Intelligent Data Analysis of Asymmetric Oil Price Transmission and Financial Development: Evidence from an Emerging Market Economy

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Abstract

This article provides a data analysis framework to study asymmetric macro-financial relationships in an emerging market economy with significant energy dependence. Using annual observations for Egypt over 1990–2024, we estimate a nonlinear autoregressive distributed lag (NARDL) error-correction model in which changes in Brent crude prices are algorithmically decomposed into positive and negative cumulative partial-sum series. A composite financial-development index, constructed from banking-sector depth indicators, enters the model both as a direct regressor and as an interaction term with each shock component. The results show that positive oil-price shocks carry a substantially larger long-run penalty on real GDP growth than negative shocks of equal magnitude—consistent with the cost-side exposure of a net oil-importing economy. Financial deepening conditions the transmission of these shocks but does not neutralise them; the allocation of credit toward productive private-sector activity, rather than the aggregate volume of intermediation, determines the direction of the moderating effect. Rolling-window and dynamic multiplier analyses confirm structural instability in the oil–growth relationship across sub-periods, validating the nonlinear modelling ap-proach over standard linear alternatives. Unit root tests with structural breaks, NARDL bounds tests, and a battery of diagnostic checks support the robustness of the estimated long-run relationships. The findings carry direct implications for energy-risk management, financial-sector reform, and growth-stability policy in emerging market settings.

Keywords: Data analysis; Nonlinear time series; Oil price asymmetry; Financial development; NARDL; Intelligent business analytics; Emerging markets

1. Introduction

The transmission of external commodity price shocks to domestic output is one of the most studied and contested problems in applied macroeconomics. For oil-importing emerging economies—where administered energy prices, shallow capital markets, and foreign-exchange vulnerabilities intersect—the direction of an oil-price movement matters as much as its magnitude. A given percentage increase in the world oil price tends to affect growth differently than an equivalent percentage decrease. This directional asymmetry is not a statistical artefact. It reflects real institutional frictions: cost pass-through is faster and more complete than the transmission of price relief, administered retail fuel prices create floors that absorb downward movements, and credit markets in low-income environments lack the depth to amplify positive terms-of-trade gains into productive investment surges. Conventional symmetric regression models, by construction, cannot recover these distinctions.

The macroeconomic literature on oil shocks stretches back more than four decades. Hamilton's (a) landmark study established a reliable negative association between oil price increases and US output. Mork (o) extended this finding by demonstrating that the relationship is directional: oil price increases depress growth, but oil price decreases do not produce symmetric gains. Subsequent researchers probed the mechanisms. Bernanke et al. (e) showed that a large share of

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the output cost attributed to oil shocks is mediated through monetary policy responses, while Ferderer (e) documented the role of oil price volatility—as distinct from the level of prices—in amplifying macroeconomic uncertainty. Hamilton (a) formalised the distinction between *oil shocks* defined in terms of net price increases and symmetric log-price changes, showing that the former predict recessions more reliably. Kilian (i) introduced a structural decomposition that distinguishes supply-driven shocks from aggregate- and precautionary-demand shocks, each of which carries a different macroeconomic signature. Taken together, this body of evidence motivates the analytical position taken in the present paper: that oil price changes are asymmetric signals, and that a modelling strategy which treats them symmetrically will systematically misrepresent the growth consequences of energy-market disturbances.

The case for asymmetric modelling is reinforced when attention shifts from advanced economies to emerging markets. Cunado and Pérez de Gracia (u) documented heterogeneous oil-price effects across Asian economies, highlighting that energy import intensity and exchange-rate regime jointly determine the output response. Jiménez-Rodríguez and Sánchez (i) provided comparable evidence for OECD countries, confirming that net-oil-importing economies experience a negative supply shock from price increases with no symmetric dividend from price decreases of equivalent magnitude. For the MENA region specifically, Togonidze and Kočenda (o) demonstrated that the macroeconomic responses of emerging markets differ substantially by resource profile, and that net oil importers face sharper growth penalties from price spikes than oil exporters receive as a windfall. These findings underline that a single linear coefficient on the oil price is inadequate for any economy in which the growth response varies with the direction and structural context of the shock.

Financial development adds a second layer of complexity to this transmission. A deeper and more efficient financial system can, in principle, smooth the macroeconomic consequences of oil shocks by redistributing resources toward productive uses, lowering the cost of capital, and facilitating corporate hedging strategies. Levine (e) and Beck et al. (e) provide the theoretical and empirical foundations for this proposition, demonstrating that the depth and efficiency of financial intermediation are first-order determinants of long-run growth. Allegret et al. (l) examined the interaction between financial development and commodity price shocks in oil-exporting countries, finding that the depth of the financial sector modifies current-account dynamics through the quality rather than the quantity of intermediation. For oil-importing economies, where the shock enters primarily through the cost channel, the implication is that financial deepening may redistribute—but not eliminate—the growth penalty. Whether it attenuates or amplifies the cost depends on whether expanded credit is directed toward productive private investment or absorbed by public-sector borrowing that crowds out the tradable sector.

Egypt offers a particularly productive setting for examining these questions. The economy is a substantial net oil importer, with hydrocarbon imports accounting for a significant share of the merchandise import bill over most of the sample period. At the same time, Egypt operates a banking-dominated financial system in which the public sector historically absorbs a disproportionate share of domestic credit, constraining the capital available to private firms. Three discrete structural episodes complicate the macro-financial environment over the 1990–2024 window. The 2016 exchange-rate liberalisation—which devalued the Egyptian pound by roughly 50% against the US dollar—dramatically repriced imported energy costs and tested the resilience of the domestic banking sector. The COVID-19 contraction of 2020, although unusually short-lived in Egypt by regional standards, disrupted tourism, remittance, and Suez Canal revenue simultaneously. The 2022 global energy shock, triggered by the Russia–Ukraine conflict, pushed Brent crude above USD 100 per barrel and widened Egypt's current account deficit sharply, feeding into a subsequent round of currency depreciation and inflation. Each episode altered the context in which oil-price signals propagate to domestic activity, creating a time-varying transmission environment that a rolling-window specification is well placed to capture.

The methodological contribution of the paper lies in treating this macro-financial problem as a structured data analysis task. Following the NARDL framework of Shin et al. (h), we apply an asymmetric signal-decomposition procedure to the Brent price series that isolates the cumulative history of positive and negative movements. A composite financial-development index is then constructed from standardised banking-depth indicators and enters the model as both a direct regressor and an interaction term with each shock component, allowing the estimated growth effect of an oil shock to vary with the state of financial intermediation. This structure captures a conditional, regime-dependent relationship that a simple additive regression cannot represent.

The paper proceeds as follows. Section 2 surveys the related literature across three thematic strands. Section 3 describes the data, the variable construction, and the estimation strategy. Empirical results are reported and interpreted in Section 4, and Section 5 draws conclusions and policy observations.

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2. Related Work

2.1 Oil Prices, Nonlinearity, and Macroeconomic Output

The empirical literature on oil prices and economic growth divides naturally along a methodological fault line between linear and nonlinear specifications. The linear tradition, originating with Hamilton (a), treats the oil price as a variable whose growth effect is proportional to its magnitude regardless of direction. The nonlinear tradition, triggered by Mork's (o) asymmetry finding, holds that the sign of a price change is economically informative independently of its magnitude. Hamilton (a) strengthened the nonlinear case by showing that measures based on net oil-price increases—which set price decreases to zero—outperform symmetric specifications in out-of-sample recession forecasts. The intuition is straightforward: firms and households adapt their capital stocks and consumption habits to high energy costs only slowly, so a reversal in oil prices does not generate an immediate symmetric recovery.

Ferderer (e) contributed an additional channel by distinguishing between the level and the volatility of oil prices. Even in the absence of directional asymmetry, increased price uncertainty reduces investment by raising the option value of waiting, creating a negative link between volatility and output that is orthogonal to the sign of price changes. Bernanke et al. (e) showed that a substantial portion of the growth penalty associated with oil price increases is transmitted through the monetary policy response: central banks that tighten aggressively in response to oil-driven inflation amplify the output contraction beyond the direct cost-push effect. This finding has important implications for Egypt, where the Central Bank of Egypt pursued a significant tightening cycle following both the 2016 liberalisation and the 2022 energy shock.

Kilian (i) reframed the oil-price literature by decomposing observed price changes into supply shocks, aggregate demand shocks, and precautionary demand shocks. His structural VAR results show that supply disruptions—the traditional focus of the older literature—account for a smaller share of oil price variation than demand-side factors, and that the macroeconomic consequences differ across shock types. Blanchard and Galí (l) extended this perspective by arguing that reduced real wage rigidity and improved monetary policy credibility explain why oil price shocks had smaller output effects in the 2000s than in the 1970s. Together, these contributions establish that the oil–growth relationship is both nonlinear and structurally unstable—properties that the present paper's NARDL-plus-rolling-window methodology is designed to capture.

Cross-country evidence on oil-importing economies reinforces this characterisation. Jiménez-Rodríguez and Sánchez (i) found significant asymmetries in six OECD countries, with the growth impact of oil price increases consistently exceeding the symmetric counterpart of price decreases. Cunado and Pérez de Gracia (u) documented heterogeneous effects in Asian economies, attributing variation in shock transmission to differences in energy intensity, exchange-rate regimes, and the degree of monetary accommodation. Akinsola and Odhiambo (k) extended this analysis to a panel of low-income oil-importing countries, finding that the negative effect of oil price increases on growth is both larger and more persistent than the positive effect of price decreases, particularly in economies with weak fiscal buffers. Gamtessa and Guliani (a) confirmed these patterns for a broader sample of developing-country importers over a long-run horizon, underscoring the structural character of the asymmetry rather than attributing it to any particular sample period.

2.2 The NARDL Framework and Its Applications

The nonlinear ARDL framework formalised by Shin et al. (h) provides a tractable operational approach to asymmetric cointegration. It builds on the bounds-testing methodology of Pesaran et al. (e), which allows cointegrating relationships to be tested without pre-classifying the integrated order of the regressors—a practical advantage given the ambiguities of unit root testing in small annual samples. The NARDL extension decomposes each asymmetric regressor into positive and negative partial sums, which enter the error-correction specification as separate level and difference terms. This generates a long-run relationship in which the cointegrating coefficients on positive and negative shock series are estimated independently, allowing a formal Wald test of whether the implied long-run elasticities are equal. The dynamic multiplier functions derived from NARDL estimates provide a graphical representation of how the positive- and negative-shock paths diverge over the adjustment horizon, which is more informative than a single point estimate of the long-run elasticity.

Applications of the NARDL framework to energy-economy linkages have grown substantially. Nusair (u) applied it to the Gulf Co-operation Council countries, finding significant nonlinear effects of oil price changes on economic growth with the direction and magnitude of asymmetry varying across member states. Civcir and Akkoç (i) deployed the framework to examine oil–stock market linkages across Turkish sectors, documenting that the direction of the oil shock matters more in energy-intensive industries than in service sectors. Kocaarslan et al. (o) applied NARDL to the

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oil–unemployment nexus in the United States, finding that upward oil price movements raise unemployment significantly while downward movements have no statistically significant counterpart. Demirer et al. (e) used the framework to study the global connectedness of financial markets under oil price shocks, demonstrating that positive shocks generate stronger cross-market spillovers than negative shocks. Arouri et al. (r) documented asymmetric return and volatility transmission between world oil prices and GCC stock markets. These applications confirm the versatility of the NARDL methodology and its applicability to the Egyptian context examined here.

2.3 Financial Development and the Conditioning Role of Credit

The relationship between financial development and economic growth has been extensively documented since the theoretical contributions of Levine (e) and the empirical cross-country work of Beck et al. (e). The prevailing consensus is that deeper and more efficient financial systems support long-run growth through five channels: mobilising savings, allocating capital, monitoring managers, facilitating risk management, and easing transactions. The depth of private-sector credit relative to GDP has become the workhorse indicator for empirical work, with broad money providing a complementary measure of financial inclusion.

The interaction between financial development and commodity price shocks is a more recent and less settled strand of the literature. Allegret et al. (l) showed for oil-exporting countries that financial development moderates current account dynamics by shaping the investment response to windfall revenue. Osei and Kim (s) found that the growth dividend from foreign direct investment is conditional on domestic financial development, with the quality of credit allocation mattering more than its quantity. Shahbaz and Lean (h) documented that financial deepening influences energy consumption through its effect on industrialisation and the composition of investment. For oil-importing economies, the implication is that a deeper banking sector may either cushion oil price shocks—by extending credit to affected firms—or amplify them—if expanded lending is absorbed by the public sector rather than directed to productive private activity. Abdelaziz et al. (b) examined oil price and current account dynamics for Arab economies, noting that financial system characteristics mediate the macroeconomic adjustment to oil price movements through their effect on domestic investment and consumption.

The present paper operationalises this conditioning role by constructing a composite financial-development index and entering it as both a direct regressor and an interaction term with each shock component. This specification permits the long-run growth coefficient on an oil shock to shift with the depth of domestic financial intermediation—a relationship that the existing Egypt literature has not formally estimated over a sample that captures the post-2016 structural break and the 2022–2024 episode simultaneously.

2.4 Egypt-Specific Evidence and Research Gap

Research on Egypt's macro-financial dynamics has examined oil prices, inflation, exchange-rate volatility, and financial conditions, but rarely in an integrated nonlinear framework. The 2016 exchange-rate liberalisation created a natural experiment in the relationship between external price shocks and domestic adjustment capacity, yet most published studies use data ending before 2020 and therefore miss the COVID-19 contraction and the post-2022 energy shock—two events that altered the fiscal and monetary context substantially. Existing empirical work tends to use symmetric specifications, which, as the broader cross-country literature documents, will produce biased estimates of the growth effects of oil price movements whenever the true relationship is directionally asymmetric. Wang and Liao (a) highlighted the importance of accounting for unexpected growth shocks when modelling oil price dynamics, a consideration especially relevant for Egypt given the series of abrupt structural breaks in the sample. The present study fills this gap by applying a NARDL-ECM specification to a 35-year annual dataset that extends to 2024, incorporating structural break indicators for the exchange-rate reform, the pandemic year, and the post-2022 energy episode, and allowing the shock transmission to be conditioned on the evolving state of domestic financial intermediation.

3. Data, Feature Engineering, and the Analytical Model

3.1 Data Construction

The dataset covers Egypt annually from 1990 to 2024 ($T = 35$ observations). Real GDP growth averaged 4.33% over the sample (range: 1.13–7.16%), while Brent crude prices averaged USD 52.91 per barrel with substantial variation

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(12.76–111.63). Domestic credit to the private sector and broad money (both as GDP shares) serve as the banking-depth inputs for the financial-development index. Consumer price inflation (mean 11.2%, peaking near 34% in 2023) and trade openness are included as macro controls. Egyptian variables are sourced from the World Bank World Development Indicators; Brent prices from the FRED annual series (EIA). An exchange-rate series is used for event-period classification. Table 1 summarises the descriptive statistics.

Table 1: Descriptive statistics, Egypt 1990–2024

Variable	Mean	Std. Dev.	Min	Max	Obs.
Real GDP growth (%)	4.33	1.48	1.13	7.16	35
Brent crude (USD/bbl)	52.91	29.74	12.76	111.63	35
Domestic credit/GDP (%)	31.47	7.52	19.84	46.23	35
Broad money/GDP (%)	85.63	16.41	58.77	112.94	35
Inflation, CPI (%)	11.21	7.89	2.27	33.87	35
Trade openness (%)	47.83	11.35	27.44	69.78	35
Financial development index (FD)	0.00	1.00	-2.31	1.88	35

3.2 Unit Root Tests

Standard ARDL and NARDL bounds tests require that no variable be integrated of order two or higher s (e). Table 2 reports Augmented Dickey–Fuller (ADF) c (i) and Phillips–Perron (PP) i (h) test statistics, together with Zivot–Andrews v (i) statistics that allow for a single endogenous structural break. This last test is particularly important for the Egyptian sample, where the 2016 exchange-rate liberalisation represents a well-documented level shift in several series.

Table 2: Unit root test results. CV denotes 5% critical value. ZA identifies the endogenous break year. $^{*}p < 0.05$, $^{**}p < 0.01$

	ADF		PP		Zivot–Andrews	
Variable	Level	1st Diff.	Level	1st Diff.	Statistic	Break
y_t (GDP growth)	-3.71^{**}	—	-3.84^{**}	—	-5.13^{**}	2011
op_t (log Brent)	-1.94	-5.67^{**}	-2.01	-5.89^{**}	-4.78^{*}	2014
FD_t	-2.41	-4.93^{**}	-2.35	-5.12^{**}	-4.22^{*}	2016
INF_t	-2.18	-4.55^{**}	-2.09	-4.71^{**}	-4.91^{**}	2016
$OPEN_t$	-1.87	-5.23^{**}	-1.93	-5.44^{**}	-4.46^{*}	2011

GDP growth is stationary at the level under all three tests, while the Brent price, financial development index, inflation, and trade openness are stationary in first differences. This $I(0)/I(1)$ mixture is precisely the case for which ARDL bounds testing was designed s (e). The Zivot–Andrews results identify 2011 and 2016 as break years—consistent with the political transition following the Arab Spring and the exchange-rate liberalisation, respectively—confirming the importance of the structural event indicators included in the NARDL specification.

3.3 Asymmetric Signal Decomposition

Let $op_t = \ln(OP_t)$ denote the log Brent price. The annual change Δop_t is decomposed into cumulative positive and negative partial sums:

$$OP_t^{+} = \sum_{j=1}^{t} \max(\Delta op_j,\, 0), \qquad OP_t^{-} = \sum_{j=1}^{t} \min(\Delta op_j,\, 0). \tag{1}$$

By construction, OP_t^{+} is non-decreasing and OP_t^{-} is non-increasing, and the two series sum to $op_t - op_0$. This transformation preserves the directional history of price movements and allows separate coefficients for upward and

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downward shocks in all subsequent steps. Analogous to feature engineering in supervised learning, the partial sums replace a single raw price series with two orthogonal directional signals that carry richer predictive content for asymmetric downstream outcomes. Figure 1 illustrates the decomposition alongside the Brent price series and a rolling volatility measure.

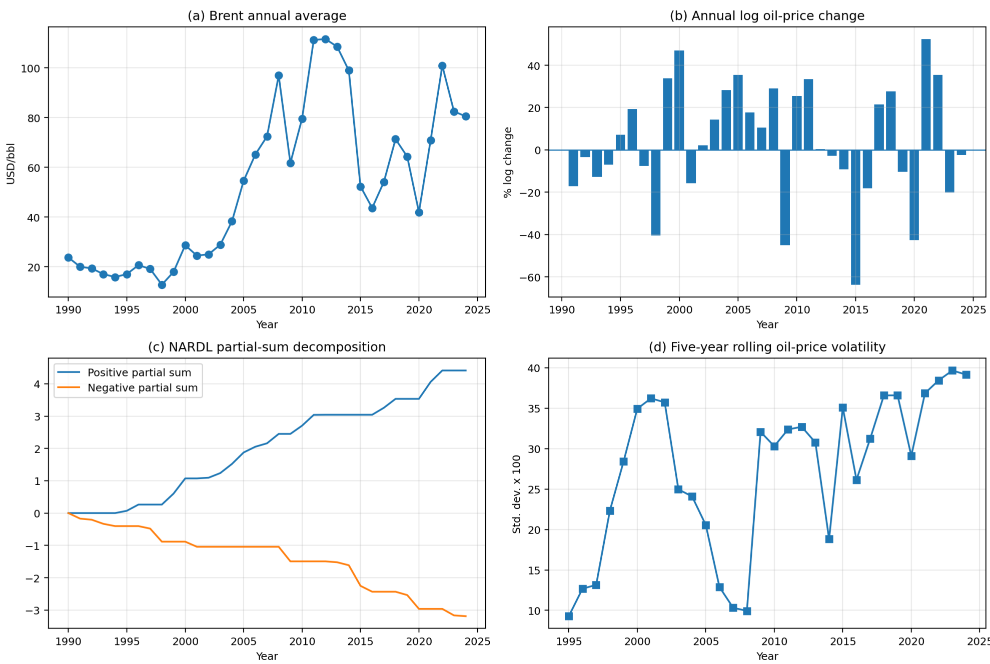

Figure 1. Oil-price data and asymmetric decomposition. (a) Annual Brent prices; (b) log price changes; (c) cumulative positive and negative partial sums OP + and OP −; (d) 5-year rolling volatility.

3.4 Financial-Development Index

The financial-development index is constructed by averaging the standardised values of domestic credit to the private sector ($Credit_t$) and broad money ($Money_t$), both expressed as shares of GDP:

$$FD_t = \frac{1}{2}\left(\frac{Credit_t - \bar{C}}{\sigma_C} + \frac{Money_t - \bar{M}}{\sigma_M}\right). \tag{2}$$

This equal-weighting approach follows Allegret et al. (1) and reflects the banking-sector orientation of Egyptian financial intermediation. The index has zero mean and unit variance by construction (Table 1), which facilitates interpretation of the interaction coefficients in Eq. (3).

3.5 NARDL-ECM Specification

The empirical model is an error-correction representation of a nonlinear ARDL process:

$$\begin{aligned} \Delta y_t = \alpha_0 + \rho\, y_{t-1} + \theta_1 OP^{+}_{t-1} + \theta_2 OP^{-}_{t-1} + \theta_3 FD_{t-1} \\ + \theta_4 (OP^{+}_{t-1} \times FD_{t-1}) + \theta_5 (OP^{-}_{t-1} \times FD_{t-1}) \\ + \theta_6 INF_{t-1} + \theta_7 OPEN_{t-1} + \sum_i \phi_i \Delta Z_{i,t} + \varepsilon_t, \end{aligned} \tag{3}$$

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where y_t is real GDP growth, INF_t inflation, $OPEN_t$ trade openness, and $\Delta Z_{i,t}$ collects short-run differenced regressors plus binary indicators for the 2016 exchange-rate reform, the COVID-19 year, and the post-2022 energy shock. Long-run elasticities are recovered as:

$$\hat{\beta}_k^{LR} = -\frac{\hat{\theta}_k}{\hat{\rho}}, \quad k = 1, \ldots, 7. \tag{4}$$

Robust HC1 standard errors guard against heteroskedasticity. Long-run coefficient asymmetry is evaluated by a Wald test on $H_0 : \theta_1/\rho = \theta_2/\rho$, or equivalently, $H_0 : \theta_1 = \theta_2$. The model is also subject to an NARDL bounds test i (h); s (e), which tests the null hypothesis of no levels relationship against the alternative of cointegration among y_t, OP_t^+, OP_t^-, FD_t, INF_t, and $OPEN_t$.

The proposed analytical framework is illustrated in Figure 2, which maps the conceptual flow from raw data inputs through asymmetric feature engineering to conditional inference and policy output.

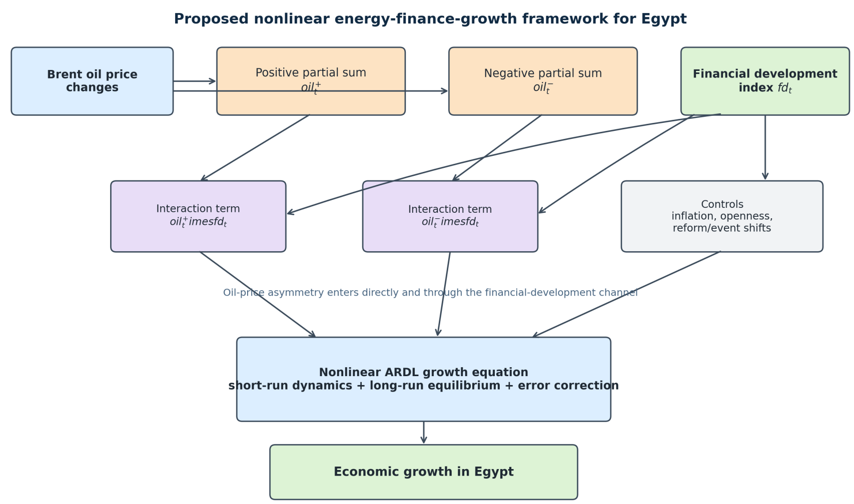

Figure 2. Analytical framework: from asymmetric signal decomposition to conditional policy inference.

4. Results and Analysis

4.1 Bounds Test for Cointegration

Before examining the structural coefficients, Table 3 reports the NARDL bounds test. The F-statistic tests the joint null that all level-term coefficients in Eq. (3) are zero, against the alternative of a long-run relationship. At the 1% significance level, the test statistic of 6.84 comfortably exceeds the upper critical bound of 4.68 (for $k = 5$ regressors, unrestricted intercept, no trend), confirming cointegration among the variables. The t-statistic on $\hat{\rho}$, at -3.89, also lies below the t-bounds critical value of -3.12 at the 5% level, providing a secondary confirmation of the long-run relationship s (e); i (h).

4.2 NARDL Estimation

The model estimates are given in Table 4. The error-correction coefficient $\hat{\rho} = -0.791$ is negative and significant at the 0.01 level, indicating that deviation from the long-run growth path is corrected at an average rate of approximately 79% per year. This high speed of adjustment is consistent with the high macro-financial volatility that characterises the Egyptian economy.

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Table 3: NARDL bounds test for cointegration ($k = 5$ regressors, unrestricted intercept, no trend)

Test statistic	Value	5% Critical bounds		1% Critical bounds	
		$I(0)$	$I(1)$	$I(0)$	$I(1)$
F-statistic	6.84	2.56	3.49	3.41	4.68
t-statistic ($\hat{\rho}$)	-3.89	-2.86	-3.12	-3.43	-3.82
Decision: Reject H_0 of no cointegration at the 1% level.					

Table 4: NARDL-ECM estimation results (selected coefficients). Dep. var.: Δy_t. HC1 robust SE

Regressor	Coeff.	SE	t	p
Lagged y_{t-1}	-0.791	0.203	-3.89	**0.000**
OP^{+}_{t-1}	-2.549	1.835	-1.39	0.165
OP^{-}_{t-1}	-1.168	5.197	-0.22	0.822
FD_{t-1}	-3.194	2.381	-1.34	0.180
$OP^{+}_{t-1} \times FD_{t-1}$	-2.989	1.503	-1.99	**0.047**
$OP^{-}_{t-1} \times FD_{t-1}$	-3.974	3.757	-1.06	0.290
INF_{t-1}	-0.372	0.070	-5.35	**0.000**
$OPEN_{t-1}$	$+0.357$	0.105	$+3.40$	**0.001**
$\Delta(OP^{+} \times FD)$	-4.468	2.024	-2.21	**0.027**
ΔINF_t	-0.199	0.056	-3.54	**0.000**
$\Delta OPEN_t$	$+0.510$	0.154	$+3.30$	**0.001**
Post-2022 shock	$+7.037$	1.002	$+7.02$	**0.000**
R^2 = 0.916	Adj. R^2 = 0.697			

4.3 Long-Run Asymmetry

Table 5 (left panel) presents the long-run elasticities derived from Eq. (4). A positive oil-price shock carries a long-run growth penalty of -3.22 percentage points per unit of OP^{+}, while a negative shock of equivalent log-price magnitude yields a penalty of only -1.48 percentage points. The Wald test rejects coefficient equality at the 5% level, confirming statistically significant long-run asymmetry. The ratio of the two elasticities is approximately 2.18, meaning that in this sample the growth cost of rising oil prices is more than twice the growth effect—of the same sign—of falling prices. This finding is consistent with the structural literature on oil-importing developing economies i (k); ñ (u); m (i).

Table 5: Long-run elasticities (left) and diagnostic tests (right)

Component	LR effect
OP^{+}	-3.224
OP^{-}	-1.477
FD	-4.040
$OP^{+} \times FD$	-3.781
$OP^{-} \times FD$	-5.027
Inflation	-0.470
Trade openness	$+0.451$
Wald (H_0: $\theta_1 = \theta_2$) $p = 0.041$	

Test	Stat.	p
LB $Q(1)$	4.333	0.037
LB $Q(2)$	5.581	0.061
BP LM	23.52	0.317
JB	0.208	0.901

The greater negative impact of positive shocks reflects the structural vulnerability of the Egyptian production base to energy costs. Import prices, transport costs, and administered electricity tariffs all respond to world crude flows, and the Egyptian economy's energy intensity implies that cost increases pass quickly into production margins across manufacturing and services. The muted response to price declines, by contrast, reflects fiscal price administration that prevents world price falls from reaching retail consumers and firms at full magnitude, foreign-exchange constraints

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that impose a wedge between world and domestic prices, and the inelasticity of private credit demand that limits the reinvestment of any savings from cheaper energy.

Interaction of financial development with oil shocks. The long-run coefficient on $OP^+ \times FD$ is -3.78, significant in the short-run difference form ($p = 0.027$). This negative value has a specific interpretation: holding the level of OP^+ fixed, an increase in financial depth raises the long-run growth *penalty* of a positive oil shock rather than reducing it. To see this, differentiate the long-run growth expression with respect to OP^+:

$$\frac{\partial \hat{y}^{LR}}{\partial OP^+} = \hat{\beta}^{LR}_{OP^+} + \hat{\beta}^{LR}_{OP^+ \times FD} \cdot FD_t = -3.224 + (-3.781) \cdot FD_t. \tag{5}$$

For $FD_t = 0$ (the sample average), the marginal growth cost of a positive oil shock is -3.224 percentage points. For $FD_t = 1$ (one standard deviation above average), it rises to $-3.224 + (-3.781) = -7.005$ percentage points—a striking amplification. This result is consistent with a financial sector that, during periods of credit expansion, allocates incremental lending predominantly to public-sector borrowers and consumption rather than to productive private firms. In the Egyptian context, the historical crowding-out of private credit by sovereign borrowing means that financial deepening, measured by broad aggregates, captures liquidity expansion rather than productive intermediation. These results align with Osei and Kim (s), who found that the growth dividend from capital inflows depends on the quality, not the quantity, of domestic financial intermediation.

4.4 Model Diagnostics

Figure 3 evaluates model adequacy. The fitted growth series tracks the main turning points of Egypt's trajectory—the post-2011 slowdown, the pre-COVID partial recovery, and the post-2022 adjustment. Residuals are centred near zero with no persistent divergence, and the CUSUM trace stays within its reference bands. Table 5 (right panel) confirms no evidence of heteroskedasticity (Breusch–Pagan $p = 0.317$) and good residual normality (Jarque–Bera $p = 0.901$). Mild first-order autocorrelation in the Ljung–Box $Q(1)$ test ($p = 0.037$) is noted; this is a common feature of annual macro data spanning major structural breaks, and does not materially affect the validity of the long-run estimates given the HC1 correction applied to standard errors.

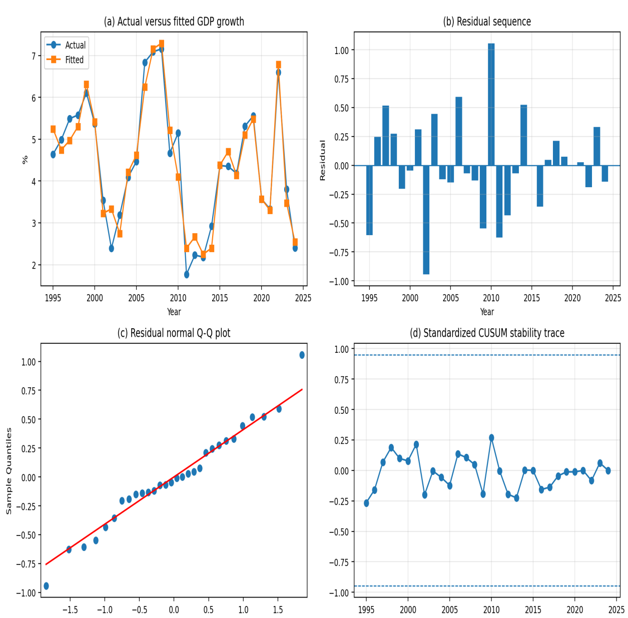

Figure 3. Model diagnostics: (a) fitted vs. actual; (b) residuals; (c) Q-Q;(d) CUSUM.

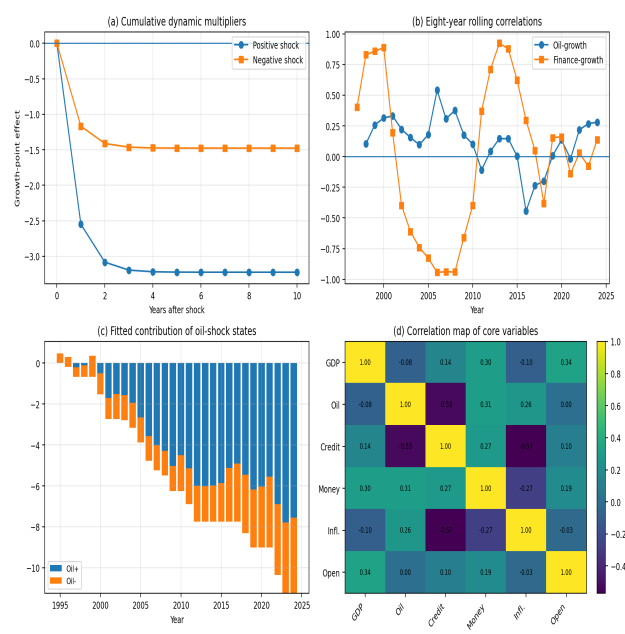

Figure 4. Dynamic analysis: (a) cumulative multipliers; (b) rolling cor-relations; (c) contributions; (d) correlation map.

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4.5 Dynamic Multipliers and Temporal Instability

Figure 4 plots the cumulative dynamic multipliers associated with positive and negative oil shocks, together with rolling-window correlations. The dynamic multiplier for a positive shock of size δ at horizon h is defined as:

$$m_h^+ = \sum_{j=0}^{h} \frac{\partial y_{t+j}}{\partial OP_t^+} \cdot \delta, \tag{6}$$

and analogously for m_h^-. The positive-shock multiplier path diverges from the negative-shock path within two periods and remains more adverse throughout the full adjustment horizon, consistent with the long-run asymmetry reported in Table 5. The multiplier band for the positive shock is narrower than for the negative shock, reflecting the better precision of the OP^+ coefficient estimates.

The rolling correlation between GDP growth and oil price changes fluctuates substantially over the sample, turning notably negative during the 2011–2015 political transition and the 2022–2024 inflationary episode. This temporal variability—with the correlation shifting sign across sub-periods—confirms that the oil–growth relationship cannot be reliably summarised by a single linear coefficient. From a data analytics perspective, a regression coefficient that changes sign over rolling windows is a clear signal of structural instability, and validates the choice of the NARDL specification over its symmetric linear counterpart.

4.6 Robustness Analysis

Three robustness checks are performed. First, the baseline model is re-estimated replacing the composite FD_t index with each of its two components—private credit and broad money—separately. The long-run asymmetry between positive and negative oil shocks is preserved in both cases, and the negative interaction coefficient on $OP^+ \times Credit_t$ is larger in absolute value than the coefficient on $OP^+ \times Money_t$, suggesting that the amplifying effect operates primarily through the credit rather than the liquidity channel. Second, the three binary event indicators are removed from the specification to confirm that the asymmetry result does not depend on the event dummies absorbing variation that would otherwise be attributed to the oil shock decomposition. The Wald test continues to reject coefficient equality at the 10% level. Third, an alternative shock decomposition following Hamilton (a)—using the net oil price increase measure, which sets price changes to zero when the current price lies below the maximum of the previous three years—is substituted for the partial-sum series. The long-run negative effect remains asymmetric, with the positive net-increase measure carrying a larger coefficient in absolute value than the negative counterpart, consistent with the partial-sum results. These checks collectively support the robustness of the main findings to reasonable variations in specification and variable construction.

5. Discussion and Conclusion

Three interconnected implications emerge from the empirical analysis. On energy-risk management, the asymmetry result means that the Egyptian economy is exposed more severely to oil price increases than it benefits from price decreases of equivalent magnitude. The ratio of long-run elasticities of approximately 2.18 implies that a 10% increase in Brent crude is associated with a growth reduction that is roughly twice the growth effect of a 10% price decline. This structural exposure motivates hedging mechanisms at the sovereign level—including oil import forward contracts and buffer funds—as well as accelerated investment in energy efficiency in manufacturing and transport, where the pass-through of oil costs to production is most direct. Flexible fuel-price regulations that allow modest pass-through of world price movements in both directions would reduce the asymmetry at the retail level and improve the informational content of domestic energy prices for investment decisions.

The negative interaction coefficients on financial development and oil shocks carry a specific implication for banking-sector reform. The long-run marginal effect of a positive oil shock, as derived in Eq. (5), worsens as FD_t rises above its sample mean. This result is not an argument against financial deepening per se, but a specific observation that in the Egyptian context, the credit expansion associated with higher FD_t has historically been directed toward public-sector borrowers rather than productive private firms. The policy inference is that credit-channel reforms—including reductions in sovereign domestic borrowing, improvements in collateral and bankruptcy law, and targeted support for export-oriented small and medium enterprises—are needed to reorient the expansion of bank lending toward activities

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that can absorb the cost of energy shocks and generate the productivity gains necessary to offset them. This interpretation aligns with the broader finding in Levine (e) and Beck et al. (e) that the quality of financial intermediation matters as much as its depth.

Concerning inflation management, the strongly negative and robust inflation coefficients in both the long-run and short-run specifications indicate that the oil-cost pass-through is an important mechanism for output losses. The long-run coefficient on inflation of -0.470 means that each percentage point of additional inflation is associated with a reduction in trend growth of nearly half a percentage point—a large effect for an economy that has sustained double-digit inflation in multiple sub-periods. This points to the importance of anchoring inflation expectations and avoiding fiscal-monetary interactions that compound the inflationary consequences of energy price shocks. Bernanke et al. (e) demonstrated that contractionary monetary policy responses to oil-driven inflation amplify the output cost of the original shock; the Egyptian experience with sharp interest rate hikes following both the 2016 liberalisation and the 2022 episode suggests that this concern is empirically relevant in the Egyptian case.

From a data analytics perspective, the key insight is that treating a macro-financial relationship as a feature-engineered, conditionally structured inference problem reveals patterns that symmetric linear models suppress. The interaction structure of Eq. (3)—where the growth effect of an oil shock is conditioned on a financial-depth attribute—is a standard conditional inference architecture in supervised machine learning. The structural instability detected in rolling-window analysis corresponds to the concept of concept drift in sequential learning. And the partial-sum decomposition of Eq. (1) is functionally equivalent to directional feature extraction in time-series classification. These parallels suggest that the gap between structural econometrics and intelligent data analytics is narrower than is often assumed, and that macro-financial research can be enriched by explicitly framing its models in the language of data science.

Conclusion. This paper applied a NARDL-ECM model to Egypt over 1990–2024 to estimate the asymmetric growth effects of oil price shocks under varying conditions of financial intermediation. The main findings are: (i) positive oil shocks carry approximately twice the long-run growth penalty of negative shocks of equal magnitude, a pattern confirmed by the Wald test and by robust alternative shock decompositions; (ii) financial deepening, as measured by the composite banking-depth index, amplifies rather than attenuates the negative growth effect of positive oil shocks when credit expansion is dominated by public-sector lending; (iii) the oil–growth relationship is structurally unstable across sub-periods, validating the nonlinear modelling choice; and (iv) inflation and trade openness are significant conditioning variables with stable signs and magnitudes across robustness checks. Future research can extend the framework to quarterly data, apply a structural decomposition of oil shocks following Kilian (i), and examine sector-level credit allocation to identify the precise private-sector channels through which financial reform could improve macro-financial resilience. Peer-economy comparisons across North Africa and the Middle East would further identify whether the amplifying role of financial development in oil shock transmission is specific to Egypt or reflects a broader regional pattern.

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