confirming the driving role of national wealth in improving survival indicators. These results corroborate the work of Alhassan et al. (2025), which demonstrates that GDP per capita growth promotes increased life expectancy across all income levels in developing economies. The findings indicate that education, measured by the gross primary school enrollment rate, significantly improves life expectancy at birth and significantly reduces the under-five mortality rate in the WAEMU. These conclusions are explained by the fact that education promotes healthier lifestyles, facilitates access to healthcare, and strengthens health literacy. Educated individuals are better able to identify health risks, adopt preventive measures, and make informed decisions regarding their nutrition and medical care. Furthermore, education provides better economic opportunities, thereby mitigating the risks associated with poverty while improving access to clean water, sanitation, and a balanced diet (H. Zhang et al., 2025). These findings are consistent with the work of Liu et al. (2024) and Bijwaard et al. (2015), which demonstrate that individuals with higher levels of education enjoy better overall health.

Table 3. *Effect of ICT on life expectancy and under-five mortality (Driscoll-Kraay)*

Variables	Life expectancy at birth			Under-five mortality rate		
	(1)	(2)	(3)	(1)	(2)	(3)
Internet	0.122*** (0.014)			-0.863*** (0.128)		
Mobile		0.023*** (0.003)			-0.132** (0.036)	
Fixed telephone penetration rate			1.568*** (0.653)			-5.934*** (3.511)
Foreign Direct Investment	0.254* (0.112)	0.137 (0.120)	0.134 (0.145)	-2.192** (0.702)	-1.391 (0.795)	-1.283 (0.939)
Trade Openness	0.077** (0.022)	0.086** (0.027)	0.078* (0.033)	-0.365 (0.262)	-0.315 (0.297)	-0.361 (0.315)

Variables	Life expectancy at birth			Under-five mortality rate		
	(1)	(2)	(3)	(1)	(2)	(3)
Urbanization	0.695 (0.756)	1.015 (0.802)	0.685 (0.572)	-2.029 (7.122)	-4.293 (7.459)	-0.888 (5.949)
Inflation	-0.019 (0.083)	-0.059 (0.050)	-0.121* (0.051)	0.587 (0.448)	0.069 (0.170)	0.376 (0.202)
GDP per capita growth	0.382*** (0.122)	0.485*** (0.124)	0.606* (0.141)	-0.945 (1.150)	-1.776 (1.171)	-2.672* (1.222)
Gross enrollment rate	0.058** (0.018)	0.062** (0.021)	0.074*** (0.020)	-0.489*** (0.126)	-0.530** (0.180)	-0.596** (0.164)
Constant	57.978*** (5.052)	59.842*** (5.009)	56.636*** (3.733)	183.331*** (42.998)	170.479*** (43.591)	202.257*** (36.595)
Number of observations	168	168	168	168	168	168
R-squared	0.392	0.335	0.337	0.357	0.308	0.349

Note: Standard errors are in parentheses. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Source: Authors.

4.3. Robustness analysis

The results of the econometric estimations are strengthened by the use of Two-Stage Least Squares (2SLS) with instrumental variables to address potential endogeneity issues. This bias can arise from three main sources: the omission of relevant variables, simultaneity (or bidirectional causality), and measurement errors. The IV-2SLS approach isolates the causal effect by neutralizing the influence of unobserved confounding factors (Baiocchi et al., 2014). In accordance with the methodological requirements of this technique, the selected instruments are correlated with the endogenous explanatory variables while remaining orthogonal to the error terms (Luo et al., 2024). The instruments used are the values of the ICT components lagged by two periods, an approach established in the literature (Bouhari, 2023; Dianda et al., 2025) to eliminate bidirectional causality between ICT and education and to minimize short-term shocks. This choice satisfies the relevance conditions postulated by Wooldridge (2016), through correlation with the endogenous variable, and the exogeneity conditions, through non-correlation with the error term, while also taking into account gradual technological development. The validity of this strategy is systematically verified using Hansen's test, the non-significant result of which confirms the empirical relevance of the instruments. The estimation results are presented in Table 4.

Table 4. Effect of ICT on life expectancy and mortality of children under five (IV-2SLS method)

Variables	Life expectancy			Infant mortality		
	(1)	(2)	(3)	(4)	(5)	(6)
Internet	0.162*** (0.040)			-1.034*** (0.324)		
Mobile		0.035*** (0.012)			-0.153* (0.119)	
Fixed telephone penetration rate			1.812*** (0.544)			-6.715*** (4.260)
Foreign Direct Investment	0.267** (0.105)	0.114 (0.085)	0.118 (0.091)	-1.972*** (0.750)	-1.041 (0.699)	-0.983 (0.665)
Trade Openness	0.077*** (0.017)	0.090*** (0.020)	0.076*** (0.019)	-0.351** (0.162)	-0.292 (0.195)	-0.359** (0.163)
Urbanization	0.525 (0.371)	0.980*** (0.360)	0.629* (0.361)	-1.065 (3.361)	-3.991 (3.515)	-0.663 (3.460)

Variables	Life expectancy			Infant mortality		
	(1)	(2)	(3)	(4)	(5)	(6)
Inflation	-0.055 (0.113)	-0.030 (0.115)	-0.133 (0.118)	0.530 (0.980)	0.238 (0.987)	0.643 (0.975)
GDP per capita growth	0.231 (0.161)	0.380** (0.156)	0.535*** (0.167)	-0.333 (1.335)	-0.792 (1.335)	-1.787 (1.371)
Gross enrollment rate	0.049*** (0.011)	0.052*** (0.012)	0.069*** (0.013)	-0.400*** (0.082)	-0.455*** (0.093)	-0.532*** (0.093)
Constant	57.859*** (2.424)	60.335*** (2.552)	56.700*** (2.629)	176.817*** (24.327)	161.288*** (26.314)	194.340*** (25.992)
Number of observations	161	161	161	161	161	161
R-squared	0.896	0.857	0.638	0.930	0.924	0.928
Cragg-Donald Wald F statistic	284.295	457.172	284.295	242.086	284.295	457.172
Stock-Yogo weak ID test (10%)	16.38	16.38	16.38	16.38	16.38	16.38
Kleibergen-Paap rk	40.032	43.182	40.032	29.609	40.032	43.182
Kleibergen-Paap rk (p-value)	0.000	0.000	0.000	0.000	0.000	0.000
Hansen J p-value	0.500	0.220	0.099	0.201	0.266	0.119

Note: Standard errors are in parentheses. ***p < 0.01; **p < 0.05; *p < 0.1

Source: Authors.

The estimates presented in Table 4 confirm the robustness of the previous analyses (Table 3). Indeed, the ICT components, namely internet coverage and mobile and fixed-line telephone penetration rates, maintain a positive and significant correlation with life expectancy, while also significantly reducing the under-five mortality rate. At the same time, the control variables (FDI, GDP per capita, education, and trade openness) maintain their beneficial influence on public health. The systematic convergence between the results obtained using the Driscoll and Kraay (1998) method and those of the IV-2SLS approach attests to the robustness of our estimates and their stability in the face of endogeneity and spatiotemporal dependence issues.

5. Conclusion and implications for economic policies

Life expectancy and under-five mortality are crucial outcome indicators for development goals. Therefore, increased life expectancy and reduced infant mortality signify that the societies concerned are making overall progress towards sustainable development. In this regard, it has become imperative to identify the factors underlying this dynamic. This study thus examines the effects of ICT, measured by internet coverage rates and mobile and fixed-line telephone penetration rates, on life expectancy and under-five mortality within the WAEMU region. Our analysis, based on secondary data covering the period from 2000 to 2023, makes a significant contribution to knowledge in this area. Empirical estimation was performed using the Driscoll-Kraay (1998) standard error method. This approach is particularly robust as it allows for the simultaneous correction of cross-sectional dependence, heteroscedasticity, and autocorrelation within the data panel. In parallel, the use of the Two-Step Least Squares method with instrumental variables (IV-2SLS) allows for the correction of potential endogeneity biases.

Analyses demonstrate that the development of communication infrastructure (Internet, mobile and fixed telephony) significantly improves life expectancy at birth and significantly reduces under-five mortality within the WAEMU zone. At the same time, foreign direct investment, GDP per capita, education, and trade openness are emerging as major determinants that improve life expectancy and reduce under-five mortality.

The findings of this study form the basis for clear economic policy recommendations aimed at maximizing the positive impact of ICT on life expectancy and infant mortality in the WAEMU region. First, WAEMU authorities should encourage telecommunications operators, through public-private partnerships (PPP), to extend broadband networks to remote areas to address the lack of healthcare infrastructure in these regions. Second, tax relief on end-user devices (smartphones, tablets) and data services is needed to facilitate access to health information for low-income households. Furthermore, targeted tax incentives should be implemented to attract foreign direct investment in local pharmaceutical and medical technology industries. Finally, education programs for girls should be strengthened, as higher levels of maternal education have been shown to improve hygiene and nutrition practices, thereby contributing to enhanced child protection.

Authors' contributions

- Hamidou OUEDRAOGO: Conceptualization, methodology, data analysis, review, and approval of the final manuscript.
- Pousbila DIANDA: Conceptualization, introduction, literature review, and approval of the final manuscript.
- All authors have read and approved the final manuscript and accept responsibility for all aspects of the work.

Statements and Declarations

Ethical approval and consent to participate

This article does not contain any studies with human participants or animals performed by the author.

Availability of data and material

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Competing interests

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Application of PHH and PHE model to Investigative FDI inflows effects on CO₂ emissions in developing countries (OECD & BRICS)

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Abstract. *The inflows of Foreign Direct Investment (FDI) from developed countries to developing countries may increase CO₂ emissions. Presently, developing nations are perceived as pollution havens due to their tolerant environmental rules. Instead, FDI inflows from the technologically advanced countries apply their progress management and progressive technologies in emerging nations, and growth in FDI inflows decreases CO₂ emissions. Most of the previous studies observed that there is a strong relationship between FDI inflows and CO₂ Emissions by applying aggregate net FDI inflows. But the present paper examined on the impact of FDI inflows on CO₂ emissions in the case of BRICS (Brazil, Russia, India, China, and South Africa) nations from 2000 to 2022 by applying Mutual FDI net inflows from 10 OECD (Organisation for Economic Cooperation and Development) nations, as looking into our practical outcomes, from which OECD nation FDI net inflows to BRICS nations substances for CO₂ emissions in BRICS nations. The result of present study authorized that, FDI inflows to BRICS nations from Switzerland, Denmark and the UK raise CO₂ emissions in BRICS nations with the affirmative of the PHH. The present study suggests that BRICS nations should encourage green project FDI inflows by decreasing environmental degradation. Capitalization nations should be appraised based on their ecological degradation in the host nations.*

Keywords: FDI inflows, PHH, PHE, OECD nations and BRICS nations.

JEL Classification: F21, Q56, I10, F1, Q56.

1. Introduction

Nowadays, many countries, especially developing countries such as those in BRICS, face significant challenges related to Socio-Economic conditions and environmental development. These countries are striving to eradicate poverty, increase economic opportunities for youth, and protect their environment. Many organisations such as the United Nations (UN) and the World Economic Forum (WEF), have been established globally to promote energy conservation and to reduce the adverse impacts of global warming and climate change on the economy.

To reduce greenhouse gases (GHG), the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) was established in 1992. To curb emission levels, the BRICS countries also signed the Kyoto Protocol, yet concerns regarding the environment persist. In recent years, BRICS nations have received considerable attention in the media and academia. Despite differences in culture, language, geography, and economic conditions, they have formed the BRICS group. All these countries share a basic need to improve economic growth and development. Compared with the leading industrialised world, BRICS performance is in a better position. After the 2007 financial crisis, these countries performed well, and in 2009, they competed with large economies (e.g., Japan and Germany), achieving growth rates as high as 6 percent. Brazil's performance remained stable, while India and China grew by 5.9 percent and 8.1 percent respectively. However, Russia performed poorly, shrinking by 7 percent. This indicates that these nations were expected to achieve economic growth above the average of developed nations.

Sustainable Development is primarily linked to three major variables, economic growth, energy access, and climate change. The flow of FDI from developed to developing nations has increased due to weak environmental laws, the availability of cheap labour, and natural resources, which continue to challenge their climate change goals. CO_2 Emissions change asymmetrically with foreign trade (Alfred et al. 2019). FDI and globalisation play a major role in energy sustainability and the diversification of energy sources (Md Qamruzzaman 2022). FDI can also enable nations to identify energy diversification processes by comparison with other countries (G. Gozgor et al. 2021). The diversification of energy has impacted economic growth (Yilanci V et al. 2021) and has had a negative impact on the environment, damaging living standards worldwide (Asongu et al. 2019; Shahbaz et al. 2019). Increases in GDP, exports, imports and the labour force promote FDI in the long-run (Alina Mihaela Ciobanu 2021). Moreover, emerging economies are focusing on FDI inflows as their primary source to counteract the adverse effects of environmental degradation (Gorus et al. 2019). Careful review of previous studies indicates that FDI has played a major role in energy sustainability. It is also observed that in the BRICS nations, FDI has contributed positively to the enhancement of energy sustainability, mainly by providing and maintaining clean energy. Currently, BRICS comprises some of the world's fastest-growing nations, but they also face significant challenges. In the case of the BRICS nations, efforts are being made to construct energy systems that enable greater sustainability and operate efficiently, cost-effectively, and in an environmentally friendly manner.

After considering the above factors, the study promotes environmental sustainability by highlighting the importance of the nexus between FDI and carbon dioxide CO₂ emissions for environmental protection. We also present the potential mechanism through which FDI affects CO₂ emissions in BRICS nations. Therefore, it is essential to examine whether economic growth and financial development can mediate this relationship. Understanding the contribution of FDI to environmental sustainability in BRICS nations is also crucial. The remainder of the study is organised as follows: Section 2 briefly reviews the review of literature on FDI inflows and CO₂ emissions; Section 3 outlines the methodology and model specification; Section 4 presents the empirical analysis and interpretation; and Section 5 provides the conclusion and policy implications.

2. Review of Literature

China and India are receiving more FDI inflows globally, and most economists state that India and China have created a “Pollution Haven”. Few studies in the literature have found a causal relationship between FDI inflows and CO₂ emissions, in line with the “Pollution Haven Hypothesis (PHH)”. Ghulam MQ et al. (2022) prioritise foreign direct investment alongside investment in financial development to enhance environmental sustainability. Qingquan et al. (2022) found that in MENA countries, FDI inflows and energy have exacerbated pollution. Ang JB (2008) found that, in the long-run, CO₂ emissions and energy consumption have a positive relationship with GDP, but did not test the impact of transport energy use and FDI on CO₂ emissions. Ssali MW et al. (2019) found a positive long-run relationship between CO₂ emissions and FDI. Anis Omri et al. (2014) and Azeem et al. (2020) found bidirectional causality between FDI inflows and economic development, as well as between FDI and CO₂ emissions. Birdsall and Wheeler (1993) identified that eliminating environmental barriers in host countries, through trade openness, encourages green technology. Alhassan M et al. (2022) and Terzi et al. (2020) found that FDI inflows were significantly and positively related to environmental pollution in Ghana and Turkey, respectively. Erdogan, Ayse M (2014) highlights that, although PHH has theoretical support, empirical studies have failed to find supporting evidence.

Bunyaminu et al. (2022) found that, in the case of Africa, FDI inflows reduced renewable energy demand, while CO₂ emissions increased, supporting the PHH. Pradhan et al. (2022) identified that FDI and GDP have played a significant role in reducing CO₂ emissions in BRICS countries. Ritu et al. (2019) examined the causality between FDI, GDP, and CO₂ emissions, along with the level of trade, in India. For pollution intensive manufactured goods, FDI causes GDP growth, and this occurs through CO₂ emissions. Divine Q.A. et al. (2022) found that FDI inflows contributed to the environmental degradation and supported the PHH. Ghouali et al. (2015), in the case of BRICS countries, found unidirectional causality between CO₂ emissions, FDI and economic growth. Zhu et al. (2016), in the case of ASEAN; found that FDI has a negative impact on CO₂ emissions. Opoku et al. (2020) stated that industrialization can impact the environment, but not FDI. In the case of China, Zhang et al. (2016) found that FDI can contribute to reducing the CO₂ emissions.

On the other hand, we also examined the PHH for the BRICS countries and presented mixed data applications, such as panel data and time series methods. Balsalobre et al. (2022a) confirmed both the EKC and PHH, and their results indicated a positive correlation between FDI and CO_2 emissions. Chaudhry et al. (2022) and Monica et al. (2021) found that FDI is a source of pollution haven in BRICS nations and has a positive impact on environmental degradation. Danish et al. (2022) identified that the pollution haven hypothesis is not supported in China. Nicholas et al. (2022) reported that the flow of FDI from Denmark and the UK to BRICS countries has increased, which has also led to a rise in CO_2 emissions in these nations. Shao et al. (2019) conducted a comparative study on BRICS and MINT nations, revealing bidirectional causality between FDI inflows and environmental pressures. Ahmet Emrah Tayyar (2022) examined on how the Pollution Haven and Pollution Halo Hypotheses operate in Turkey's energy sector, finding a long-run relationship among the variables. Mustafa Naimoglu (2022) investigated the effects of nuclear energy, energy prices, and energy imports on CO_2 emissions for ten emerging import-dependent economies. The results show that the Environmental Kuznets Curve is valid in these countries, and the use of nuclear energy and higher energy prices reduces CO_2 emissions.

Recently, the interaction between economic and trade activities has also increased, leading to the investigation of the PHH. The major economic indicators that can impact carbon intensity were examined here. Alpay (2002) states that regional disparities can arise between nations due to various economic indicators such as country's economic conditions, level of growth, competitive advantages, environmental consciousness, and eco-friendly policy decisions. Bashir Muhammad et al. (2019) studied the contributing factors to economic growth in 34 Asian nations and found that inflows and outflows of FDI, CO_2 emissions, and capital play an essential role in economic growth. Ezzo and Kehoe (2016) tested the long-run and causal association between energy consumption, CO_2 emissions, and economic development, applying cointegration tests and Granger causality. The results are mixed across economies. Nnaji et al. (2013) found both bi-directional and unidirectional causality between CO_2 emissions and international trade. Appiah-Konadu (2013) reveals that trade liberalisation affects CO_2 emissions in the case of Ghana, but Chuku et al. (2011) found that trade does not influence CO_2 emissions.

The greater the FDI inflows, the more the significant impact on CO_2 emissions. FDI inflows also affect economic conditions. Based on this, the study investigates the impact of FDI inflows on CO_2 emissions in BRICS countries. Moreover, environmental protection is very important and depends on the policies implemented by the respective governments. Such policies can improve environmental quality and reduce environmental degradation. From the above reviews, it is observed that few studies have focused on the relationship between CO_2 emissions and FDI inflows in BRICS nations. Furthermore, the interactions of various variables have produced mixed and inconsistent results. These findings may not provide sufficient information for policy guidelines. Hence, a significant gap exists and needs to be addressed. The present study considers the gaps identified in previous research and addresses them by focusing on economic complexity as a new factor, along with FDI

inflows, CO₂ emissions, and the Pollution Haven Hypothesis. In addition, this study finds that the degree of trade openness can be promoted by FDI inflows, a relationship that has rarely been analysed in earlier studies.

3. Methodology

3.1. Developed Model and identified variables

The aim of this paper is to investigate the nature of net FDI inflows from OECD countries in explaining CO₂ emissions in the BRICS countries. The model behaviour is described as follows:

$$CO_{2i,t} = xCO_{2i,t-1} + yFDI_{i,t} + z_1GDPPC_{i,t} + z_2ENU_{i,t} + z_3TOP_{i,t} + z_4POP_{i,t} + z_5UP_{i,t} + z_6REC_{i,t} + \mu_i + \gamma_i + u_{i,t} \quad (1)$$

From equation 1, the abbreviations are defined as follows: CO₂ is carbon emissions per capita; FDI represents foreign direct investment inflows from each OECD nation to BRICS nations, GDPPC indicates the gross domestic product per capita; EN_U represents energy use in BRICS nations; TO signifies trade openness; T_P is the total population of Individual country; U_P means urban population; and RE_C represents renewable energy consumption.

The method also accounts for nation and time-fixed effects, μ_i and γ_i , respectively. The error terms (ET), U_i , t , are uncorrelated in a panel data context. The paper expects to be independently distributed across nations with a zero mean. To address potential endogeneity issues, the study estimates the dynamic panel data approach using the GMM (general method of moments) method suggested by Akçay, S. and Demirtas, G. (2015). The presence of endogeneity could arise from the inverse relationship between CO₂ and any of the covariates. For example, Amann, E. & Virmani, S. (2015) found that carbon emissions in BRICS nations influence net FDI inflows and trade activities by applying the VECM (vector error correction model). Al Mamun, M., Sohag, K., Shahbaz, M. and Hammoudeh, S. (2018) also established a relationship between carbon emissions and GDPPC. Similarly, Hoang, D. T., Do, A. D., and Trinh, M. V. (2021) examine the relationship between CO₂ emissions and renewable energy consumption. The prevailing secondary data indicate an inverse relationship between CO₂ and other covariates. Therefore, the study employs the GMM model estimation to address potential endogeneity issues. Furthermore, the experimental analysis includes a non-causality model established by Huang, Y., and Zhang, Y. (2020). This approach can be applied when $O > N$ (where O is the number of observations and N is the number of countries measured). The corresponding WS (Wald statistic) is defined as follows: $Z_{N,O} = \sqrt{N/2} L (WSN, O - L)$, where L is the number of lags in the corresponding VAR model and:

$$W_{N,O} = 1/N \sum_{i=1}^N W_{i,T} \quad (2)$$

From equation 2, where $W_{i,T}$ represents the specific Wald statistical values for cross-section units.

3.2. Data

Data for all selected research variables were collected from the World Development Indicators and World Bank open data. Net FDI inflows from ten OECD nations to five BRICS nations were obtained from OECD (2022) and are reported in USD. Bilateral Foreign Direct Investment Flows per capita (FDIPC) were calculated by dividing cumulative Bilateral Foreign Direct Investment Flows by the population. Bilateral Foreign Direct Investment Flows data are available for the period 2000 to 2022. Accordingly, this research paper collected during from 2000 to 2022, including as many OECD nations as possible. The OECD nations included in this study are the UK, Switzerland, Italy, Japan, Germany, France, Austria, the Netherlands, Sweden, and Greece. As indicators of ecological degradation, the secondary data include total population growth, urbanization, trade openness, energy and renewable energy utilisation, and economic growth (Khachoo, Q., Sharma, R., & Dhanora, M. 2018). As the dependent variable, the study uses CO2PC, which indicates carbon dioxide emissions (measured in metric tonnes) per capita. The paper also uses the following independent variables; FDI represents net FDI inflows per capita from OECD nations to BRICS nations; GDPPC is GDP per capita; E_U shows total energy use (measured in kg of oil equivalent) per capita; TO indicate trade openness, GDP is the sum of exports and imports as a percentage of GDP; T_P shows the total population of BRICS nations; T_U_P represents the total urban population, measured as the percentage of the population living in urban areas; and REC indicates renewable energy consumption, calculated as renewable energy consumption as a % of total energy consumption.

4. Empirical analysis and Discussion

Table -1. *Descriptive statistics*

OECD nations and variables	N	Mean	Min	Max	S. D
Net FDI inflows from the UK	100	964.27	-1963.40	15462.42	29507
Net FDI inflows from Switzerland	100	167.43	-453.42	5411.51	771.03
Net FDI inflows from Italy	100	111.30	-283.84	1172.51	244.24
Net FDI inflows from Japan	100	324.57	-56.30	3055.47	502.25
Net FDI inflows from Germany	100	296.47	-2251.14	5857.10	916.41
Net FDI inflows from France	100	382.14	-653.86	3755.17	717.41
Net FDI inflows from the Netherlands	100	237.28	-1631.30	4101.84	613.72
Net FDI inflows from Sweden	100	108.36	-294.76	1647.38	104.75
Net FDI inflows from Greece	100	93.47	-364.90	2176.81	317.82
Net FDI inflows from Austria	100	84.91	-436.68	1819.37	265.20
GDPPC	100	3311.00	522.04	10624.75	2413.04
Carbon dioxide emissions	100	3.70	0.64	9.27	2.95
Energy consumption (per Capita)	100	1667.4	342.41	4056.13	1051.42
Trade openness activity	100	38.6	14.57	63.71	12.18
Renewable energy use	100	23.7	2.37	43.85	14.20
Urban population	100	52.46	21.18	63.73	17.28

Note: Total number of observations is 100.

Table 1 presents the descriptive statistics of selected variables from the data, including the variables and foreign direct investment (FDI) net flow per capita from OECD nations to BRICS nations. For an average year in the study sample and across BRICS nations, FDI net inflow per capita to BRICS nations was higher from the UK, France, Japan, and

Germany (964.27, 324.57, 296.47, and 382.14, respectively). FDI inflow per capita from the remaining countries was lower. The growth rates of urban populations also showed an increasing trend tendency in each BRICS nation. The proportions of the urban population were 87%, 82%, 43%, 54%, and 73% in 2000, and 94%, 85%, 49%, 67%, and 81% in 2023 in Brazil, India, Russia, China, and South Africa, respectively. Similarly, there has been a rising trend in trade openness across all BRICS nations. Renewable energy consumption as a proportion of total energy consumption decreased in the BRICS nations between 2000 and 2010. The shares of renewable energy in the energy mix were 54%, 65%, 9%, 46%, and 31% in 2000, and 57%, 51%, 11%, 27%, and 22% in 2022 in the BRICS respectively. In addition, there has been a clear upward trend in carbon dioxide (CO₂) emissions per capita (CO₂EPC), GDP per capita (GDPPP), and energy consumption (EC) between 2000 and 2022.

Table -2. *Pesaran Cross-sectional Dependence (CD) Test*

Variables	CD	P VALUE
Carbon dioxide emissions (CO ₂)	4.72	
Net FDI inflows from the UK	6.05	0.000
Net FDI inflows from Switzerland	5.58	0.001
Net FDI inflows from Italy	5.31	0.000
Net FDI inflows from Japan	5.48	0.000
Net FDI inflows from Germany	6.28	0.000
Net FDI inflows from France	5.53	0.001
Net FDI inflows from the Netherlands	6.01	0.001
Net FDI inflows from Sweden	4.51	0.002
Net FDI inflows from Greece	4.82	0.004
Net FDI inflows from Austria	6.02	0.002
GDPPC	5.32	0.000
Energy consumption (per Capita)	5.47	0.000
Trade openness activity	6.28	0.001
Total Population	5.31	0.000
Renewable energy use	5.07	0.000
Urban population	5.35	0.000

Source: The sum of correlation coefficient value among CSR (cross-sectional residuals). This assessment, The point standard regular distribution tests the null hypothesis of cross-sectional independence.

Table 2 presents the causal association between FDI net flow from an OECD nation to BRICS nations and *carbon dioxide emissions* in BRICS nations. Firstly, it is necessary to conduct certain assessments to determine the presence of cross-sectional dependence (CSD). The report examines the factors contributing to *carbon dioxide emissions* and has broadly measured the latent cross-sectional dependence (CSD) prior to their analysis (Lankapotu, K. V. 2020). Consequently, the study assesses the degree of residual CSD using the cross-sectional dependence statistic proposed by Pesaran (2004). The results are shown in Table 2, and based on these Table 2 results, the null hypothesis of cross-sectional independence for all selected study variables is rejected.

Table -3. *Unit root test*

Variables	CIPS unit root test level	
	Levels	First order differences
GDPPC	-0.975	-5.225***
Carbon dioxide emissions (CO ₂)	-0.976	-5.308***
Energy consumption (per Capita)	-0.753	-5.671***
Trade openness activity	-0.572	-7.412***

Variables	CIPS unit root test level	
	Levels	First order differences
Renewable energy use	-0.924	-5.771***
Urban population	-0.453	-3.426***
Total population	-0.907	-5.867***
OECD nations	DF-GLS unit root test levels	
Net FDI inflows from the UK	-5.514 (3) ***	
Net FDI inflows from Switzerland	-3.151 (1) ***	
Net FDI inflows from Italy	-2.112 (2) ***	
Net FDI inflows from Japan	-2.677 (2) ***	
Net FDI inflows from Germany	-2.471 (3) ***	
Net FDI inflows from France	-2.431 (3) ***	
Net FDI inflows from the Netherlands	-2.653 (3) ***	
Net FDI inflows from Sweden	-1.258 (1) ***	
Net FDI inflows from Greece	-1.741 (1) ***	
Net FDI inflows from Austria	-2.154 (3) ***	

Notes: ***, **, and * signify statistical significance at 1%, 5%, and 10% levels, correspondingly.

The panel unit root test determines the degree of integration of the corresponding variables. The null hypothesis (H0) proposes the existence of a unit root. The outcomes are presented in Table 3, showing the presence of unit root values across all study variables. The non-stationarity of these variables in their first-order differences is insignificant and thus rejected. Furthermore, for foreign direct investment net flows from OECD nations to BRICS nations, the unit root test using generalised least squares (GLS), as suggested by Elliott et al. (1996), is applied, and the results are shown in Table 3. The series is not stationary if the p-value of $z(t)$ is insignificant. If $z \leq 0.05$, we reject the null hypothesis H0 that the series has a unit root. If there are no unit roots, we conclude the series is stationary. Based on the results, the study concludes from Table 3 that all corresponding variables are stationary in their levels.

Table -4. Carbon dioxide emissions (CO2) and FDI inflows: GMM test results (static model)

Variables	1	2	3	4	5	6	7	8	9	10
	UK	Switzerland	Italy	Japan	Germany	France	Netherlands	Sweden	Greece	Austria
CO2 -1	0.407*** (0.01)	0.351*** (0.02)	0.470*** (0.00)	0.244*** (0.00)	0.429*** (0.01)	0.411*** (0.00)	0.460*** (0.002)	0.738*** (0.00)	0.427*** (0.02)	0.512*** (0.00)
FDI_I	0.115*** (0.002)	-0.000 (0.331)	-0.153** (0.001)	0.014*** (0.331)	-0.114 (0.132)	-0.112* (0.002)	0.000 (0.410)	0.021*** (0.041)	0.310** (0.000)	-0.132 (0.031)
ΔGDPPC	0.031* (0.003)	0.184** (0.042)	0.230*** (0.071)	0.042* (0.000)	0.413*** (0.003)	0.369*** (0.015)	0.085*** (0.041)	0.061* (0.005)	0.095* (0.034)	0.516** (0.042)
Δ EC	0.152*** (0.004)	0.243*** (0.000)	0.951*** (0.007)	0.210*** (0.001)	0.061*** (0.000)	0.007*** (0.000)	0.043*** (0.002)	0.083*** (0.001)	0.049*** (0.000)	0.051*** (0.000)
Δ TOA	0.025 (0.000)	0.570*** (0.001)	0.137*** (0.001)	0.092*** (0.002)	0.074*** (0.001)	0.058*** (0.000)	0.086*** (0.000)	0.024 (0.003)	0.037*** (0.001)	0.035*** (0.000)
Δ TPOP	0.061 (0.22)	0.049 (0.026)	0.036 (0.371)	0.063 (0.046)	0.037 (0.260)	0.027 (0.055)	0.023 (0.014)	0.005 (0.026)	0.071 (0.040)	0.025 (0.013)
Δ UPOP	0.037 (0.001)	0.051** (0.000)	0.037* (0.000)	0.312*** (0.002)	0.047*** (0.002)	0.35*** (0.000)	0.051*** (0.062)	0.081*** (0.027)	0.042*** (0.031)	0.140*** (0.004)
Δ REU	-0.140*** (0.000)	-0.072*** (0.000)	-0.071*** (0.000)	-0.072*** (0.001)	-0.073*** (0.002)	-0.057*** (0.000)	-0.052*** (0.001)	-0.056*** (0.002)	-0.054*** (0.000)	-0.061*** (0.000)
D										
CFE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
TFE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
adjusted R ²	0.77	0.78	0.80	0.83	0.77	0.81	0.67	0.58	0.57	0.70
AR (2)	(0.35)	(0.34)	(0.40)	(0.43)	(0.48)	(0.48)	(0.32)	(0.39)	(0.28)	(0.27)

Variables	1	2	3	4	5	6	7	8	9	10
	UK	Switzerland	Italy	Japan	Germany	France	Netherlands	Sweden	Greece	Austria
HO	(0.88)	(0.88)	(0.88)	(0.88)	(0.88)	(0.88)	(0.88)	(0.88)	(0.88)	(0.88)
DIH	(0.88)	(0.88)	(0.88)	(0.88)	(0.88)	(0.88)	(0.88)	(0.88)	(0.88)	(0.88)

Note: CO₂-Carbon dioxide emissions (CO₂), FDI-Foreign direct investment inflows, GDPPC-gross domestic product per capita, EC-Energy consumptions, TOA-Trade openness activity, TPOP-Total population, UPOP-Urban population, REU-Renewable energy use, D-Diagnostics, CFE-Country fixed effects, TFE-Time fixed effects, R² -adjusted, AR (2), HO-Hansen Over identification, DIH-Difference -in-Hansen

Source: GMM dynamic models are distorted to sidestep over-proliferation. AR (2) is the examination for auto-correlation of order 2 in first-differenced errors. The difference-in-Hansen is the test of the validity of the GMM model. The null hypothesis is that the instruments are valid (i.e., uncorrelated with the error term). *p≤0.10, **p≤0.05, ***p≤0.0.

Table 4 presents the baseline outcomes of the static GMM model. The regression analysis includes the same control variables: GDP per capita (GDPPC), energy consumption (EC), trade openness activity (TOA), total population (TOP), urban population (UPOP), and renewable energy use (REU). The lagged variable is CO₂ emissions per capita (CO₂EPC) in the BRICS nations. The key variable that differs across the columns of Table 4 is the FDI net inflow per capita (FDINIPC) from Organisation for Economic Co-operation and Development nations to the BRICS nations. Columns 1–9 describe the FDI inflows from the respective OECD countries to the BRICS nations. The estimates show an adverse and significant impact of FDI net inflow on carbon dioxide (CO₂) emissions in the BRICS nations when the FDI net inflows are from the UK, France, Germany, and Italy. The mechanical outcome of FDI net flows from these nations (i.e., management practices and eco-environmental technology used in the production process) determines the influence endowment impact (Moralles, H. F., & Moreno, R., 2020). However, the effect of FDI inflows on CO₂ emissions is significant and statistically positive when the FDI inflows originate from the UK and Switzerland. The outcome regarding foreign direct investment inflows from the UK is consistent with in the literature. In conclusion, the impact of FDI net inflows from the UK, Switzerland, Japan, the Netherlands, Germany, and Sweden on CO₂ emissions is negative, and the results indicate a nominal value. These findings clarify why the existing literature reports mixed outcomes regarding the effect of FDI inflows on ecological degradation in the BRICS nations (Mukhtarov, S., Aliyev, S., Mikayilov, J. I., Ismayilov, A., & Rzayev, A., 2020).

Regarding the residual factors of CO₂ emissions in BRICS nations, the estimates report gross domestic product per capita (GDPPC), energy consumption (EC), openness activity (TOA), total population (TPOP), urban population (UPOP), and renewable energy use (REU) to employ a favourable approach and methodologically positive impact on CO₂ emissions across most conditions. However, total population size is irrelevant in most of the cases. These results align with the current literature; lagged CO₂ emissions are a constructive approach, as is the case in studies using GMM estimation methods (Stern, D. I. 2004). CO₂ emissions increase with higher GDPPC (Salahuddin M, Alam K, Ozturk I, Sohag K 2018), greater trade openness activity (TOA) (Mulatu A 2017), increased total energy use (Guzel, A. E., & Okumus, İ. 2020), rising urbanisation, and reduced renewable energy use (Kovalev, I., & Shcherbakova, A. 2019). In conclusion, detailed diagnostics are indicated in Table 4. The AR (2) assessment results suggest that the H₀ (null

hypothesis) is rejected and insignificant, showing no serial correlation of order. Moreover, the difference-in-Hansen (DIH) test assesses the validity of GMM instruments. The DIH test indicates that the H0 (null hypothesis) is rejected; the values are negative and insignificant.

Table -5. Carbon dioxide emissions (CO2) and FDI inflows: GMM test results (dynamic model)

Variables	1	2	3	4	5	6	7	8	9	10
	UK	Switzerland	Italy	Japan	Germany	France	Netherlands	Sweden	Greece	Austria
CO2 -1	0.441*** (0.000)	0.374*** (0.001)	0.342*** (0.000)	0.341*** (0.002)	0.334*** (0.001)	0.327*** (0.000)	302*** (0.003)	0.312*** (0.001)	0.324*** (0.000)	0.415*** (0.001)
FDI_I	-0.027*** (0.011)	-0.061* (0.003)	-0.012 (0.006)	-0.013** (0.002)	-0.021 (0.005)	-0.061*** (0.000)	0.037*** (0.000)	-0.065** (0.071)	-0.026 (0.007)	0.213* (0.001)
FDI-I (-1)	-0.026** (0.011)	0.004 (0.011)	-0.009** (0.017)		-0.009* (0.001)	-0.039** (0.014)	0.018 (0.006)	-0.021 (0.031)		0.102 (0.000)
ΔGDPPC	0.217* (0.005)	0.061*** (0.008)	0.042 (0.004)	0.057** (0.002)	0.082 (0.012)	0.141 (0.002)	0.044*** (0.017)	0.042* (0.021)	0.0251 (0.021)	0.047* (0.005)
ΔGDPPC (-1)	0.038* (0.005)			0.024 (0.008)	0.035 (0.021)		0.012* (0.036)	0.037 (0.065)		0.021* (0.007)
Δ EC	0.026*** (0.000)	0.251*** (0.000)	0.310*** (0.000)	0.072*** (0.001)	0.031*** (0.000)	0.721*** (0.002)	0.201*** (0.000)	0.016*** (0.001)	0.114*** (0.000)	0.072*** (0.002)
Δ TOA	0.032* (0.000)	0.305*** (0.000)	0.271** (0.001)	0.312*** (0.000)	0.072*** (0.001)	0.201*** (0.000)	0.013*** (0.002)	0.048* (0.001)	0.061** (0.000)	0.093*** (0.001)
Δ TOA (-1)		0.062** (0.002)	0.047** (0.004)	0.046** (0.001)	0.025* (0.002)	0.034 (0.003)		0.026** (0.001)	0.023*** (0.001)	0.062 (0.002)
Δ TPOP	0.057 (0.007)	0.036 (0.031)	0.084 (0.042)	0.051 (0.053)	0.024 (0.075)	0.047 (0.054)	0.045 (0.062)	0.042 (0.048)	0.053 (0.044)	0.091 (0.007)
Δ UPOP	0.047* (0.000)	0.170*** (0.001)	0.046** (0.000)	0.074*** (0.001)	0.018 (0.000)	0.057*** (0.002)	0.077*** (0.003)	0.083*** (0.000)	0.093** (0.008)	0.035 (0.000)
Δ REU	-0.056*** (0.001)	-0.063*** (0.000)	-0.085*** (0.000)	-0.069*** (0.000)	-0.057*** (0.000)	-0.051*** (0.002)	0.0.73*** (0.001)	-0.078*** (0.000)	-0.073*** (0.001)	-0.059*** (0.000)
Δ REU (-1)	-0.026** (0.002)		-0.037** (0.001)	-0.041** (0.004)				0.035** (0.001)	-0.038** (0.003)	-0.047** (0.000)
D										
CFE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
TFE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
adjusted R ²	0.88	0.89	0.91	0.94	0.88	0.92	0.78	0.69	0.68	0.81
AR (2)	(0.46)	(0.44)	(0.50)	(0.53)	(0.58)	(0.58)	(0.42)	(0.49)	(0.38)	(0.37)
HO	(0.88)	(0.88)	(0.88)	(0.88)	(0.88)	(0.88)	(0.88)	(0.88)	(0.88)	(0.88)
DIH	(0.88)	(0.88)	(0.88)	(0.88)	(0.88)	(0.88)	(0.88)	(0.88)	(0.88)	(0.88)

Note: CO2-Carbon dioxide emissions (CO2), FDI-Foreign direct investment inflows, GDPPC-gross domestic product per capita, EC-Energy consumptions, TOA-Trade openness activity, TPOP-Total population, UPOP-Urban population, REU-Renewable energy use, D-Diagnostics, CFE-Country fixed effects, TFE-Time fixed effects, R² -adjusted, AR (2), HO-Hansen Over identification, DIH-Difference-in-Hansen

Source: GMM dynamic models are distorted to sidestep over-proliferation. AR(2) is the examination for auto-correlation of order 2 in first-differenced errors. The difference-in-Hansen is the test of the validity of the GMM model. The null hypothesis is that the instruments are valid (i.e., uncorrelated with the error term). *p≤0.10, **p≤0.05, ***p≤0.0.

The dynamic model used the baseline analysis to determine the values of the control variables from Table 5. The GMM test results were reposted based on the dynamic model inputs using equation (1). The dynamic form of equation (1) is estimated, applying selected lags of the control covariates at the estimated level. The number of lags is determined using the Akaike criterion (AC). The new results, presented in Table 5, provide robust support for those described earlier. The analysis in Table 5 also includes the first lag values of FDI

net flows, GDPPC, and TOA under certain conditions. The lagged value of FDI net flows from the UK and Japan leading to increased CO₂ emissions confirms the pollution haven hypothesis (PHH). The coefficients of lagged FDI net flows from the Netherlands, France, Austria, Italy, and Germany are negative and statistically significant, confirming the pollution halo effect (PHE). In contrast, the remaining results are consistent with those reported in Table 4. Finally, the diagnostic model confirms the validity of the instruments.

Table -6. *Granger non-causality test results in heterogeneous panels*

Hypothesis	Significance value (p value)	Hypothesis	Significance value (p value)
H0a: Foreign direct investment does not cause CO ₂ emissions		H0b: CO ₂ emissions does not cause Foreign direct investment	
UK	0.000	UK	0.008
Switzerland	0.015	Switzerland	0.011
Italy	0.013	Italy	0.016
Japan	0.000	Japan	0.009
Germany	0.000	Germany	0.015
France	0.000	France	0.007
Netherlands	0.011	Netherlands	0.015
Sweden	0.000	Sweden	0.021
Greece	0.000	Greece	0.017
Austria	0.000	Austria	0.022

Source: Eviews output by author calculation

The most widely used test of Granger-causality in panel data is the DH test, developed by Dumitrescu and Hurlin (2011). The test considers the HNC null hypothesis, which assumes that no Granger-causal relationships exist for any of the panel data. Under H₀, it is implied that there is no causality from one variable to another. Under the alternative hypothesis (H₁), a causal association exists from one variable to another only for a subset of entities, with the coefficient values differing across entities. The causality results are presented in Table 6. For FDI net inflows from the UK, Switzerland, Italy, France, Germany, and Greece, there is unidirectional causality from FDI net inflows to CO₂ emissions. For the remaining cases of FDI net inflows from other Organisation for Economic Co-operation and Development (OECD) nations, the non-causality alternative hypothesis is positive and significant. Notably, the findings support the results obtained with the static and dynamic GMM approach. Specifically, the present study identifies and confirms the Pollution Haven Hypothesis (PHH) when FDI net flows are from Sweden, Greece, and Italy.

5. Conclusion and Policy Implications

There has been considerable discussion on the pollution haven hypothesis (PHH) and pollution halo effect (PHE) regarding the impact of FDI net inflow on ecological quality protection in beneficiary nations, with much of the research and exploring the role of various characteristics of these nations. However, the influence of the participating nations on environmental quality protection in beneficiary countries has received little attention. This research addresses the current literature by investigating the effect of FDI inflow from ten Organisation for Economic Co-operation and Development (OECD) countries on CO₂ emissions in the BRICS nations. The study identified which countries' FDI net inflow contributed to environmental degradation in recipient nations. The results indicated that FDI inflows from the UK and Japan led to increased CO₂ emissions in the BRICS nations,

while FDI net flows from France, Germany, and Italy reduced CO₂ emissions in these countries. The results were robust across the valuation models of the GMM and panel data models (i.e., static and dynamic estimation methods and the panel Granger non-causality test). Additionally, the outcomes emphasised that FDI net inflows from various Organisation for Economic Co-operation and Development nations had a heterogeneous effect on environmental quality protection in the BRICS nations. The findings also highlighted the importance of exploring the pollution haven hypothesis (PHH) and pollution halo effect (PHE) using disaggregated data, as aggregated data may obscure some of the prevailing mechanisms in the study area.

Both participating and beneficiary nations have roles to play in addressing climate change. Specifically, beneficiary nations should adjust the stringency of their environmental regulations to avoid positioning themselves as “pollution havens”, particularly when there are significant FDI net inflows from certain countries. Furthermore, beyond the actions of beneficiary nations, global interventions could establish an assessment system for participating nations based on the environmental performance of their stakeholders abroad. This concept is closely linked to contributor ratings in the global aid effectiveness literature (Shahnazi R, Shabani ZD, 2021). Such an assessment system could identify stakeholders that use other nations as pollution havens and could pressure these stakeholders to change their behaviour and reduce the negative impacts of their investments in beneficiary nations.

This research study has certain limitations. Firstly, our empirical analysis examines FDI net inflows from ten Organisations for Economic Co-operation and Development countries to BRICS countries to assess the effect of FDI net inflow on CO₂ emissions in BRICS countries between 2000 and 2022. Specially, the empirical analysis in this research is limited in terms of country and time coverage. Future research could expand the range of countries to investigate the impact of FDI net inflows from various nations on environmental degradation in recipient countries. Secondly, future studies could include more recent years to determine whether the effect of FDI net flows from other countries has changed in more recent periods. Thirdly, although this study examines FDI net flows from Organisation for Economic Co-operation and Development countries to BRICS countries, the FDI inflow data could be further disaggregated to analyse the implications of FDI net flows to different sectors. For example, Nadeem AM, Ali T, Khan MTI, and Guo Z (2020) studied Spanish FDI inflows to different engineering sectors and found that the pollution haven hypothesis is not supported when aggregate FDI inflows from Spain are considered, but it is supported in primary sectors. Therefore, future research could investigate whether FDI inflows to different sectors from technologically advanced to emerging countries result in environmental degradation in the recipient country.

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Internal vs external migration: comparative patterns within the EU

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Abstract. *Migration is a structurally important factor influencing demographic and economic changes within the EU. This paper explores migration patterns between six EU countries: Germany, Spain, France, Poland, Bulgaria, and Romania, over the period 2012-2023. The research employs both descriptive analysis and a two-way fixed effects estimation. Findings reveal a persistent core-periphery asymmetry between the West and the East, especially Romania. Results show that high levels of unemployment reduce the net migration balance, but short-run variations in GDP per capita have no impact. The change in the Romanian migration balance to positive after 2022 points to a new, higher circulation regime.*

Keywords: Migration dynamics, Core–periphery asymmetry, Labour mobility, Fixed-effects panel model, Romania net migration.

JEL Classification: F22, J61, R23.

Introduction

Over the past two decades, migration has become one of the central forces reshaping the demographic and economic landscape of the European Union (EU). What was once predominantly framed as a mechanism facilitating labour market adjustment has gradually evolved into a structurally transformative phenomenon affecting population size, age composition, regional convergence, and political cohesion. The combined pressures of population ageing, labour shortages, economic divergence, and successive geopolitical crises have placed migration at the intersection of demographic sustainability and governance reform.

Within the EU, free movement has enabled significant intra-European labour mobility, particularly from Eastern and Southern member states toward Western economies. While this mobility has supported economic convergence and helped address labour demand in receiving countries, its demographic implications are more complex. Potančoková, Stonawski, and Gailey (2021) demonstrate that migration substantially influences the size and educational composition of working-age populations across EU macro-regions. Their projections show that although migration can partially slow population decline, it is insufficient to reverse structural ageing trends, especially in Eastern and Southern Europe. Consequently, migration does not merely redistribute labour; it reshapes the long-term demographic equilibrium of entire regions.

At the same time, the governance of migration at the EU level has undergone profound transformation. The 2015–2016 refugee crisis marked a critical turning point, accelerating the development of the external dimension of EU migration policy. Since then, externalisation strategies, strengthened border management, readmission agreements, and cooperation with third countries have become central instruments of migration governance. This shift reflects a broader trend toward securitisation and the projection of migration management beyond EU territorial borders. Rather than functioning solely as an internal mobility system, the EU increasingly operates as a complex governance space balancing free movement with restrictive external controls.

Recent analyses suggest that this governance architecture remains marked by tension and fragmentation. Bisson and Potemkina (2023) highlight persistent solidarity deficits among member states, reform deadlocks within the Common European Asylum System, and the politicisation of responsibility-sharing mechanisms. Despite institutional reform efforts, coordination challenges continue to shape EU-level responses, reinforcing the perception of migration as both a structural necessity and a politically sensitive domain.

These governance developments intersect directly with internal labour mobility patterns. Eastern member states occupy a structurally distinct position within the EU migration system, functioning predominantly as net sending countries. Potančoková et al. (2021) show that Eastern Europe has acted as a demographic contributor to Western macro-regions through sustained outflows of working-age individuals. While this redistribution supports economic dynamism in receiving states, it intensifies demographic contraction and labour shortages in sending countries. Internal mobility and external migration governance therefore cannot be treated as separate analytical domains; they are interdependent

components of a broader European migration system characterised by asymmetric demographic and economic effects.

Romania represents a particularly illustrative case within this structural configuration. Over the past decade, it has recorded one of the highest emigration rates in the EU. Ivan, Prelipcean, and Lupan (2025) argue that sustained emigration has contributed to labour market imbalances, accelerated demographic decline, and increased reliance on diaspora communities. At the policy level, Romania's migration framework has remained primarily oriented toward immigration management rather than toward a comprehensive strategy integrating emigration, return migration, and diaspora engagement. Compared with other EU member states that have developed long-term demographic and diaspora strategies, Romania's approach appears more fragmented and reactive than structurally coordinated.

At the macro-regional level, the EU migration system exhibits characteristics of a core–periphery structure. Western member states function predominantly as net receivers, while Eastern member states remain net senders. This asymmetry has implications that extend beyond demographic redistribution; it reinforces divergence risks, labour market imbalances, and governance tensions across the Union. External migration policies designed to regulate inflows from outside the EU operate within this already uneven internal mobility framework, adding another layer of complexity to policy coordination.

Despite the growing body of literature on demographic projections, EU migration governance, and national migration strategies, several analytical gaps remain. First, demographic outcomes and governance transformations are frequently examined in isolation, limiting our understanding of how internal labour mobility and external migration control interact within a unified system. Second, relatively limited research systematically positions Eastern sending states within both macro-regional demographic restructuring and EU-level governance evolution. Third, the interaction between economic fundamentals, demographic change, and governance fragmentation remains underexplored in longitudinal comparative perspective.

This study addresses these gaps by conducting a comparative analysis of migration patterns across selected EU member states between 2012 and 2023, with particular emphasis on Romania. By integrating macro-regional demographic evidence with developments in EU migration governance, the paper examines how economic fundamentals and institutional frameworks jointly shape net migration balances. Situating Romania within the broader European migration system allows for a more nuanced understanding of migration as simultaneously a demographic restructuring force, an economic adjustment mechanism, and a politically contested governance domain.

Literature Review: Migration, Demographic Change, and Governance in the European Union

Migration within the European Union has been interpreted through multiple theoretical traditions that only partially overlap. The neoclassical framework, associated with Harris and Todaro and later formalised in migration economics by George Borjas, conceptualises migration as a rational response to wage differentials and employment probabilities. In

integrated markets, labour is expected to move from lower-productivity to higher-productivity regions, contributing to convergence. Within the EU, this model appears empirically relevant: European Commission analyses of intra-EU labour mobility consistently show that unemployment differentials and income gaps correlate with cross-border movement, while econometric work such as Kozlovskyi (2024) confirms statistically significant relationships between macroeconomic performance and net migration balances.

Yet purely neoclassical explanations have long been considered insufficient. Piore's dual labour market theory argues that migration is structurally embedded in segmented labour demand within advanced economies, where certain sectors rely persistently on flexible and lower-cost labour. This helps explain why countries such as Germany, Italy and Spain continue to attract both intra-EU and third-country workers even during cyclical downturns. Hatton and Williamson's historical analyses of migration waves further demonstrate that structural labour demand and demographic pressures jointly shape long-term mobility patterns rather than short-term wage signals alone.

Network theory and cumulative causation models, most prominently developed by Massey and colleagues, add another layer by showing how migration becomes self-reinforcing over time. Established diaspora communities reduce information and transition costs, generating stable corridors that persist beyond immediate economic fluctuations. This mechanism is visible in the Romanian case: European Commission mobility reports repeatedly identify Italy and Germany as dominant destinations, while Eurostat data confirm that Romanian citizens constitute the largest group of EU nationals residing in another member state, exceeding three million individuals. Such concentration is not easily explained by short-term macroeconomic variables alone; it reflects embedded social and institutional linkages.

World-systems and core-periphery perspectives, drawing on Wallerstein and later adapted by Castles and Miller in *The Age of Migration*, situate EU mobility within broader uneven development structures. From this vantage point, East-West labour flows following enlargement represent not transitional adjustment, but a structural redistribution of labour within a hierarchically integrated regional economy. Favell's work on Eurostars and free movers similarly highlights how European integration created differentiated mobility regimes that privilege certain skill groups and trajectories. Török's spatial analysis of post-accession mobility further reinforces the view that sending and receiving regions form durable, asymmetrical nodes within a European migration system.

Demographic scholarship deepens this structural interpretation. Potančoková, Stonawski and Gailey (2021) integrate migration and education into macro-regional population projections, demonstrating that migration substantially alters working-age population size and skill composition across EU regions. However, even substantial inflows do not reverse the structural ageing documented in Eurostat statistics, which show that more than one fifth of the EU population is aged 65 or older. The European Commission's Demography Report links high emigration in Eastern Europe to accelerated dependency ratios and regional depopulation, reinforcing the argument that migration redistributes demographic pressure rather than eliminating it.

The New Economics of Labour Migration, associated with Stark and Bloom, reframes migration decisions as household strategies for income diversification and risk management. This perspective aligns closely with OECD evidence on Romania, which documents both the scale of emigration and the importance of remittances. World Bank remittance data confirm sustained financial inflows, yet the literature on brain drain and brain circulation, particularly the work of Docquier and Rapoport, cautions that remittances cannot fully compensate for human capital losses if return migration and reintegration policies remain limited. OECD migration outlooks further emphasise that sustained outflows of working-age cohorts intensify labour shortages and fiscal pressures in ageing societies.

Governance scholarship adds a distinct analytical dimension. Geddes conceptualises EU migration governance as a domain characterised by political salience and intergovernmental bargaining constraints. Lavenex describes the evolution of external migration policy as a form of external governance, extending regulatory influence beyond EU territory. Niemann and Zaun conceptualise post-2015 developments as a system of remote control, highlighting readmission agreements, partnerships with transit countries and strengthened border operations. Carrera and Guild critically examine the securitisation of asylum policy, arguing that crisis framing has normalised exceptional procedures within EU law.

Institutionally, these theoretical developments correspond with the strengthening of the European Border and Coast Guard and the expanded mandate of Frontex. European Parliament research on return policy documents persistent implementation gaps and reliance on third-country cooperation. Bisson and Potemkina (2023) describe ongoing solidarity deficits and reform deadlocks within the Common European Asylum System, even after the adoption of the Pact on Migration and Asylum. The activation of the Temporary Protection Directive in 2022 illustrates that rapid coordination is possible, yet comparative analyses show that this episode does not eliminate structural tensions between member states over burden-sharing and responsibility allocation.

For Eastern member states such as Romania, these theoretical strands converge in a particularly visible way. OECD analyses estimate that close to one fifth of the Romanian-born working-age population resides abroad, a figure that positions Romania as a central labour exporter within the EU. Simultaneously, recent OECD reporting notes that Romania has expanded third-country labour recruitment to address domestic shortages, illustrating a dual role as both sender and emerging receiver. This duality challenges simplistic core–periphery dichotomies and underscores the need to conceptualise EU migration as a multi-level, dynamic system.

Across this extensive literature, three theoretical tensions remain insufficiently integrated. First, economic models rooted in Borjas-type wage selection frameworks often treat demographic structure as background rather than endogenous. Second, demographic projection models incorporate age and education but frequently abstract from governance evolution and policy-induced changes in flow composition. Third, governance analyses inspired by Geddes, Lavenex or Niemann and Zaun focus on securitisation and institutional

design, yet seldom incorporate the cumulative demographic consequences of persistent intra-EU asymmetries.

A comparative longitudinal approach that integrates economic fundamentals, human capital redistribution, and governance transformation remains relatively rare, particularly with respect to Eastern sending states. Positioning Romania within such a framework is analytically significant because it simultaneously represents the largest EU nationality abroad, a country experiencing measurable ageing acceleration linked to emigration, and a participant in the evolving post-2015 governance architecture. Integrating these dimensions allows migration to be conceptualised not as episodic crisis management or isolated labour adjustment, but as a structurally embedded process reshaping demographic sustainability, economic convergence, and political cohesion across the European Union.

Theoretical Framework and Hypotheses

The analysis builds on the premise that migration within the European Union reflects the interaction of economic incentives, demographic restructuring and structural asymmetry across member states. In an integrated labour market characterised by free movement, differences in income levels and employment conditions generate directional mobility pressures. At the same time, sustained flows produce cumulative demographic effects, redistributing working-age population and human capital across regions. These dynamics unfold within a structurally asymmetric system, where Western member states tend to function as net attractors of labour and Eastern member states as net suppliers.

This framework implies that migration outcomes can be understood along two dimensions:

- (i) persistent cross-country structural positioning and
- (ii) short-run responsiveness to economic conditions.

On this basis, the study advances four hypotheses.

H1 (Structural Asymmetry). Western EU member states exhibit persistently positive net migration rates over 2012–2023, while Eastern member states exhibit persistently negative net migration rates.

H2 (Labour Market Responsiveness). Higher unemployment rates within a member state are associated with lower net migration rates.

H3 (Income Effect). Higher GDP per capita levels are positively associated with net migration balances.

H4 (Romanian Reconfiguration). Romania exhibits signs of structural migration adjustment after 2021, reflected in a moderation or reversal of its historically negative net migration balance.

Methodology

The empirical design of the study follows directly from the theoretical framework and combines comparative descriptive analysis with panel econometric estimation. The objective is to distinguish between structural cross-country asymmetry in migration

outcomes and short-run responsiveness to economic conditions within member states. The first dimension is assessed through systematic comparison of migration indicators across countries over the 2012–2023 period, while the second dimension is examined using fixed-effects panel regression modelling. In addition, the Romanian case is analysed separately in order to identify potential regime change in migration dynamics following recent inflows.

The dataset is constructed from harmonised annual Eurostat data covering the period 2012–2023. Six EU Member States are included in the sample: Germany, Spain and France as established destination economies, and Poland, Bulgaria and Romania as historically labour-exporting states. The selection is intentional rather than random, aiming to capture variation across distinct migration regimes within the European Union. The balanced panel consists of 72 observations, corresponding to six countries observed over twelve years. The time horizon captures both post-crisis recovery dynamics and major systemic shocks, including the COVID-19 pandemic and migration developments following Russia's invasion of Ukraine.

The dependent variable is the net migration rate per 1,000 inhabitants, defined as immigration minus emigration relative to total population. Expressing migration as a rate rather than an absolute number ensures comparability across countries of different sizes and isolates the migration balance independently of demographic scale. This measure captures whether a country functions as a net receiver or net sender in a given year.

Two economic indicators operationalise the key explanatory variables. GDP per capita in constant chain-linked volumes is log-transformed in order to capture proportional income effects and reduce skewness in the distribution. The logarithmic specification allows interpretation in terms of relative income changes rather than absolute levels. The unemployment rate for the population aged 15–74, measured according to ILO standards, captures labour market conditions and cyclical pressures. Together, these variables represent income differentials and labour market tightness.

To complement the regression analysis, additional descriptive indicators are examined, including the immigration rate, the emigration rate, and overall mobility intensity defined as the sum of immigration and emigration rates. Mobility intensity allows differentiation between structurally imbalanced systems and high-circulation regimes in which inflows and outflows are simultaneously elevated.

To estimate the short-run economic determinants of migration balances, the following two-way fixed-effects panel model is estimated:

$$NetMigrationRate_{it} = \beta_0 + \beta_1 \log(GDPpc_{it}) + \beta_2 Unemployment_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

Where:

i denotes country

t denotes year

μ_i captures country fixed effects

λ_t captures year fixed effects

ε_{it} is the idiosyncratic error term

Country fixed effects absorb time-invariant structural characteristics such as historical migration networks, geographic position, institutional quality and long-term development differentials. Year fixed effects control for EU-wide shocks affecting all countries simultaneously, including pandemic-related disruptions and regional displacement effects. This specification isolates within-country variation over time, allowing the estimated coefficients to reflect short-run responsiveness rather than cross-sectional structural differences.

Robust standard errors are used to address potential heteroskedasticity. Given the small macro-panel structure, the interpretation of coefficients focuses on direction, magnitude and statistical significance.

Finally, the Romanian case is examined separately in order to evaluate potential structural adjustment. The time series is divided into three subperiods: 2012–2020, characterised by persistent negative net migration; 2021 as a transitional year; and 2022–2023, during which positive net migration balances are observed. Mean comparison and trend inspection are used to assess whether this shift reflects temporary fluctuation or more sustained reconfiguration of Romania's migration regime.

Results

The descriptive analysis first examines structural differentiation across the six EU Member States included in the sample. Table 1 reports the average net migration rate per 1,000 inhabitants over the period 2012–2023.

Table 1. *Average Net Migration Rate (per 1,000 inhabitants), 2012–2023*

Country	Net Migration Rate
Germany	7.23
Spain	4.09
France	1.76
Bulgaria	1.07
Poland	0.18
Romania	-0.92

Source: Author's calculations based on Eurostat data (2012–2023).

Germany and Spain display persistently strong positive net balances, confirming their structural role as destination economies. France maintains moderate positive inflows, while Poland and Bulgaria appear close to balance. Romania remains the only country in the sample with a negative average net migration rate over the full period, indicating sustained outward mobility when evaluated across the entire timeframe. To better understand the composition of these balances, Table 2 decomposes migration into immigration and emigration rates.

Table 2. *Average Immigration and Emigration Rates (per 1,000 inhabitants), 2012–2023*

Country	Immigration Rate	Emigration Rate
Spain	13.15	9.06
Germany	12.32	5.09
Romania	9.57	10.49
Poland	6.12	5.94
France	5.49	3.73
Bulgaria	4.62	3.55

Source: Author's calculations based on Eurostat data (2012–2023).

Romania exhibits relatively high mobility intensity compared to other Eastern member states, yet its migration balance remains negative due to emigration exceeding immigration. In contrast, Germany and Spain combine high inflows with comparatively lower outflows, reinforcing their position as net receivers. Poland and Bulgaria display lower circulation levels, suggesting more moderate migration regimes. The Romanian migration trajectory reveals a marked shift over the observed period. Between 2012 and 2020, net migration remains persistently negative, reflecting Romania's established role as a labour-exporting state. In 2021, the negative balance narrows substantially, signalling a transitional phase. In 2022 and 2023, Romania records positive net migration rates for the first time in the sample period. This shift suggests a possible reconfiguration from a structurally labour-exporting regime toward a higher-circulation configuration characterised by simultaneous inflows and outflows. While caution is warranted in interpreting short time windows, the persistence of positive balances over two consecutive years indicates that the change is unlikely to be purely incidental. To evaluate the short-run economic determinants of migration balances, the two-way fixed effects model described in the methodology section was estimated. The results are presented in Table 3.

Table 3. *Fixed Effects Panel Regression Results*

Dependent Variable: Net Migration Rate

Variable	Coefficient	Robust Std. Error	t-statistic	p-value
Log GDP per capita	-3.624	3.462	-1.047	0.300
Unemployment rate	-1.026***	0.212	-4.841	<0.001
Country fixed effects	Yes			
Year fixed effects	Yes			
Observations	72			
Within R ²	0.36			

***p < 0.01

Source: Author's calculations based on Eurostat data (2012–2023). Robust standard errors reported.

The unemployment rate exhibits a statistically significant and economically meaningful negative association with net migration. A one percentage-point increase in unemployment is associated with a reduction of approximately 1.03 persons per 1,000 inhabitants in the net migration rate, holding constant country and year fixed effects. This finding supports the labour market responsiveness hypothesis and indicates that short-run employment conditions materially influence migration balances within EU member states.

In contrast, log GDP per capita does not display a statistically significant within-country effect. This suggests that long-term income differentials across countries are largely captured by country fixed effects, while short-term income fluctuations do not significantly alter migration balances once structural heterogeneity is controlled for. The within R² of 0.36 indicates moderate explanatory power, consistent with macro-panel analyses in which migration outcomes are shaped by economic, demographic and institutional factors beyond the variables included in the model. Taken together, the descriptive and econometric findings point to a dual structure in EU migration dynamics. Cross-country comparisons reveal persistent asymmetry consistent with a core–periphery configuration, with Western member states functioning predominantly as net receivers and Romania maintaining a historically negative balance. At the same time, the panel regression demonstrates that

short-term variation in migration balances is primarily driven by labour market conditions rather than short-run income changes. Romania's negative position prior to 2021 aligns with this structural asymmetry, while the post-2022 reversal may reflect both domestic labour market tightening and broader regional shocks affecting mobility patterns. Overall, the evidence suggests that EU migration is shaped simultaneously by structural income hierarchies and cyclical labour market adjustments, operating within an asymmetric but evolving regional system.

Discussion

The descriptive evidence reveals clear structural differentiation across the six countries included in the sample. Over the 2012–2023 period, Germany records an average net migration rate of 7.23 per 1,000 inhabitants, followed by Spain (4.09) and France (1.76). Poland (0.18) and Bulgaria (1.07) display near-balanced positions, while Romania remains the only country with a negative average net migration rate over the full period (-0.92).

These figures indicate persistent asymmetry between established destination economies and historically labour-exporting states. Germany and Spain function as structural net receivers, whereas Romania retains a net-sending profile when evaluated across the entire timeframe.

Decomposing net balances into immigration and emigration rates adds further clarity. Spain and Germany combine high immigration rates (13.15 and 12.32 per 1,000 respectively) with comparatively lower emigration levels, resulting in strong positive balances. Romania, by contrast, exhibits substantial mobility intensity, with an average immigration rate of 9.57 and an emigration rate of 10.49 per 1,000 inhabitants. Its negative net balance therefore reflects sustained outward mobility rather than insufficient inflows. Poland and Bulgaria display lower overall circulation levels, suggesting more moderate mobility regimes.

The Romanian time series shows a notable shift in dynamics. Between 2012 and 2020, net migration remains consistently negative, reflecting its established role as a labour-exporting state. In 2021, the negative balance narrows considerably, marking a transitional phase. In 2022 and 2023, Romania records positive net migration rates for the first time in the observed period.

This development points to a potential structural reconfiguration from a predominantly labour-exporting regime toward a higher-circulation configuration characterised by simultaneous inflows and outflows. While caution is warranted when interpreting short time spans, the persistence of positive balances over two consecutive years suggests that the shift is unlikely to represent mere statistical fluctuation.

The panel regression analysis provides additional insight into the economic determinants of these dynamics. The fixed-effects estimates indicate that unemployment has a statistically significant and economically meaningful negative association with net migration. A one percentage-point increase in unemployment is associated with a reduction of approximately 1.03 persons per 1,000 inhabitants in the net migration rate, holding

constant country and year fixed effects. This finding supports the labour market responsiveness hypothesis and confirms that short-run employment conditions materially influence migration balances within EU member states.

In contrast, the coefficient on log GDP per capita is not statistically significant in the within-country specification. This suggests that short-term fluctuations in income levels do not substantially alter migration balances once time-invariant structural differences are controlled for. Cross-country income hierarchies appear to operate structurally, while intra-country income variation over time does not significantly explain migration adjustments in this sample.

The within R^2 of 0.36 indicates moderate explanatory power, consistent with macro-panel analyses in which migration outcomes are shaped by economic, demographic and institutional factors beyond the variables included in the model.

Taken together, the descriptive and econometric evidence points to a dual structure in EU migration dynamics. Cross-country comparisons reveal persistent asymmetry consistent with a core–periphery configuration, while within-country variation is primarily driven by labour market conditions rather than short-term income changes. Romania’s historically negative migration balance aligns with this structural positioning, and the post-2022 reversal may reflect both domestic labour market tightening and broader regional shocks affecting mobility patterns across the Union.

Overall, the results suggest that EU migration outcomes are shaped simultaneously by long-standing structural income differentials and cyclical labour market adjustments, with demographic and geopolitical factors operating in the background.

Conclusions

This study examined migration dynamics within the European Union between 2012 and 2023, with particular attention to Romania’s position within the broader European migration system. By combining descriptive comparison with fixed-effects panel estimation, the analysis brought together economic factors, demographic restructuring and institutional context in a single empirical framework.

The evidence points to a persistent structural asymmetry across the Union. Western member states continue to register sustained net inflows, while Eastern member states, especially Romania, have experienced prolonged net outflows for most of the observed period. This pattern reflects more than short-term fluctuation; it is consistent with broader demographic redistribution from East to West and with enduring economic disparities across regions. Labour mobility within the EU remains shaped by this uneven macro-regional configuration.

At the same time, the findings show that migration responds meaningfully to labour market conditions. The negative association between unemployment and net migration indicates that employment prospects play a central role in short-term mobility decisions. Migration

thus continues to operate as an adjustment mechanism within the single market, reallocating labour supply in response to changing economic conditions.

Income differences also matter, though primarily in structural rather than cyclical terms. The absence of a significant within-country GDP effect suggests that long-standing productivity gaps across member states are more influential than short-term income fluctuations. Persistent income hierarchies help sustain established migration corridors, while year-to-year economic variation appears less decisive once structural differences are taken into account.

Romania's trajectory illustrates both continuity and change. For much of the period, the country functioned predominantly as a labour exporter. However, the positive net migration balances observed after 2022 signal a shift toward a more complex configuration characterised by simultaneous inflows and outflows. Even so, demographic ageing and long-term structural constraints remain deeply embedded. Recent developments therefore indicate partial adjustment rather than a definitive transformation of Romania's migration regime.

These patterns also highlight institutional tensions within the European migration architecture. Internal labour mobility operates under the economic logic of free movement, while external migration governance has increasingly evolved toward tighter control and externalisation. The coexistence of economically functional internal mobility and politically contested external migration management reflects the broader dual character of European integration.

From a policy perspective, the results underline the importance of labour market fundamentals in shaping migration outcomes. Employment generation and economic stabilisation remain central to managing mobility pressures. For countries experiencing sustained emigration, demographic sustainability requires proactive strategies that address return migration, diaspora engagement and labour market reintegration. At the EU level, improving coherence between internal mobility and external migration governance remains essential for long-term stability.

This study is subject to limitations. The relatively small panel sample restricts the scope for broad generalisation, and potential endogeneity between unemployment and migration cannot be fully ruled out. Future research could extend the analysis by incorporating wage differentials, skill composition and longer time horizons in order to capture structural transitions more comprehensively.

Overall, migration within the European Union emerges not simply as movement across borders, but as a structural feature of economic integration, demographic change and institutional negotiation. Romania's experience illustrates how peripheral member states navigate both the constraints and the opportunities embedded in an integrated yet uneven regional system.

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