QUANTITATIVE RESEARCH REPORT

Multi-Currency Risk Modeling and Volatility Targeting : Empirical Evidence from an EGARCH-Student Model on the MASI 20

Casablanca Stock Exchange (CSE)

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1 Introduction

Financial markets stand at the core of macroeconomic development, serving as a primary engine for capital allocation, liquidity provision, and economic growth. Bridging the gap between abstract macroeconomic principles and the practical realities of live trading is essential for robust market analysis.

This report maps out the convergence between theoretical market oversight and advanced quantitative time-series analysis, focusing on the Casablanca Stock Exchange (CSE).

Quantitative Research Objectives

The core objective of this study is to utilize empirical market data to conduct sophisticated time-series analysis, exploring how econometric modeling can be actively deployed to understand asset price behavior and order flow dynamics within the Moroccan equity market.

Technical Scope

Beyond conceptual knowledge, this research serves to transition from clean, textbook datasets to complex, real-world financial data using the R programming language. The goal is to transcend purely abstract mathematical concepts and transform advanced econometric theory into functional, real-world solutions that add tangible value to market risk analysis and portfolio management.

2 Quantitative Analysis : Market Volatility and Tail Risk Modeling

2.1 Introduction and Methodological Framework

This study investigates market risk and dynamic asset allocation for Morocco's MASI 20 index by addressing non-normality, volatility clustering, and leverage effects. Using an EGARCH(1,1) framework specified with a Student-t distribution, we capture asymmetric shocks to forecast conditional variance, estimate multi-currency Value-at-Risk (MAD, EUR, USD), and validate model accuracy through Kupiec backtesting. These econometric forecasts are subsequently integrated into a systematic Volatility Targeting overlay, evaluating whether dynamic exposure scaling enhances risk-adjusted performance.

2.2 Data and Descriptive Statistics

The empirical analysis utilizes the daily closing prices of the MASI 20 index, spanning from January 2021 to early 2026. The daily logarithmic returns are computed as follows :

$$R_t = \ln\left(\frac{P_t}{P_{t-1}}\right) \tag{1}$$

where P_t and P_{t-1} denote the closing prices of the index at days t and $t-1$, respectively.

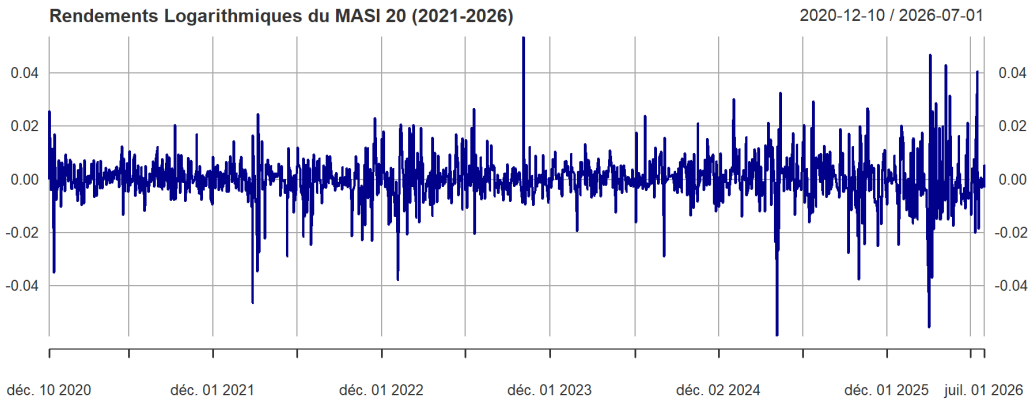


FIGURE 1 – Daily Logarithmic Returns of the MASI 20 Index (2021-2026)

Table 1 summarizes the foundational descriptive statistics for the return series, providing initial insights into the distributional properties of the Moroccan equity market.

Metric	Value
Observations	1,382
Mean	0.0003
Standard Deviation	0.0089
Skewness	-0.3822
Excess Kurtosis	7.3931

TABLE 1 – Descriptive Statistics of MASI 20 Log-Returns

The summary statistics reveal a negative skewness (-0.38) and a substantially high excess kurtosis (7.39). These metrics confirm that the MASI 20 return distribution is strictly non-normal, exhibiting an asymmetric, leptokurtic profile with pronounced fat tails. This structural characteristic statistically invalidates the standard assumption of normality for accurate downside risk modeling, necessitating the use of heavy-tailed distributions.

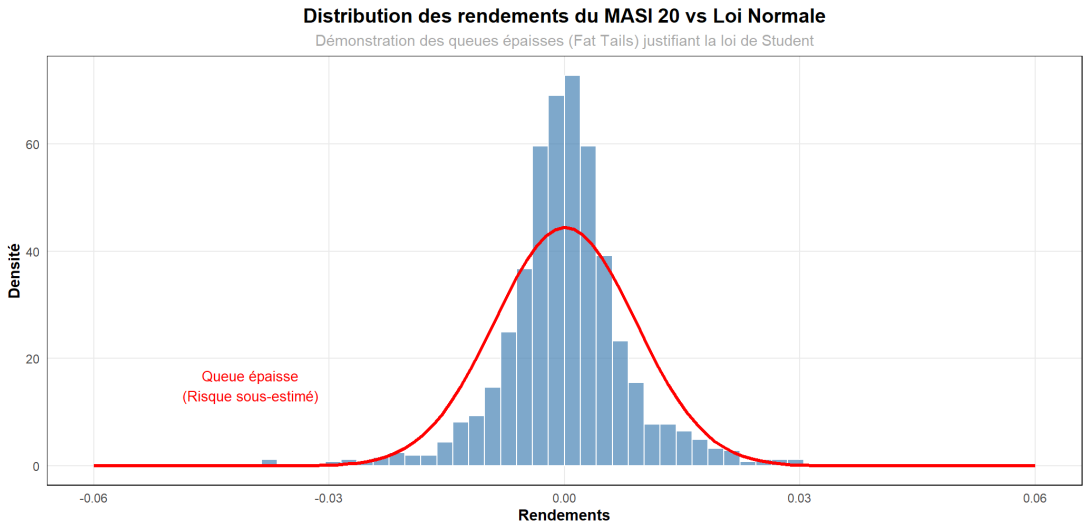


FIGURE 2 – MASI 20 Tail Risk : Empirical Distribution vs. Standard Normal

2.3 Econometric Diagnostics

2.3.1 Stationarity and Conditional Heteroskedasticity

Prior to specifying a volatility model, it is mandatory to verify the stationarity of the return series and confirm the presence of volatility clustering. We employ the Augmented Dickey-Fuller (ADF) test for unit roots and the ARCH-Lagrange Multiplier (ARCH-LM) test to detect conditional heteroskedasticity.

Test	Null Hypothesis (H_0)	Lag	Statistic	p-value	Decision
ADF	Non-stationary	11	-11.226	0.0100	Reject H_0
ARCH-LM	No ARCH effects	5	144.360	< 0.0001	Reject H_0

TABLE 2 – Preliminary Econometric Tests on MASI 20 Returns

As reported in Table 2, the ADF test unequivocally rejects the presence of a unit root, confirming that the log-return series is strictly stationary. Furthermore, the highly significant ARCH-LM test proves the existence of strong conditional heteroskedasticity. This statistically validates the empirical observation of volatility clustering within the Moroccan equity market, thereby justifying the application of the GARCH econometric framework.

2.4 Volatility Model Specification and Selection

To properly account for the heavy tails identified in the descriptive statistics, the models are evaluated using both Normal and Student-t distributions. The general mean equation is defined as $R_t = \mu + \epsilon_t$, where the residual $\epsilon_t = \sigma_t z_t$.

Additionally, equity markets typically exhibit an "asymmetric leverage effect," where negative shocks (price drops) induce higher subsequent volatility than positive shocks of the same magnitude. To identify the optimal variance specification, we compare the Standard GARCH(1,1), GJR-GARCH(1,1), and EGARCH(1,1) models using the Akaike Information Criterion (AIC).

Model Specification	**Distribution**	**AIC**	**Rank**
Standard GARCH(1,1)	Normal ($z_t \sim N(0,1)$)	-6.8677	4
Standard GARCH(1,1)	Student-t ($z_t \sim t_\nu$)	-7.0413	3
GJR-GARCH(1,1)	Student-t ($z_t \sim t_\nu$)	-7.0550	2
EGARCH(1,1)	**Student-t ($z_t \sim t_\nu$)**	**-7.0567**	**1**

TABLE 3 – Volatility Model Selection Criteria

The selection procedure yields two critical findings. First, shifting from a Normal to a Student-t distribution significantly improves the model fit, successfully absorbing the excess kurtosis. Second, the Exponential GARCH (EGARCH) formulation minimizes the AIC, outperforming symmetric models.

Consequently, the EGARCH(1,1)-Student model is retained for all subsequent Value-at-Risk (VaR) estimations. Its variance equation is expressed as :

$$\ln(\sigma_t^2) = \omega + \alpha\left(|z_{t-1}| - E|z_{t-1}|\right) + \gamma z_{t-1} + \beta \ln(\sigma_{t-1}^2) \tag{2}$$

By utilizing the natural logarithm of the conditional variance, the EGARCH model ensures that volatility remains strictly positive without imposing artificial non-negativity constraints on the parameters. More importantly, the parameter γ explicitly captures the asymmetric response of the MASI 20 to market shocks, reflecting the behavioral realities observed within the exchange's trading dynamics.

2.5 Multi-Currency Value-at-Risk (VaR) Estimation

2.5.1 Composite Returns and Currency Exposure

To assess the total risk exposure for international investors, exchange rate risk must be integrated with the pure equity market risk. Utilizing logarithmic returns allows for the approximation of the composite return for a foreign investor through linear addition.

Let $R_{t,\text{MAD}}$ be the daily log-return of the MASI 20 index, and $R_{t,\text{FX}}$ be the daily log-return of the exchange rate (expressed as foreign currency per MAD). The composite return is defined as :

$$R_{t,\text{Composite}} = R_{t,\text{MAD}} + R_{t,\text{FX}} \tag{3}$$

This transformation is applied to construct two new series : the return for a US Dollar investor ($R_{t,\text{USD}}$) and a Euro investor ($R_{t,\text{EUR}}$). The selected EGARCH(1,1)-Student model is subsequently re-estimated on these composite series to capture the distinct volatility dynamics associated with each currency profile.

2.5.2 Dynamic VaR Computation

Value-at-Risk (VaR) measures the maximum expected loss over a specific time horizon at a given confidence level. Based on the EGARCH estimations, the one-day ahead conditional VaR is computed dynamically for each time step t. At a significance level α (e.g., $\alpha = 5\%$), the VaR is given by :

$$\text{VaR}_t^{\alpha} = \mu_t + \sigma_t \times t_{\alpha,\nu}^{-1} \tag{4}$$

Where μ_t is the conditional mean, σ_t is the conditional standard deviation forecasted by the EGARCH variance equation, and $t_{\alpha,\nu}^{-1}$ is the α-quantile of the standardized Student-t distribution with ν degrees of freedom.

2.5.3 Empirical Results : Risk Divergence by Currency

The dynamic VaR is estimated at a 95% confidence level using the conditional volatility forecasted by the respective models.

Currency Profile	Average 1-Day VaR (95%)	Risk Composition
Local Investor (MAD)	-1.23%	Pure equity market risk
Euro Investor (EUR)	-1.38%	Equity risk + EUR/MAD exchange risk
US Dollar Investor (USD)	-3.17%	Equity risk + USD/MAD exchange risk

TABLE 4 – Average Conditional VaR (95%) by Investor Profile

The empirical results presented in Table 4 strongly validate the theoretical impact of the Moroccan exchange rate regime on foreign investment risk. The Dirham (MAD) is pegged to a currency basket weighted at 60% EUR and 40% USD. Consequently, EUR/MAD volatility is structurally dampened, resulting in a daily VaR for a Euro-based investor (-1.38%) that closely tracks the pure local market risk (-1.23%).

Conversely, the USD/MAD parity acts as the primary shock absorber for international EUR/USD fluctuations. This mechanism drastically inflates composite volatility. As a result, a US Dollar-based investor faces a structurally amplified downside risk, with an average 1-day VaR of -3.17%—more than double the risk exposure of a local market participant.

Methodological Note on Joint Tail-Dependence : It is important to acknowledge that the linear addition of returns ($R_{t,\text{MAD}} + R_{t,\text{FX}}$) assumes zero short-term correlation

between local equity shocks and currency fluctuations. In reality, severe market drawdowns often trigger simultaneous capital flight, introducing non-linear dependencies. While the current univariate EGARCH framework effectively captures distinct volatility profiles, future research aiming to optimize international MASI 20 portfolios should consider multivariate frameworks or Copula functions to accurately model this joint tail-dependence during extreme crises.

2.6 Backtesting Value-at-Risk Models

2.6.1 Evaluation Methodology : Kupiec Unconditional Coverage

To assess the predictive accuracy of the dynamic VaR estimates, formal backtesting procedures are implemented. The Kupiec Unconditional Coverage (UC) test is employed to evaluate whether the empirical rate of VaR exceedances matches the theoretical significance level α (here, 5%). The null hypothesis (H_0) states that the model is statistically accurate ; a p-value greater than 0.05 indicates that H_0 cannot be rejected, validating the VaR forecasts.

2.6.2 Empirical Backtesting Results

Table 5 synthesizes the Kupiec backtesting results for the three currency profiles over 1,204 observations at the 95% confidence level.

Currency Profile	**Expected**	**Actual**	**Kupiec p-value**	**Decision (H_0)**
MAD Investor	60	58	0.7698	Accepted (Valid model)
EUR Investor	60	59	0.8735	Accepted (Valid model)
USD Investor	60	95	< 0.0001	Rejected (Underestimates risk)

TABLE 5 – Kupiec Backtesting Results (95% VaR)

Figure 3 provides a visual representation of the dynamic backtesting process over the sample period. The solid red line plots the time-varying 95% VaR threshold estimated by the EGARCH(1,1)-Student model, dynamically adapting to incoming volatility shocks.

The scatter points represent the daily returns of the MASI 20, with the dark red markers explicitly highlighting the exceedances (violations)—the instances where the actual daily portfolio loss breached the forecasted risk limit.

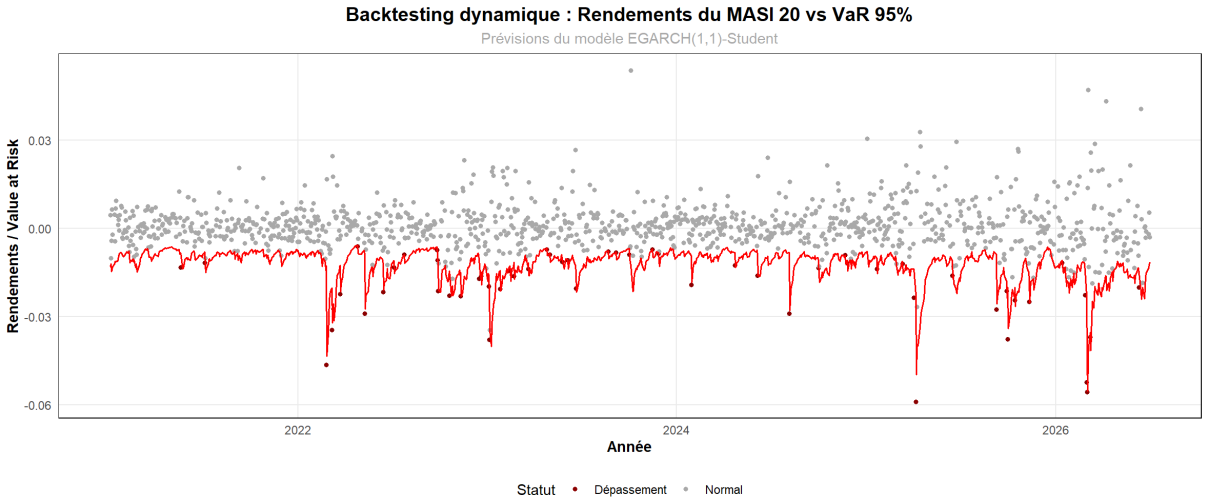


FIGURE 3 – Dynamic Backtesting : MASI 20 Returns vs. EGARCH(1,1)-Student VaR (95%)

Beyond the absolute frequency of exceedances, the visual plot highlights a clear temporal concentration of these tail events. The visible clustering of violations—particularly during the high-volatility regime spanning late 2022 and 2023—graphically corroborates the statistical findings and justifies the need for the subsequent sub-period analysis.

The diagnostics reveal a significant divergence in model performance based on currency exposure. For the local (MAD) and Euro-pegged (EUR) profiles, the EGARCH(1,1)-Student model performs remarkably well, tightly aligning with the expected 60 exceedances. However, the model systematically fails for the US Dollar profile, significantly underestimating downside risk with 95 actual exceedances.

2.6.3 Robustness Check : Sub-Period Analysis

To understand the failure of the USD VaR, a robustness check is conducted by splitting the data into two distinct macroeconomic regimes : Period 1 (2021-2023, characterized by global inflation and high EUR/USD volatility) and Period 2 (2024-2026, characterized by monetary normalization).

Period	Expected	Actual	Deviation Ratio	Kupiec p-value
2021-2023	33	61	1.84x	< 0.0001
2024-2026	27	39	1.44x	0.0258

TABLE 6 – Sub-Period Kupiec Backtesting for the USD Portfolio

The sub-period analysis confirms that the model's underperformance is heavily concentrated in the 2021-2023 window, where actual exceedances were nearly double the expected frequency. While the univariate EGARCH model effectively captures domestic equity leverage effects, it cannot endogenously price in external, non-linear FX shocks.

Methodological Limitation : It should be noted that while the Kupiec Unconditional Coverage test effectively evaluates the absolute frequency of VaR exceedances, it does not measure their temporal distribution. A valuable avenue for future research would be to integrate a conditional coverage test (such as Christoffersen's) to mathematically verify the serial independence of these exceedances and test for volatility clustering during acute macroeconomic shocks.

2.7 Practical Application : Dynamic Volatility Targeting

2.7.1 Strategy Mechanism

To demonstrate the economic value of the EGARCH conditional volatility forecasts, a Volatility Targeting (VT) strategy is simulated on the MASI 20 index. Unlike a passive "Buy and Hold" approach, this dynamic strategy systematically adjusts the portfolio's market exposure inversely proportional to the forecasted risk.

The daily exposure weight is calculated as the ratio of a predefined target volatility (the historical average of the MASI 20) to the next-day conditional volatility forecasted by the EGARCH(1,1)-Student model. To maintain a realistic modeling environment, the maximum leverage is capped at 1.5x. During low-risk periods, the strategy scales up exposure, and during identified volatility clusters, it mathematically deleverages into cash to mitigate deep drawdowns.

2.7.2 Performance Evaluation

Table 7 compares the risk-adjusted metrics of the active VT strategy against the static benchmark.

Metric	Buy & Hold (MASI 20)	Volatility Targeting	Delta (Abs.)
Annualized Return	1.09%	3.32%	+2.23 pts
Maximum Drawdown	-31.01%	-28.60%	+2.41 pts
Annualized Sharpe Ratio	0.0768	0.2588	+0.1820

TABLE 7 – Performance Metrics : Buy & Hold vs. EGARCH Volatility Targeting

The Volatility Targeting framework substantially outperforms the static benchmark. By effectively timing volatility regimes—reducing exposure ahead of structural shocks and maximizing exposure during stable uptrends—the VT strategy more than triples the annualized return, elevating the Sharpe Ratio from an inefficient 0.07 to 0.25.

2.7.3 Market Microstructure and Implementation Limits

While the theoretical outperformance of the VT strategy is robust, its practical execution must be contextualized within the operational realities of the Casablanca Stock Exchange. Observations of trading mechanisms and market depth highlight structural liquidity constraints within the MASI 20.

A quantitative strategy requiring daily rebalancing to precisely track EGARCH volatility targets would incur substantial friction costs. High bid-ask spreads, institutional brokerage fees, and the market impact (slippage) of executing orders in an environment

with limited liquidity would inevitably erode a portion of this theoretical alpha. Consequently, while the econometric forecasting holds significant predictive power, real-world institutional deployment on the Moroccan capital market would require optimizing the rebalancing frequency (e.g., implementing tolerance bands or weekly rebalancing) to balance risk mitigation against prohibitive execution costs.

3 Conclusion

This research provides a comprehensive empirical analysis bridging theoretical financial econometrics and the practical realities of market risk management.

From an empirical standpoint, this report delivered a statistically validated risk-modeling architecture for the flagship MASI 20 index. By combining an EGARCH(1,1) specification with a heavy-tailed Student-t error distribution, the model effectively captured the asymmetric leverage effects and conditional volatility clustering inherent in the Moroccan equity market. Crucially, the multi-currency Value-at-Risk (VaR) framework demonstrated the structural impact of the Dirham exchange rate regime on foreign investors : while Euro-denominated portfolios experience downside risk close to local levels (-1.38% vs. -1.23% for MAD), US Dollar-denominated portfolios face more than double the risk exposure (-3.17% VaR) due to exogenous FX volatility. Furthermore, the dynamic Volatility Targeting strategy proved the economic value of econometric forecasting, significantly elevating the portfolio's Sharpe ratio from 0.07 to 0.25, while highlighting the liquidity constraints and friction costs associated with execution on frontier markets.