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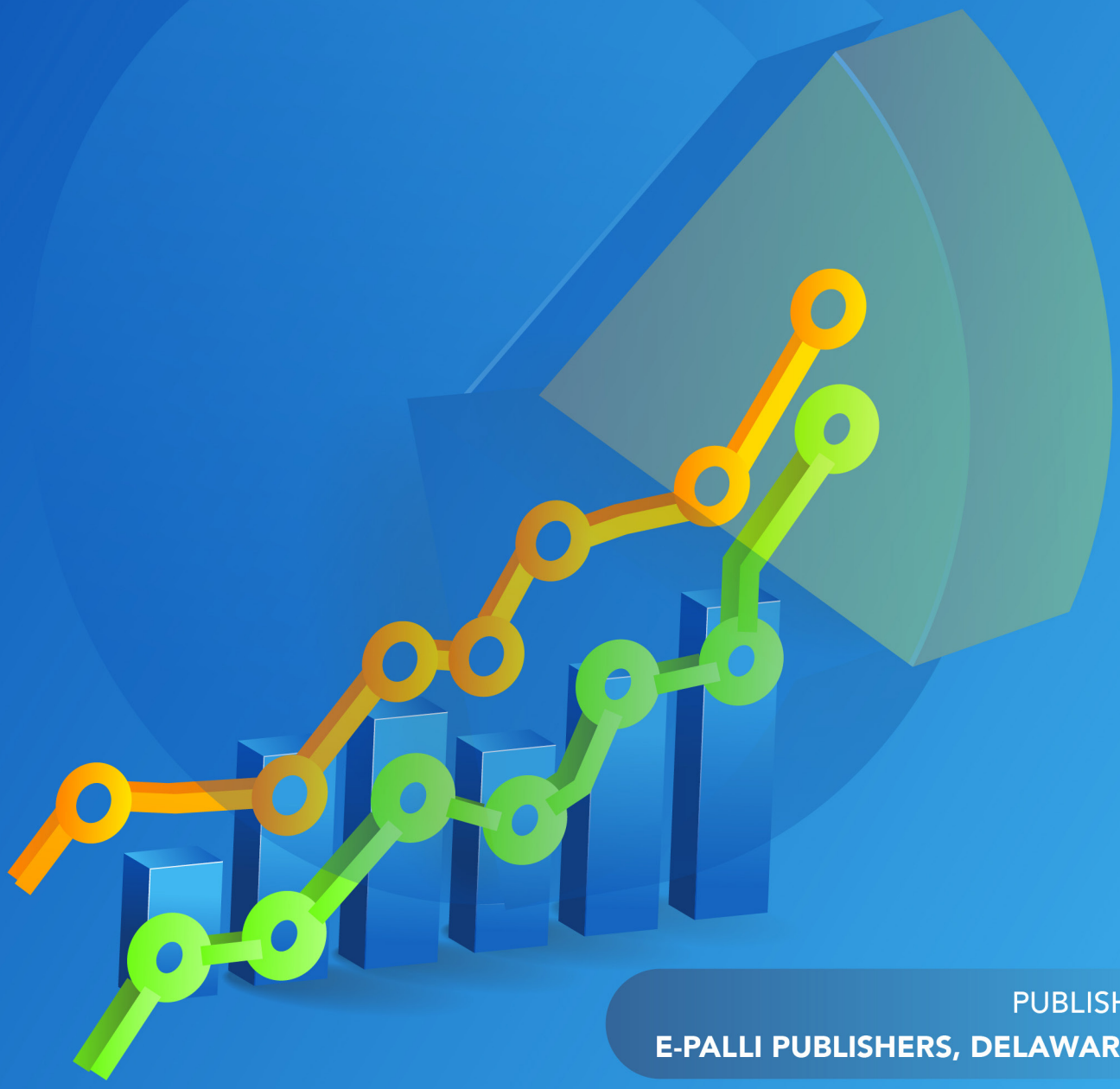

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# Forecasting Key Macroeconomic Indicators in Ghana Using a Time-Varying VECM with Conformal Prediction Intervals

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## ABSTRACT

This paper presents a six-month-ahead forecast of three key Ghanaian macroeconomic indicators: the USD/GHS exchange rate, the Consumer Price Index (CPI) and the Monetary Policy Rate (MPR). A Time-Varying Vector Error Correction Model (TV-VECM) is utilized to capture dynamic interrelationships among the variables. Conformal prediction intervals are incorporated to quantify uncertainty under minimal distributional assumptions. The results suggest moderate currency depreciation, persistent inflationary trends and stability in nominal interest rates over the forecast horizon.

## INTRODUCTION

Forecasting macroeconomic indicators is essential for effective policy design and economic planning. This study employs a Time-Varying Vector Error Correction Model (TV-VECM) to analyze short-term movements in three critical Ghanaian macroeconomic variables: the USD/GHS exchange rate, the Consumer Price Index (CPI) and the Monetary Policy Rate (MPR). The TV-VECM framework captures both long-run equilibrium and evolving short-term dynamics. To account for forecast uncertainty, conformal prediction intervals are utilized which offer valid coverage without assuming specific error distributions.

## LITERATURE REVIEW

### Time-varying VECM (TV-VECM) for Ghana

Macroeconomic relationships in Ghana among inflation, the cedi/US$ rate, policy rates, money, output, and commodity prices are well known to be non-stationary with evolving long-run equilibria and shifting short-run dynamics (policy regime shifts, commodity price cycles, IMF programs, and disinflation episodes). Standard (time-invariant) VAR/VECM studies on Ghana capture cointegration and error-correction but assume fixed parameters, which can miss structural drifts that matter for forecasting and policy analysis. Using a time-varying cointegration framework lets the data accommodate gradual changes in adjustment speeds or even the cointegration vector itself exactly the type of flexibility needed in an economy that has seen alternating easing cycles and large disinflation in 2024–2025.

### Core Advances on Time-Varying Cointegration and VECM

Early contributions showed how cointegration can evolve smoothly and proposed tests for time-invariance of the long-run vector (and rank). Bierens & Martins (2009/2010) formalize a time-varying cointegration setup where the cointegrating relationship changes smoothly; they derive a likelihood-ratio test against time-variation. This line of work motivates allowing $\beta t$ and even $\alpha t$ to drift in a VECM.

A cautionary strand highlights pitfalls with state-space/Kalman estimation of time-varying cointegration: if not handled carefully, the Kalman filter can absorb unit-root behavior into the time-varying state and spuriously "find" time-varying cointegration between unrelated I(1) series. Robust procedures and bootstrap testing frameworks are proposed to distinguish no cointegration vs. fixed vs. time-varying cointegration. This is highly relevant if one estimates TV-VECMs for Ghana with state-space methods. Recent econometric theory pushes further with smoothly time-varying VECMs: Gao, Peng & Yan (2023, 2025) develop a time-varying Granger Representation Theorem, estimation/inference for both short-run and long-run coefficients, a singular-value-ratio rank test, and stability tests providing a principled toolkit to build and validate TV-VECMs without resorting solely to ad-hoc filters.

Related strands include threshold/smooth-transition VECMs (to handle nonlinear adjustment) and applications showing that allowing for time-variation materially changes conclusions about long-run relations. These reinforce the empirical gains from flexible cointegration structures.

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**Estimation Strategies for TV-VECMs**
Three broad routes appear in the literature:

**State-space / Kalman TVP-VECMs (or TVP-VARs with Cointegration)**
Flexible but require care to avoid spurious cointegration; bootstrap or robust testing is recommended.

**Nonparametric/Smoothly-Varying Coefficients**
Treat $\alpha(\tau)$, $\Pi(\tau)$ as smooth functions of rescaled time $\tau$ with associated theory for rank, stability, and inference; this avoids some Kalman pitfalls and aligns with gradual Ghanaian regime shifts.

**Bayesian TVP-VAR/Cointegration Frameworks (And Sparsity Priors)**
Common in macro; while much of this work is in TVP-VARs, ideas translate to VECMs (shrinkage on time-variation, stochastic volatility), though dedicated Bayesian TV-VECM software remains less standard.

**Forecast Uncertainty**
Classical VECM forecast intervals rely on parametric assumptions (Gaussian errors, correct specification). In volatile, shifting environments like Ghana's, distribution-free uncertainty quantification is attractive. Conformal prediction (CP) provides finite-sample, model-agnostic prediction sets with marginal coverage guarantees. For time series, Adaptive Conformal Inference (ACI) and related online methods adjust interval widths to distribution shift and non-exchangeability, which are precisely the challenges in macro data with evolving regimes.
Key extensions handle multi-step and multivariate time-series forecasting crucial when producing joint paths for inflation, FX, and policy rates or when reporting horizon-h TV-VECM forecasts. Recent work develops online/multi-step CP with provable properties, and multivariate CP to form valid prediction regions across series.
An alternative, EnbPI (Ensemble Batch Prediction Intervals), uses ensemble residuals to deliver approximately valid intervals under dependence and shift; while often paired with ML forecasters, it is model-agnostic and can calibrate VECM residuals too.

**TV-VECM and Conformal Pipeline for Ghana**
The literature jointly suggests:

**Specify a Ghana macro system [ $P_t$, $e_t$, $i_t$, $y_t$, $m_t$]**
Inflation, exchange rate, policy rate, output proxy, money; optionally commodity/terms-of-trade).

**Estimate Cointegration And Time-Variation**
Using a smoothly time-varying VECM (Gao–Peng–Yan framework) or carefully designed state-space TV-VECM with robust cointegration testing/bootstrapping to guard against spurious time-variation (Eroğlu *et al.*, 2022).

**Forecast**
Multi-step paths from the TV-VEC

**Wrap Forecasts with CP**
use online ACI (or variants) for one- and multi-step horizons; for multiple variables/horizons, apply recent multivariate/multistep conformal methods to obtain valid joint or per-horizon intervals that adapt to regime changes particularly important around policy turning points documented for Ghana in 2025.

**Empirical Expectations And Gaps**

Relative to fixed-parameter VECMs used in many country studies, a TV-VECM should improve calibration during regime shifts and commodity shocks, and better capture changing error-correction speeds.

Conformal layers are complementary to econometric inference: they provide finite-sample predictive coverage without re-specifying the TV-VECM and remain robust to mild misspecification.

Gap: Few (if any) studies combine TV-VECM with conformal intervals in macroeconomic practice especially for Ghana. The emerging multi-step/multivariate CP literature now makes this feasible and methodologically justified.

## MATERIALS AND METHODS

**Data Description**
Monthly data from January 2014 to June 2025 were compiled. CPI data were obtained from the Ghana Statistical Service, while exchange rate and MPR data were sourced from the Bank of Ghana. All series were tested for unit roots using the Augmented Dickey-Fuller (ADF) test and found to be integrated of order one, I(1). Cointegration was verified using Johansen's method, confirming at least one cointegrating relationship among the variables.
The ADF test is based on the following regression:

$$\Delta y_t = \alpha + \beta t + \gamma y_{t-1} + \sum_{i=1}^{p} \delta_i \Delta y_{t-i} \quad (1)$$

The Johansen cointegration test is derived from the Vector Autoregression (VAR) representation:

$$\Delta X_t = \Pi X_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-i} + \epsilon_t \quad (2)$$

where the rank of the matrix $\Pi$ determines the number of cointegrating relationships.

**Model Specification**
A Time-Varying VECM was implemented using a rolling window approach. This technique allows model parameters to evolve, accommodating structural breaks and time-varying relationships. The model captures both equilibrium correction mechanisms and short-term adjustments.

**Forecasting and Conformal Prediction**
A six-month forecast horizon was selected. To quantify

forecast uncertainty, conformal prediction intervals were constructed using residual-based nonconformity scores. These intervals maintain valid coverage under mild assumptions and are robust to model misspecification.

Gradient Boosting Regression was employed to generate point forecasts. This method builds an ensemble of decision trees in a forward stage-wise fashion, minimizing a loss function by iteratively fitting residuals:

$$F_0(x) = \underset{\gamma}{\operatorname{argmin}} \sum_{i=1}^{n} L(y_i, \gamma) \quad (3)$$

$$F_m(x) = F_{m-1}(x) + \nu \cdot h_m(x) \quad (4)$$

$$h_m(x) = -\left[\frac{\partial L(y, F(x))}{\partial F(x)}\right]_{F(x)=F_{m-1}(x)} \quad (5)$$

## RESULTS AND DISCUSSION

**Table 1:** Forecast and 90% Conformal Prediction Intervals

| Date | USD/GHS | [PI] | CPI | [PI] | MPR | [PI] |
|---|---|---|---|---|---|---|
| 2025-07-31 | 10.4600 | [10.12, 10.90] | 258.87 | [254.09, 261.07] | 28.00 | [28.00, 28.05] |
| 2025-08-31 | 10.5900 | [10.19, 10.93] | 261.36 | [260.11, 262.67] | 28.00 | [28.00, 28.01] |
| 2025-09-30 | 10.7100 | [10.42, 11.07] | 264.56 | [262.61, 265.19] | 28.00 | [28.00, 28.01] |
| 2025-10-31 | 10.8400 | [10.55, 11.21] | 268.25 | [265.82, 268.43] | 28.00 | [28.00, 28.01] |
| 2025-11-30 | 10.9700 | [10.67, 11.35] | 272.09 | [269.53, 272.18] | 28.00 | [28.00, 28.01] |
| 2025-12-31 | 11.1000 | [10.80, 11.48] | 275.99 | [273.39, 276.08] | 28.00 | [28.00, 28.01] |

*Source: Authors Computation and Projections*

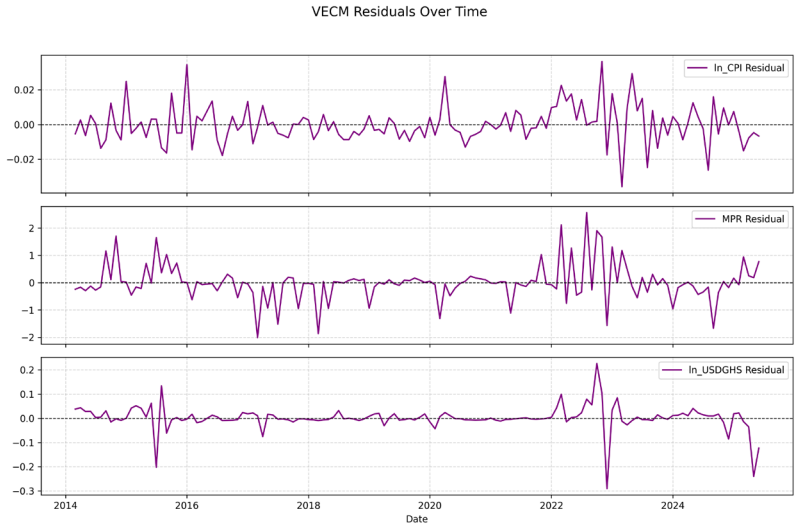


**Figure 1:** Residual plot for ln CPI, MPR, and ln USDGHS (July–December 2025)

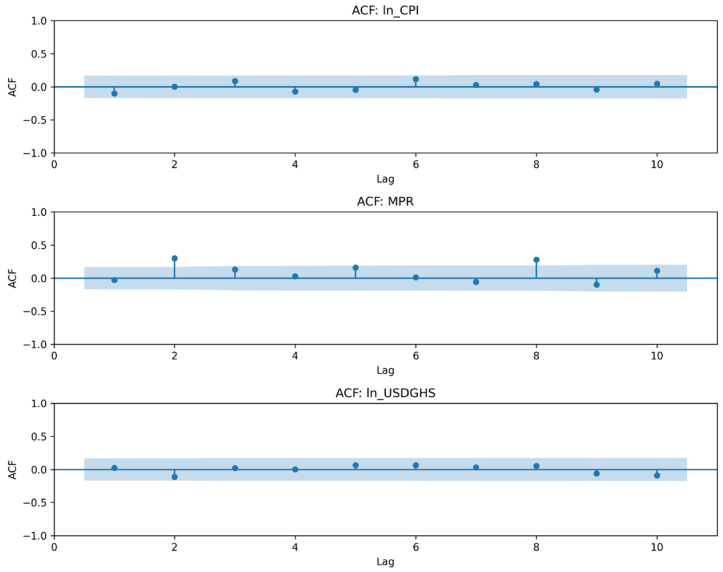


**Figure 2:** Autocorrelation Function (ACF) plot for residuals

**Residual Plot Observations**

• ln_CPI: Residuals are centered around zero with low variance but show a slight increase in variance from 2022 onward.

• MPR: High residual variance with frequent spikes, suggesting potential outliers or structural breaks.

• ln_USDGHS: Residuals are mostly stable over time, with a few sharp spikes between 2022 and 2023 likely reflecting volatility during that period.

**Autocorrelation Function (ACF) Observations**

• ln_CPI Residuals: All spikes are within the 95% confidence bands across lags 0 to 10, confirming the absence of significant autocorrelation.

• MPR Residuals: A visible spike at lag 2 exceeds the confidence bounds, indicating residual autocorrelation.

• ln_USDGHS Residuals: All spikes remain within the confidence bounds, confirming white noise residuals.

**Discussion**

**USD/GHS Exchange Rate**

The forecasted exchange rate path indicates a gradual depreciation of the Ghanaian Cedi, rising from 10.46 to 11.10 over the six-month period. The widening prediction intervals over time reflect increasing uncertainty as the forecast horizon extends.

**Consumer Price Index**

CPI is projected to increase gradually from 258.87 to 275.99, suggesting continued inflationary pressure. The forecast intervals remain tight, indicating strong model confidence in the inflation trajectory over the horizon.

**Monetary Policy Rate**

The MPR remains effectively stable at around 28.00% across the entire forecast window. The extremely narrow interval bounds suggest little model uncertainty and high temporal persistence in this rate.

**Model Pitfalls and Deployment**

From the estimated parameters value and diagnostic plots, we observed that Monetary Policy Rate residuals show strong autocorrelation and large spikes especially after 2022, confirming that the model does not capture MPR dynamics well. This suggests the presence of possible outliers, structural breaks after 2022, and insufficient lags. Therefore, the model can be deployed to forecast only the Consumer Price Index (CPI) and USD/GHS. The long-run links look usable, but MPR short-term forecasts may not be reliable unless the MPR pitfalls are fixed and improved.

## CONCLUSION

This study utilizes a Time-Varying VECM with conformal prediction to forecast Ghana's key macroeconomic indicators over a six-month horizon. Results suggest moderate exchange rate depreciation, persistent inflation, and stability in nominal interest rates. These forecasts are grounded in historical data patterns and subject to limitations arising from policy shocks or structural changes outside the model's framework.

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