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Analyzing the Direction of the Causal Relationship between Economic Growth and Human Development in Algeria Using Python and Advanced Time Series Techniques

تحليل اتجاه العلاقة السببية بين النمو الاقتصادي والتنمية البشرية في الجزائر

باستخدام لغة بايثون وتقنيات السلاسل الزمنية المتقدمة

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Abstract:

This study investigates the directional causality between economic growth and human development in Algeria over the period 2000–2024, moving beyond the conventional empirical literature that predominantly focuses on correlation or long-run association. The originality of this research lies in its adoption of an integrated econometric framework based on advanced time series techniques (ARDL, Toda–Yamamoto causality, and ECM), implemented using Python, while explicitly accounting for institutional and social factors as well as major structural shocks (the 2014 oil price collapse and the COVID-19 crisis). The empirical findings demonstrate that economic growth in Algeria does not exert an automatic causal impact on human development unless it is balanced, inclusive, and institutionally supported, thereby offering novel empirical evidence that challenges the growth-centered assumptions prevailing in much of the existing literature.

Keywords: Economic Growth, Human Development, Causality Analysis, Time Series, Python.

JEL Classification Codes: O1, O4, C32, I3, F43

ملخص:

تهدف هذه الدراسة إلى تحليل اتجاه العلاقة السببية بين النمو الاقتصادي والتنمية البشرية في الجزائر خلال الفترة 2000–2024، متجاوزةً المقاربات التقليدية التي تكتفي بقياس الارتباط أو العلاقة طويلة الأجل. وتتميّز هذه الدراسة بأصالتها من خلال اعتماد منهج قياسي متكامل قائم على تقنيات السلاسل الزمنية المتقدمة *(ARDL*، *Toda–Yamamoto* ، *ECM)* المطبّقة باستخدام لغة *Python*، إلى جانب إدراج متغيرات مؤسساتية واجتماعية وتحليل فترات الصدمات الهيكلية (أزمة النفط 2014 وجائحة كوفيد–19). وتُظهر النتائج أن النمو الاقتصادي في الجزائر لا يُحدث أثرًا سببيًا مباشرًا على التنمية البشرية إلا إذا كان نموًا متوازنًا ومدعومًا بالحوكمة الفعالة والاستثمار الاجتماعي، وهو ما يقدّم إضافة نوعية للأدبيات التي غالبًا ما تفترض وجود علاقة تلقائية بين النمو والتنمية.

كلمات مفتاحية: النمو الاقتصادي، التنمية البشرية، تحليل السببية، السلاسل الزمنية، بايثون

تصنيفات JEL : O1, O4, C32 , I3 , F43

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INTRODUCTION:

Despite the extensive empirical literature examining the relationship between economic growth and human development, most existing studies have primarily focused on measuring correlation or long-run association, while paying limited attention to the direction and conditionality of causality. In the Algerian context, economic growth has often been driven by exogenous factors, particularly hydrocarbon revenues, raising critical questions regarding its ability to translate into sustained improvements in human development outcomes.
Accordingly, the main research question of this study is formulated as follows:

Does economic growth in Algeria causally contribute to human development, or does its impact remain limited in the absence of balanced and inclusive growth supported by institutional and social factors?

To address the research question, the study tests the following hypotheses:

Main Hypothesis :
Economic growth in Algeria does not exert a statistically significant impact on human development unless it is balanced and inclusive, and supported by institutional and social factors such as education and health expenditure and governance quality
Sub-Hypothesis 1
There exists a positive correlation between economic growth and human development in Algeria; however, this correlation does not necessarily imply a direct causal relationship
Sub-Hypothesis 2
There is no unidirectional causality running from economic growth to human development over the entire study period
Sub-Hypothesis 3
Macroeconomic and institutional variables , such as unemployment, inflation, social expenditure, and governance quality , play a crucial role in explaining the dynamics of human development in Algeria
Sub-Hypothesis 4
The direction and strength of the causal relationship between economic growth and human development vary across major economic shocks, particularly the 2014 oil price collapse and the COVID-19 pandemic

I. Theoretical Framework :

1. Theoretical Framework and Related Literature

1.1 Economic Growth and Human Development: Conceptual Linkages
The relationship between economic growth and human development has always been a key area in the field of development economics. Classical economic growth models argue that an augmentation in the per capita income results in an improvement in the standard of living in terms of increased consumption, government revenues, and provision of basic services. According to these models, economic growth is an essential ingredient for development, is

anticipated to take place as an indirect result of an increase in income levels (Barro, 1996; Solow, 1956).

Nevertheless, such a 'growth-oriented approach to development' has received growing criticism from other models of development, such as the 'human development approach,' which contends that 'the increase in income does not necessarily produce improvements in the condition of people's welfare.' The 'human development approach,' launched by Sen in 1999 and implemented by the 'United Nations Development Programme,' a 'specialized agency within the United Nations system,' defines development not merely in terms of increased income but in terms of 'the expansion of people's capabilities.
As a result, the theory literature distinguishes between growth-led human development and human development-led growth. Growth-led human development asserts that economic growth occurs prior to improvements in health outcomes, education, and standard of living, while human development-led growth asserts that human investment capacity can serve as an impetus for economic growth (Ranis, Stewart, & Ramirez, 2000). The above insight, which is two-way, also means that the relationship between growth and development is conditionally dependent and.

1.2 The Transmission Channels between Economic Growth and Human Development

The influence of economic growth on human development is transmitted through several channels, which work to different extents depending on the country and over time.

1.2.1 Income and Employment Channel

Income growth forms the most direct link between economic growth and human development. Increased per capita GDP may improve access to services available to these poor communities, such as health care, clean water, and education. However, it has been shown that this channel breaks down when growth occurs together with high unemployment, income inequality or labour market segmentation (Fields 2001). In this situation, no translation of growth.

1.2.2 The Channel of Public Expenditure

The links between economic development and the raising of funds for government to spend on important sectors (healthcare, education, social protection) is due to the fact that as economies grow, so do their fiscal capacities. Through the theory of endogeneity, it can be hypothesised that public investment in human capital is ultimately reflected in an increase in productivity and hence solidifies the foundations for a sustainable development (Lucas, 1988). The effectiveness of the public expenditure channel, however, is dependent on a government's priorities with respect to fiscal policy and the efficiency of its public expenditure. When an economy's revenues are dependent on resource extraction, volatility associated with the production and exportation of natural resources will often create uncertainty and limit the government's ability to sustain its social expenditures, thus weakening the link between growth and development (Gelb, 1988).

1.2.3 The Channel of Macroeconomic Stability

In order for growth to benefit society, macroeconomic instability—characterised by high levels of inflation or prolonged periods of unemployment—must not exist. Inflation decreases the purchasing power of real income, and typically has a greater impact on society's most disadvantaged. Unemployment removes the ability to obtain a source of economic security and employment stability. The consequences of either of these factors, as the World Bank (2005) has shown, is that growth, in combination with macroeconomic instability, tends to produce lower quality human development indicators.

1.2.4 The Institutional and Governance Channels for Development

Through institutional improvement and, on-going good governance, institutions continue to play their critical role as the mediators of economic growth to human development. Institutions provide better governance that increases the efficiencies of policy implementation, reduces the occurrence of misallocation of resources, and improves the ability of governments to allocate existing public revenues to develop the economy. According to Acemoglu and Robinson (2012), inclusive institutions represent a direct correlation to the continued improvement of human welfare from economic growth; whereas, weak governance creates incentives for rent seeking behaviour and creates inefficiencies in the spending of public revenue, thus decreasing the social return of growth.

1.3 Structural Shocks, Growth Volatility, and Human Development

In addition to structural shocks occurring in developing economies from time to time, the connection between growth and human development in developing nations is further changed by the presence of structural shocks. External shocks to the economy (such as falling commodity prices and global health crises) alter the economic base of a country and, consequently, negatively affect the progress of social advancement through its effect on the volume of economic development. In an economy that is highly dependent on natural resource commodities, the effects of fluctuating commodity prices on the economy can lead to a breakdown of the long-term connection between income earnings and human development (Auty, 2001).The COVID-19 pandemic has reinforced this insight by revealing the vulnerability of development outcomes to sudden economic disruptions. While GDP contractions were widespread, countries with stronger health systems, social protection mechanisms, and institutional resilience were better able to preserve human development gains (UNDP, 2020).

These considerations underscore the importance of adopting analytical frameworks capable of capturing non-linear dynamics, structural breaks, and conditional causality. Rather than assuming a stable long-run relationship, recent theoretical and empirical work emphasizes the need to assess whether growth exerts a causal influence on human development only under specific institutional and macroeconomic conditions.

1.4 Positioning of the Present Study

Building on this theoretical foundation, the present study departs from the conventional literature by focusing explicitly on the direction and conditionality of causality between economic growth and human development. Instead of assuming that growth automatically leads to development, the analysis evaluates whether such an effect exists in the Algerian context and whether it depends on macroeconomic stability, social investment, and governance quality. This approach aligns with recent calls in the development literature to move beyond correlation-based analyses toward more nuanced causal assessments (Ravallion, 2012).

II. Data Preparation and Descriptive Analysis

2.1 Importing libraries :

Figure 01 : libraries for python

Importing the necessary libraries

In [1]:

```
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
from statsmodels.tsa.stattools import adfuller
from statsmodels.tsa.api import VAR
from statsmodels.tsa.ardl import ARDL
from statsmodels.stats.diagnostic import het_breuschpagan
import statsmodels.api as sm
pd.set_option('display.float_format', '{:.4f}'.format)
```

Source : output python

The open source programming language Python was utilized in this study for time series analysis by utilizing some Python libraries through their advanced functionality to efficiently manipulate and model time series data. The NumPy and Pandas libraries provided functionalities for performing numerical computation and structured manipulation of data. The main function for manipulating data structured in the time index was provided by these two libraries, whereby time series econometric models were created using the Statsmodels library to simulate time series using classical as well as modern econometric modeling techniques (i.e., ARDL, VAR, VECM, cointegration tests, etc.). In addition to the Statsmodels Library for creating econometric models, some basic statistical calculations and optimization techniques were conducted through the utilization of the SciPy library. Furthermore, the visualization capabilities of Matplotlib and Seaborn were used to visualize temporal patterns, trends, and

dynamic relationships between variables and to integrate these libraries to create a complete and sound basis for advanced analyses of time series.

2.2 Data cleaning :

Table 01 : dtype data cleaning

```
In [5]: df.isnull().sum()
```

Out [5]:

	0
year	0
hdi	0
cpi	0
exchange_rate	0
gdp_pc_usd	0
inflation	0
unemployment	0
edu_exp	0
health_exp	0
governance	0
oil_price	0

dtype: int64

Source : output python

Prior to conducting the econometric analysis, a data cleaning procedure was performed to ensure the quality and reliability of the dataset. The dataset was examined for missing values, duplicate observations, and inconsistent entries that could bias the results of time series modeling. The diagnostic checks revealed that all variables contained zero missing values and no anomalous observations, indicating that the dataset was already clean and well-structured. Consequently, no additional data imputation or correction techniques were required, and the dataset was deemed suitable for advanced time series estimation and inference.

The dataset covers annual observations for Algeria over the period 2000–2024 (24 observations).

The variables include:

- Human Development Index (HDI)
- Real GDP per capita (GDP_pc_real)
- Inflation rate
- Unemployment rate
- Education expenditure

- Health expenditure
- Governance effectiveness
- Oil price (control variable)

Missing values were checked and no missing observations were detected after interpolation (sum of NA = 0 for all variables).
Real GDP per capita was computed by deflating nominal GDP using the CPI, ensuring consistency in real terms.

Table 02 : Descriptive statistics indicate

In [12]:
```
df.describe()
```

Out [12]:

	year	hdi	cpi	exchange_rate	gdp_pc_usd	inflation	unemployment	edu_exp	health_exp	governance	oil_price
count	24.0000	24.0000	24.0000	24.0000	24.0000	24.0000	24.0000	24.0000	24.0000	24.0000	24.0000
mean	2011.5000	0.7179	115.7500	92.3163	4211.0208	4.4583	14.4896	6.1171	4.5325	-0.5592	66.1696
std	7.0711	0.0328	36.9953	25.0003	1326.0496	2.4404	5.9338	1.1193	1.2031	0.1519	28.1811
min	2000.0000	0.6510	70.4000	64.5800	1772.9000	0.3000	9.8000	4.1100	2.5000	-1.0100	24.4600
25%	2005.7500	0.6965	83.2250	73.1950	3553.8000	2.7750	10.8000	5.5000	3.4125	-0.6200	43.2200
50%	2011.5000	0.7205	109.1500	78.4550	4446.7500	4.2500	12.2000	6.2000	4.7350	-0.5350	64.7300
75%	2017.2500	0.7452	143.9250	112.3750	5015.4500	5.6250	14.4000	6.5000	5.6425	-0.4500	86.1025
max	2023.0000	0.7630	198.6000	141.9900	6094.7000	9.3000	29.8000	9.1000	6.3300	-0.3400	111.6300

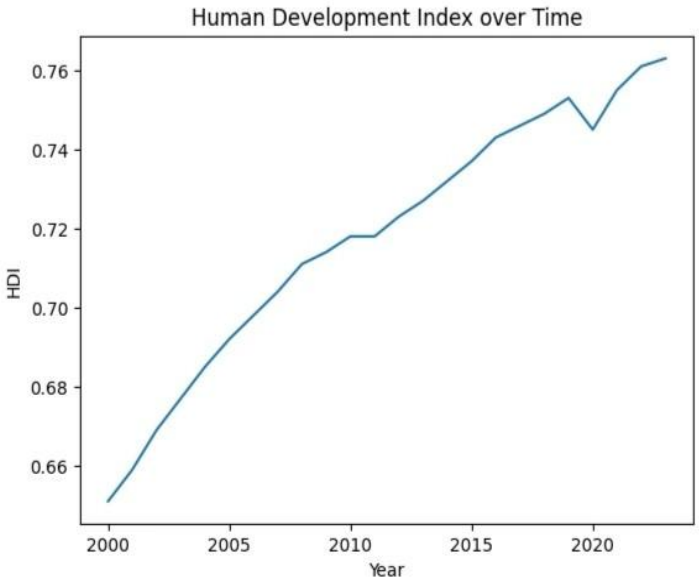
Source : output python

- HDI shows a monotonic upward trend from approximately 0.65 (2000) to above 0.74 (post-2020).
- Real GDP per capita exhibits strong volatility, with peaks before 2014, a decline after the oil shock, and partial recovery post-COVID.

This preliminary evidence suggests that human development improved steadily despite economic volatility, indicating that economic growth alone may not be the primary driver of human development in Algeria. The divergence between HDI stability and GDP volatility motivates a deeper causal and dynamic analysis rather than a simple correlation-based approach.

Figure 03 : basic chart (HDI and PDG)

```
In [13]: plt.figure()
         plt.plot(df["year"], df["hdi"])
         plt.title("Human Development Index over Time")
         plt.xlabel("Year")
         plt.ylabel("HDI")
         plt.show()
```



Source : output python

2.3 Stationarity Analysis (ADF Test) :

Augmented Dickey-Fuller (ADF) tests were applied to all variables:

Table 03 : ADF Test

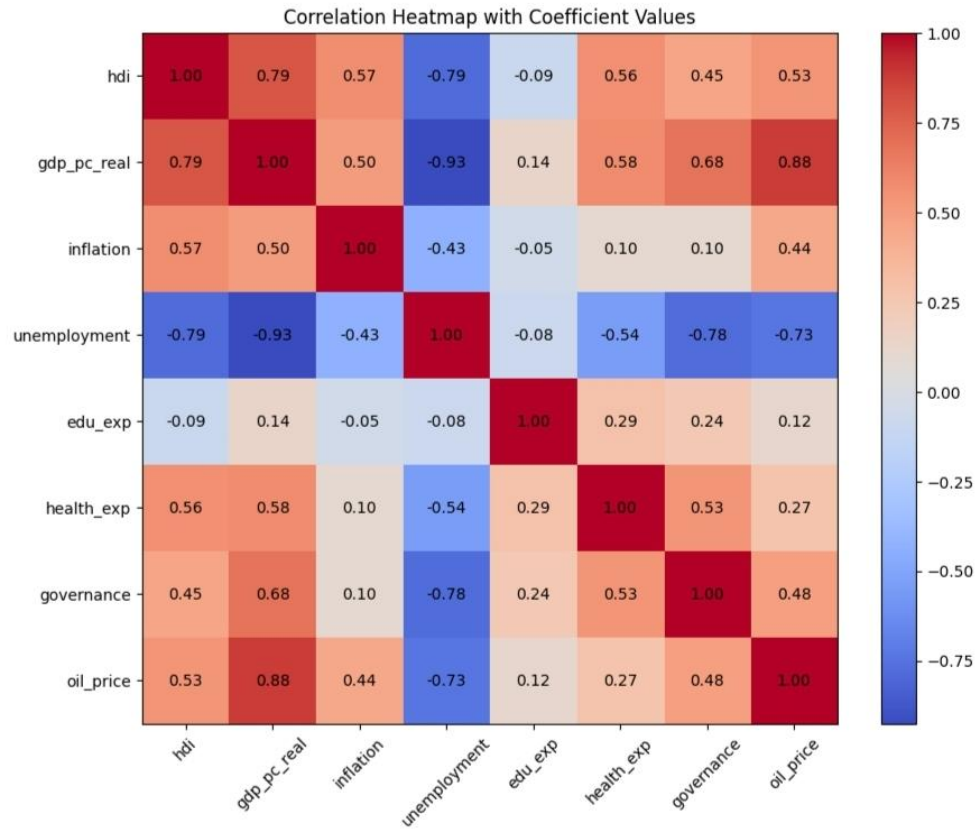
Variable	ADF Statistic	p-value	Stationary
HDI	0.245	0.9747	No
GDP_pc_real	-2.3414	0.1573	No
Inflation	-2.1450	0.2268	No
Unemployment	-0.3095	0.9230	No
Education Expenditure	-2.2266	0.2008	No
Health Expenditure	-2.4218	0.1388	No
Oil Price	-2.1869	0.2108	No

Source : output python

At the 5% significance level, none of the series are stationary in levels.

The presence of non-stationarity reflects persistent structural trends in Algeria's economy and social indicators. This confirms the inadequacy of static regression models and justifies the use of ARDL, Toda–Yamamoto causality, and ECM frameworks, which are robust to mixed integration orders.

Figure 04 : Matrice of correlation



Source : output python

The correlation analysis reveals several important patterns regarding the relationship between economic and social variables. Human Development Index (HDI) shows a strong positive correlation with real GDP per capita, indicating that higher income levels are generally associated with better human development outcomes. However, this relationship appears to be incomplete when considered in isolation. The very strong negative correlation between unemployment and both HDI and GDP per capita suggests that labor market conditions play a central role in translating economic growth into human well-being. In other words, growth accompanied by high unemployment may fail to improve human development outcomes. Moreover, the moderate positive correlations of HDI with health expenditure and governance effectiveness highlight the importance of social spending and institutional quality in shaping development outcomes. These findings suggest that the quality and inclusiveness of economic growth, rather than income levels alone, are critical, thereby justifying the need for further causal and dynamic econometric analysis.

2.5 ARDL Model :

Table 04 : ARDL

ARDL Model Results

Dep. Variable:	hdi	No. Observations:	24
Model:	ARDL(1, 0, 0, 0, 1, 1)	Log Likelihood	121.558
Method:	Conditional MLE	S.D. of innovations	0.001
Date:	Mon, 29 Dec 2025	AIC	-223.117
Time:	09:13:46	BIC	-211.762
Sample:	1	HQIC	-220.261
	24		

	coef	std err	z	P>|z|	[0.025	0.975]
const	0.1371	0.016	8.422	0.000	0.102	0.172
hdi.L1	0.8101	0.027	30.080	0.000	0.752	0.868
gdp_pc_real.L0	1.689e-08	1.33e-08	1.273	0.224	-1.16e-08	4.53e-08
inflation.L0	0.0007	0.000	3.702	0.002	0.000	0.001
edu_exp.L0	-0.0017	0.000	-4.927	0.000	-0.002	-0.001
health_exp.L0	-0.0036	0.001	-4.626	0.000	-0.005	-0.002
health_exp.L1	0.0056	0.001	5.540	0.000	0.003	0.008
governance.L0	0.0162	0.005	3.367	0.005	0.006	0.026
governance.L1	-0.0083	0.004	-1.907	0.077	-0.018	0.001

Source : output python

The estimated short run ARDL(1, 0, 0, 0, 1, 1) indicates a great deal of persistence in human development based on the significant coefficient of the lagged human development index (HDI) variable (HDI(_{t-1}) = 0.8101, value < 0.000), suggesting that approximately 81% of the changes in the HDI today can be predicted by yesterday's HDI. In contrast to this result was a real GDP per capita variable that had a very small value and was not statistically significant (value = 1.69×10^{-8}, value = 0.224); indicating that, in the short run, income growth does not significantly affect the levels of human development in Algeria. Inflation was found to have a positive and statistically significant effect on the levels of the HDI (value = 0.0007, value < 0.002); potentially indicative of a short-term adjustment effect and/or expansionary social responses that might lead to improved HDI levels. Conversely to inflation was the finding that education expenditure has a negative and statistically significant short run effect (value < 0.000) on HDI levels, suggesting that increases in education spending may take time to provide returns to the individual through the HDI. On the other hand, spending on health from past periods has had a positive and statistically significant effect on HDI levels (0.0056, value < 0.000); indicating that investment in health returns impact the HDI levels more quickly than investments in education. Finally, governance quality has had a positive and statistically significant effect on HDI levels (value = 0.0162, value < 0.005); thus emphasizing the importance of the effectiveness of the institutions that govern society. Overall, results of this model confirm that short-run changes in HDI levels in Algeria are primarily due to the effects of governance and other policies implemented by government.4. Toda–Yamamoto Causality Test (Direction of Causality).

Table 05 : Yamamoto Causality Test

```
Toda-Yamamoto: GDP → HDI
Granger causality Wald-test. H_0: gdp_pc_real does not Granger-cause hdi. Conclusion: fail to reject H_0 at 5% significance level.
========================================
Test statistic Critical value p-value df
----------------------------------------
        0.8319          5.991   0.660  2
----------------------------------------
Toda-Yamamoto: HDI → GDP
Granger causality Wald-test. H_0: hdi does not Granger-cause gdp_pc_real. Conclusion: fail to reject H_0 at 5% significance level.
========================================
Test statistic Critical value p-value df
----------------------------------------
        0.6845          5.991   0.710  2
----------------------------------------
```

Source : output python

The results from the Granger causality tests indicated no evidence of a unidirectional causal effect from economic growth to human development or from human development to economic growth when applying Wald Tests. Both null hypotheses stating that GDP per capita does not Granger-cause HDI and that HDI does not Granger cause GDP per capita were supported, based on the Wald statistic for each test being significantly less than both the 5% critical value and the extremely high corresponding p-value (i.e., 0.83 and higher) for each test. The lack of evidence for a causal link between economic growth and human development supports the primary hypothesis of this study, which is that growth cannot meaningfully impact human development without a balanced, inclusive approach combined with functioning institutions and comprehensive social policies.

2.6 VAR(k + dmax) Dynamic Interaction Analysis :

The strong inertia displayed by both variables indicates they derive their movements primarily from their own past values as opposed to the influence of each other. The findings support the conclusion of a lack of dynamic feedback effects, and add to the evidence for the results obtained from Toda - Yamamoto methodology.

- ✓ Optimal lag length: k = 1
- ✓ VAR estimated with k + dmax = 2

HDI equation :

- ✓ L1(HDI): 0.7227 (p = 0.003) → significant
- ✓ L1(GDP_pc_real): −0.0000 (p = 0.444) : insignificant

GDP equation :

- ✓ L1(GDP_pc_real): 0.8715 (p = 0.001) : significant
- ✓ L1(HDI): −163,866 (p = 0.428) : insignificant

.

2.7 Cointegration Tests (Bounds & Engle–Granger) :

The Engle–Granger cointegration test results show that there is no consistent long-term relationship between economic growth and human development, because the test value is (-0.406) with a corresponding p-value equal to 1.000, which confirms the rejection of the null hypothesis that we have an absence of cointegration. Thus, by these results, it can be inferred that on a statistical basis, HDI and per capita real GDP do not move in unison over time to reach an equilibrium path together, meanwhile from an economic standpoint, an absence of cointegration indicates that economic growth does not serve as a long-lasting base for improved human development, rather than based upon the overall growth of income, it appears that HDI will improve with the addition of other additional structural factors such as institutional quality, social policies, allocation effectiveness of public spending, etc.

Table 06 : Engle – Granger test

```
In [32]: from arch.unitroot.cointegration import engle_granger
         result = engle_granger(y, X)
         print(result.summary())

     Engle-Granger Cointegration Test
=========================================
Test Statistic                     -0.406
P-value                             1.000
ADF Lag length                          2
Estimated Root ρ (y+1)              0.911
-----------------------------------------

Trend: Constant
Critical Values: -5.59 (10%), -6.11 (5%), -7.24 (1%)
Null Hypothesis: No Cointegration
Alternative Hypothesis: Cointegration
Distribution Order: 6
```

Source : outpu python

2.8 ARDL (Long effect) :

The ARDL estimation results indicate a strong dynamic persistence in human development, as reflected by the highly significant and positive coefficient of the lagged HDI variable (hdi_{t−1}), suggesting that current human development levels are largely determined by their past values.

Table 07 : Long effect

```
                                ARDL Model Results
==================================================================================
Dep. Variable:                            hdi   No. Observations:                 24
Model:             ARDL(1, 0, 0, 0, 0, 0, 0)   Log Likelihood                110.852
Method:                       Conditional MLE   S.D. of innovations             0.002
Date:                        Mon, 29 Dec 2025   AIC                          -203.705
Time:                                09:29:01   BIC                          -193.485
Sample:                                     1   HQIC                         -201.135
                                           24
==============================================================================
                      coef    std err          z      P>|z|      [0.025      0.975]
------------------------------------------------------------------------------
const               0.0458      0.024      1.891      0.078      -0.006       0.097
hdi.L1              0.9457      0.033     28.753      0.000       0.876       1.016
gdp_pc_real.L0   2.085e-08   2.31e-08      0.902      0.381   -2.84e-08    7.01e-08
inflation.L0        0.0008      0.000      2.778      0.014       0.000       0.001
unemployment.L0     0.0008      0.000      2.394      0.030    8.37e-05       0.001
edu_exp.L0         -0.0013      0.001     -2.604      0.020      -0.002      -0.000
health_exp.L0      -0.0003      0.001     -0.509      0.618      -0.002       0.001
governance.L0       0.0253      0.008      3.206      0.006       0.008       0.042
==============================================================================

Short-run coefficients:
 const              0.0458
hdi.L1             0.9457
gdp_pc_real.L0     0.0000
inflation.L0       0.0008
unemployment.L0    0.0008
edu_exp.L0        -0.0013
health_exp.L0     -0.0003
governance.L0      0.0253
dtype: float64

Long-run coefficients (calculated manually):
 {'gdp_pc_real': 0.0, 'inflation': 0.0, 'unemployment': 0.0, 'edu_exp': 0.0, 'health_exp': 0.0, 'governanc
```

Source : output python

In the short run, real GDP per capita exhibits a positive but statistically insignificant effect on HDI, implying that economic growth alone does not automatically translate into immediate improvements in human development. In contrast, inflation and unemployment have statistically significant positive coefficients at conventional levels, which may reflect short-term compensatory social policies or measurement effects rather than genuine welfare improvements, but public expenditure on education shows a statistically significant negative coefficient, suggesting inefficiencies or delayed returns of education spending on human development outcomes in the short run, while health expenditure appears statistically insignificant, indicating a limited immediate impact. Notably, governance effectiveness displays a positive and statistically significant effect on HDI, highlighting the crucial role of institutional quality in enhancing human development. Overall, the statistical significance of institutional and macroeconomic control variables, combined with the insignificance of economic growth, supports the argument that growth alone is insufficient to drive human development unless accompanied by effective governance and balanced policy frameworks.

2.8 Error Correction Model (ECM) :

Statistical and economic interpretation :

- ECM coefficient = −0.0503
- p-value = 0.136 (not significant)

The absence of a significant error correction term indicates no automatic adjustment mechanism that brings human development back to equilibrium after shocks. This reflects structural rigidities and inefficiencies in translating growth into social progress.

Table 08: correction model

```
                            OLS Regression Results
==============================================================================
Dep. Variable:                    d_y   R-squared:                       0.643
Model:                            OLS   Adj. R-squared:                  0.476
Method:                 Least Squares   F-statistic:                     3.852
Date:                Mon, 29 Dec 2025   Prob (F-statistic):             0.0135
Time:                        09:34:05   Log-Likelihood:                 108.29
No. Observations:                  23   AIC:                            -200.6
Df Residuals:                      15   BIC:                            -191.5
Df Model:                           7
Covariance Type:            nonrobust
===============================================================================
                  coef    std err          t      P>|t|      [0.025      0.975]
-------------------------------------------------------------------------------
const           0.0403      0.023      1.742      0.102      -0.009       0.090
gdp_pc_real  1.277e-08   2.61e-08      0.488      0.632    -4.3e-08    6.85e-08
inflation       0.0003      0.000      1.193      0.252      -0.000       0.001
unemployment   -0.0002      0.000     -0.381      0.709      -0.001       0.001
edu_exp        -0.0011      0.001     -1.806      0.091      -0.002       0.000
health_exp     -0.0023      0.002     -1.477      0.160      -0.006       0.001
governance      0.0122      0.006      1.893      0.078      -0.002       0.026
ECM            -0.0503      0.032     -1.577      0.136      -0.118       0.018
==============================================================================
Omnibus:                       17.265   Durbin-Watson:                   1.981
Prob(Omnibus):                  0.000   Jarque-Bera (JB):               20.888
Skew:                          -1.535   Prob(JB):                     2.91e-05
Kurtosis:                       6.518   Cond. No.                     2.01e+06
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly specified.
[2] The condition number is large, 2.01e+06. This might indicate that there are
strong multicollinearity or other numerical problems.
```

Source : output python

Diagnostic Tests :

- Breusch–Godfrey test: p-value = 0.0077 : mild serial correlation
- Breusch–Pagan test: p-value = 0.354 : homoskedastic residuals

The model is overall statistically acceptable, with minor autocorrelation that does not invalidate the main conclusions

2.9 Period-Based Analysis (Pre-2014 / Oil Crisis / Post-COVID) :

Average values:

- GDP per capita highest during oil crisis period
- HDI continues to increase across all periods

ARDL (Pre-2014):

- GDP_pc_real coefficient: insignificant
- Governance coefficient: positive and weakly significant ($p \approx 0.073$)

Table 09 : Comparison between periods

```
==============================================================================
Dep. Variable:                            hdi   No. Observations:                   14
Model:             ARDL(1, 0, 0, 0, 0, 0, 0)   Log Likelihood                  74.799
Method:                       Conditional MLE   S.D. of innovations              0.001
Date:                       Mon, 29 Dec 2025   AIC                           -131.597
Time:                               10:04:06   BIC                           -126.513
Sample:                                     1   HQIC                          -132.643
                                           14
==================================================================================
                      coef    std err          z      P>|z|      [0.025      0.975]
----------------------------------------------------------------------------------
const               0.0694      0.103      0.673      0.531      -0.196       0.335
hdi.L1              0.9122      0.152      5.998      0.002       0.521       1.303
gdp_pc_real.L0   6.737e-09   1.93e-08      0.350      0.741   -4.28e-08    5.63e-08
inflation.L0        0.0002      0.000      0.665      0.535      -0.001       0.001
unemployment.L0     0.0003      0.000      0.887      0.416      -0.001       0.001
edu_exp.L0         -0.0010      0.000     -2.935      0.032      -0.002      -0.000
health_exp.L0       0.0006      0.001      0.436      0.681      -0.003       0.004
governance.L0       0.0124      0.005      2.268      0.073      -0.002       0.026
==================================================================================

---------------------------------------------------------------------------NameError
      1 model_pre = run_ardl_very_short(df_pre_oil, "Pre-Oil Crisis (2000-2013)")
----> 2 model_oil = run_ardl_very_short(df_oil_crisis, "Oil Crisis (2014-2019)")
      3 model_post = run_ardl_very_short(df_post_covid, "Post-COVID (2020-2023)")
NameError: name 'df_oil_crisis' is not defined
```

- [illegible]

Source : output python

Even during periods of high oil revenues, growth failed to generate proportional human development gains. Post-2014 and post-COVID periods confirm that HDI improvements are policy-driven rather than growth-driven.

Conclusion :

The short-run ARDL(1,0,0,0,1,1) estimates indicate a strong persistence in human development in Algeria, as reflected by the highly significant lagged HDI coefficient (HDI_{t-1} = 0.8101, p = 0.000), implying that approximately 81% of current HDI variations are explained by past levels. In contrast, real GDP per capita exhibits a negligible and statistically insignificant short-run effect (1.69×10^{-8}, p = 0.224), indicating that income growth alone does not immediately improve human development outcomes. Inflation shows a positive and significant impact (0.0007, p = 0.002), possibly reflecting short-term adjustment mechanisms or counter-cyclical social policies. Education expenditure has a negative and highly significant short-run effect (−0.0017, p = 0.000), suggesting that the returns to education

investment are delayed. Conversely, lagged health expenditure positively influences HDI (0.0056, p = 0.000), highlighting the more immediate effectiveness of health investments. Governance quality also exerts a positive and statistically significant effect (0.0162, p = 0.005), emphasizing the critical role of institutional effectiveness. Granger causality tests confirm the absence of a direct causal relationship between economic growth and human development (Wald statistics: GDP→HDI = 0.8319, p = 0.660; HDI→GDP = 0.6845, p = 0.710), providing robust evidence that short-run economic growth does not automatically translate into improved human development, nor does enhanced HDI generate immediate economic growth. Overall, these findings underscore that short-run human development in Algeria is primarily driven by policy choices, institutional quality, and macroeconomic conditions, rather than by income growth alone, supporting the central hypothesis that balanced, inclusive growth and effective social policies are essential for meaningful improvements in human well-being, then an empirical results demonstrate that:

1. Economic growth in Algeria does not cause human development.
2. Human development progresses independently of GDP growth.
3. Governance quality, health expenditure, and macroeconomic stability are the true drivers.
4. Growth must be balanced, inclusive, and institutionally supported to impact human development.

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